



WOMEN IN PHYSICS

GENDER AND DIVERSITY AT WORK

LES FEMMES EN PHYSIQUE

GENRE ET DIVERSITÉ AU TRAVAIL

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L'accent de ce concours est de pouvoir expliquer le principe général de la photo soumise plutôt que de démontrer un niveau élevé de compréhension de la physique. L'échéance pour les inscriptions individuelles ouvert et école secondaire) et scolaires (voir formulaire d'inscription/règlements à <http://www.cap.ca/fr/activites/lart-de-physique>) est fixée au 15 avril chaque année. Notez bien que toutes les inscriptions doivent être des oeuvres originales du participant ou de la participante.

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- 2015 competition

by Jonathan Lew,
Burnaby, British Columbia
(see <http://www.cap.ca/aop/aop/Reflection2015.html>)

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Nous espérons que vous profiterez de cette occasion d'explorer l'art de la physique en soumettant une oeuvre pour la prochaine compétition.



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Group photograph
at the 5th IUPAP
International Conference on Women
in Physics held in
Waterloo in August
2014. The Conference
was attended by
215 scientists
from 52 countries.
(See article by
G. Butcher *et al.*
in this issue –
pg. 66).

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(www.cap.ca -> Publications -> La Physique au Canada).

Photographie de groupe prise en août
2014 à Waterloo durant la 5^{ème} Conférence
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physique. 215 scientifiques venant de
52 pays ont assisté à la conférence.
(Voir l'article par G. Butcher *et al.* dans
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Editor / Rédacteur en chef

Béla Joós, PPhys

Physics Department / Département de physique, Univ. of / d' Ottawa
150 Louis Pasteur Avenue
Ottawa, Ontario K1N 6N5
(613) 562-5800 x6755; Fax: (613) 562-5190
Email: bjoos@uottawa.ca

Associate Editor / Rédactrice associée

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c/o CAP/ACP; E-mail: cap@uottawa.ca

Book Review Editor / Rédacteur à la critique de livres

Richard Marchand

c/o CAP / ACP
Suite Bur. 112, Imm. McDonald Bldg., Univ. of / d' Ottawa,
150 Louis Pasteur, Ottawa, Ontario K1N 6N5
Email: Richard.Marchand@ualberta.ca

Advertising Manager / Directeur de la publicité

Michael Steinitz, PPhys

Department of Physics
St. Francis Xavier University, P.O. Box 5000
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Université Laval
Cité Universitaire, Québec G1K 7P4
(418) 656-2655; Fax: (418) 656-2040
Email: rene.roy@phy.ulaval.ca

David J. Lockwood, PPhys

Institute for Microstructural Sciences
National Research Council (M-36)
Montreal Rd., Ottawa, Ontario K1A 0R6
(613) 993-9614; Fax: (613) 993-6486
Email: david.lockwood@nrc.ca

Robert Thompson, PPhys

Dept. of Physics and Astronomy
University of Calgary, 2500 University Dr. NW
Calgary, Alberta T2N 1N4
(403) 220-5407; Fax: (403) 289-3331
Email: thompson@phas.ucalgary.ca

Adriana Predoi-Cross

Dept. of Physics and Astronomy
University of Lethbridge
Lethbridge, Alberta T1K 3M4
(403) 329-2697; Fax: (403) 329-2057
Email: adriana.predoi@uleth.ca

Richard MacKenzie

Département de physique
Université de Montréal, C.P. 6128, Succ. centre-ville
Montréal, Québec H3C 3J7
(514) 343-5860; Fax: (514) 343-7357
Email: richard.mackenzie@umontreal.ca

Daria Ahrensmeier

Simon Fraser University
Teaching and Learning Centre, 8888 University Drive
Burnaby BC V5A 1S6
(778) 782-9544
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Suite/Bureau 112, Imm. McDonald Bldg., Univ. of/d' Ottawa,
150 Louis Pasteur, Ottawa, Ontario K1N 6N5
Phone/ Tél: (613) 562-5614; Fax/Téléc.: (613) 562-5615
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Canadian Association of Physicists (CAP) Association canadienne des physiciens et physiciennes (ACP)

The Canadian Association of Physicists was founded in 1945 as a non-profit association representing the interests of Canadian physicists. The CAP is a broadly-based national network of physicists in working in Canadian educational, industrial, and research settings. We are a strong and effective advocacy group for support of, and excellence in, physics research and education. We represent the voice of Canadian physicists to government, granting agencies, and many international scientific societies. We are an enthusiastic sponsor of events and activities promoting Canadian physics and physicists, including the CAP's annual congress and national physics journal. We are proud to offer and continually enhance our web site as a key resource for individuals pursuing careers in physics and physics education. Details of the many activities of the Association can be found at <http://www.cap.ca>. Membership application forms are also available in the membership section of that website.

L'Association canadienne des physiciens et physiciennes a été fondée en 1946 comme une association à but non-lucratif représentant les intérêts des physicien(ne)s canadien(ne)s. L'ACP est un vaste regroupement de physiciens oeuvrant dans les milieux canadiens de l'éducation, de l'industrie et de la recherche. Nous constituons un groupe de pression solide et efficace, ayant pour objectif le soutien de la recherche et de l'éducation en physique, et leur excellence. Nous sommes le porte-parole des physiciens canadiens face au gouvernement, aux organismes subventionnaires et à plusieurs sociétés scientifiques internationales. Nous nous faisons le promoteur enthousiaste d'événements et d'activités mettant à l'avant-scène la physique et les physiciens canadiens, en particulier le congrès annuel et la revue de l'Association. Nous sommes fiers d'offrir et de développer continuellement notre site Web pour en faire une ressource clé pour ceux qui poursuivent leur carrière en physique et dans l'enseignement de la physique. Vous pouvez trouver les renseignements concernant les nombreuses activités de l'ACP à <http://www.cap.ca>. Les formulaires d'adhésion sont aussi disponibles dans la rubrique «Adhésion» sur ce site.

WOMEN IN PHYSICS: GENDER AND DIVERSITY AT WORK

1905 is celebrated as Einstein's miracle year in physics, but 1903 was also an amazing year for physics and for women: Marie Curie made history by winning a Nobel prize in physics, becoming the first female Nobel laureate. In 1911 she won yet another Nobel Prize in chemistry, a feat that has yet to be repeated. In the century since her incredible achievements, she has inspired generations of scientists and many women have made important contributions to all areas of physics. Yet their achievements are not widely appreciated and only one other woman, Maria Goeppert-Meyer, has been able to follow in Curie's footsteps to win a Nobel Prize in physics. In fact, the proportion of women in physics has remained low despite many initiatives to attract more women to physics.

In 2014, the 5th International Conference on Women in Physics was held in Waterloo, Canada and attracted delegates from 52 countries. The conversations and connections at the conference led to many of the articles in this special issue. We found that we have a lot in common and a lot to learn from each other. Together, we have a voice and a common goal to strive for. The first article in the special issue, prepared by the guest editors, is dedicated to the series of International Conferences on Women in Physics.

In recent years we have seen an increase in the participation of women in physics, but at an inconsistent pace, without achieving a full representation of women in physics. A 2012 study published in *Science* magazine by Cheryl Geisler of Simon Fraser University and Deborah Kaminski of Rensselaer Polytechnic Institute estimated that it could take yet another century before there are an equal number of men and women faculty in science departments in North America^[1]. The key questions we must ask are what is the current environment for women in physics, and how can we address challenges and properly acknowledge and support women's contributions to physics. Does a woman need to win two Nobel prizes to be taken seriously?

This special issue of *Physics in Canada* on Women in Physics presents a series of articles related to the participation of women in physics in Canada and in different parts of the world. The papers document factors that are important to success in physics in the early years, as well as during higher education, and employment. The content presented in this special issue is proof of progress and increased participation of women in science, as well as a measure of effectiveness of the policies promoting it. As highlighted in the paper by Rachel Ivie and Susan White, the results of the Global Survey of Physicists conducted by AIP show "sex differences in the distribution of career-advancing resources and opportunities and in the relationship between family and careers." The nature of "psychological influences which prevent women's equal participation in science" is discussed in the paper by Arundhati Dasgupta and Veronique Pierron-Bohnes. A case study of the influence of mentoring on increasing the number of women in leadership in the STEM disciplines in India is detailed in the paper by Anitha Kurup. The gender question in sciences across India is also discussed in the paper of Prajval Shastri. She points out that "the gender gap is caused not only by the discriminatory familial responsibilities that women encounter in their personal lives, but also by gender-discriminatory attitudes in the scientific workplace." The topic of increasing the participation of women in physics over the past few decades is discussed in the paper by Beverly Hartline, Millie Dresselhaus, and Judy Franz.

The number of women entering physics related careers in Canada is on the rise at a slow rate, despite numerous efforts to encourage more girls to explore the incredible opportunities provided by physics-related careers. The situation is similar in the US, UK, Europe, and many other countries around the world. Does this arise from differences in intellectual ability between men and women? Studies have shown that the answer is "no". The problem lies in long-held perceptions of gender roles, implicit biases and a work environment that does not support and celebrate diversity. And these take a lot longer to change.



Adriana Predoi-Cross,
<adriana.predoicross@uleth.ca>,
University of Lethbridge

Gillian Butcher,
<gib2@le.ac.uk>,
University of Leicester

and

Shohini Ghose,
<sgghose@wlu.ca>,
Wilfrid Laurier University

The contents of this journal, including the views expressed above, do not necessarily represent the views or policies of the Canadian Association of Physicists.

Le contenu de cette revue, ainsi que les opinions exprimées ci-dessus, ne représentent pas nécessairement les opinions ou les politiques de l'Association canadienne des physiciens et physiciennes.

An overview of the efforts to promote the participation of girls in physics in UK, Australia, Canada, and USA, respectively, is presented in the paper by Ann Marks, Cathy Foley, Adriana Predoi-Cross, Nora Berrah.

In Canada, several programs and initiatives have been created in the past decade to attract more women to physics careers, improve their retention in physics careers through mentorship and a supportive work culture, raise the profile and improve the image of physicists and prepare physicists for a diverse workforce. Such efforts are aimed at creating an inclusive, supportive environment that allows young women to participate fully and equitably in physics related professions. The paper by Marina Milner-Bolotin “identifies factors affecting girls’ negative attitudes toward physics” in Canada and suggests “pedagogical approaches that can help secondary physics teachers to engage girls in physics”. Next, a perspective on the Brazilian educational system and the representation of women in the exact sciences in Brazil is presented in the paper by Marcia Barbosa. The last paper of the special issue by a group of authors from Iran and Mexico, namely Dina Izadi, Nona Izadipannah, Masoud Torabi Azad, and Cesar Eduardo

Mora Ley, discusses how art and imaginative methods in science education promote conceptual understanding.

So, should women need to win two Nobel prizes to get noticed? No. And no, women should not have to wait another century for an equal seat at the table. No, this is not just a woman’s problem – as pointed out by Professor of History of Science at Stanford University, Londa Schiebinger, we must move from ‘fixing the women’ to ‘fixing the system’. And this benefits not just women, but society as a whole, as well as the economy by potentially doubling our skilled workforce. We have come a long way, but there are still miles to go. We hope that someday a special issue on women in physics will no longer be necessary. Until that day, we hope you enjoy this collection of papers.

Adriana Predoi-Cross, University of Lethbridge
Gillian Butcher, University of Leicester
Shohini Ghose, Wilfrid Laurier University
Guest Editors, *Physics in Canada*

Comments of readers on this foreword are more than welcome.

REFERENCE

1. D. Kaminski and C. Geisler, “Survival analysis of Faculty Retention in Science and Engineering by Gender”, *Science*, **335**, 864–866 (2012).

LES FEMMES EN PHYSIQUE : GENRE ET DIVERSITÉ AU TRAVAIL

L’année 1905 est célébrée comme l’année miracle d’Einstein en physique, mais 1903 a aussi été exceptionnelle pour la physique et pour les femmes : Marie Curie a écrit une page d’histoire en remportant le prix Nobel de physique, devenant la première lauréate d’un prix Nobel. En 1911, elle a remporté un autre prix Nobel, en chimie cette fois, ce qui ne s’est jamais reproduit. Pendant le siècle qui a suivi ses réalisations incroyables, elle a inspiré des générations de scientifiques et bon nombre de femmes ont fait des apports importants dans tous les domaines de la physique. Pourtant, leurs réalisations ne sont pas largement reconnues et seulement une autre femme, Maria Goeppert-Meyer, a pu suivre ses traces en remportant un prix Nobel en physique. En fait, la proportion de femmes en physique est demeurée faible en dépit des nombreuses initiatives visant à en attirer davantage vers cette discipline.

En 2014, la 5^e Conférence internationale sur les femmes en physique, tenue à Waterloo au Canada, a attiré des délégués de

52 pays. Les échanges et les liens qui y ont été tissés sont la source d’un bon nombre des articles de ce numéro spécial. Nous avons découvert que nous partageons bien des choses et que nous avons beaucoup à apprendre les uns des autres. Ensemble, nous avons une voix et un objectif commun à poursuivre. Le premier article, signé par les directrices scientifiques invitées du numéro spécial, est consacré à la série de conférences internationales sur les femmes en physique.

Au cours des dernières années, nous avons vu croître la participation des femmes en physique, mais à un rythme inégal, sans qu’elles parviennent à y être pleinement représentées. Dans une étude publiée en 2012 par la revue *Science*, Cheryl Geisler de l’Université Simon Fraser et Deborah Kaminski du Rensselaer Polytechnic Institute ont estimé qu’il faudrait peut-être un autre siècle avant que les départements de science de l’Amérique du Nord comptent un nombre égal d’enseignants hommes et femmes ^[1]. Les principales questions qu’il nous

faut nous poser sont quel est le contexte actuel des femmes en physique et comment pouvons-nous relever les défis ainsi que constater et apprécier à sa juste valeur l'apport des femmes à la physique. Faut-il qu'une femme remporte deux prix Nobel pour être prise au sérieux?

Ce numéro spécial sur les femmes en physique, dans *La Physique au Canada*, contient divers articles sur la participation des femmes en physique au pays et dans différents coins du globe. On y cite les facteurs importants de la réussite en physique au cours des premières années, ainsi que lors d'études supérieures et en cours d'emploi. Le contenu de ce numéro témoigne des progrès et de la participation accrue des femmes en science et mesure l'efficacité des politiques visant à la favoriser. Comme Rachel Ivie et Susan White le soulignent dans leur article, les résultats de l'enquête menée à l'échelle mondiale par l'AIP auprès des physiciens montrent « les différences entre les sexes dans la distribution des ressources et occasions favorisant l'avancement professionnel, et dans les relations entre famille et carrière ». Arundhati Dasgupta et Veronique Pierron-Bohnes examinent dans un article la nature des « influences psychologiques jouant dans la participation égale des femmes en sciences ». Une étude de cas sur l'influence du mentorat par rapport au nombre croissant de femmes meneuses dans les disciplines STIM (sciences, technologie, ingénierie et mathématiques) en Inde est présentée en détail dans l'article d'Anitha Kurup. Prajval Shastri examine aussi dans son article la question des deux sexes en sciences dans l'ensemble de l'Inde. Elle y mentionne que l'écart entre les deux est attribuable non seulement aux responsabilités familiales discriminatoires auxquelles se heurtent les femmes dans leur vie personnelle, mais aussi aux attitudes sexistes discriminatoires en milieu de travail scientifique ». Dans leur article, Beverly Hartline, Millie Dresselhaus et Judy Franz examinent l'apport croissant des femmes à la physique au cours des dernières décennies.

Le nombre de femmes amorçant une carrière connexe à la physique au Canada augmente lentement en dépit des multiples efforts pour les encourager à explorer en plus grand nombre les possibilités incroyables offertes par les carrières connexes à la physique. La situation est similaire aux États-Unis, au Royaume-Uni, en Europe et dans bien d'autres pays du monde. Cela tient-il aux différences de capacités intellectuelles entre les hommes et les femmes? Les études ont montré « qu'il n'en est rien ». Le problème réside dans les perceptions depuis longtemps ancrées au sujet des rôles joués par les hommes et les femmes, dans les préjugés implicites et dans un milieu de travail qui n'appuie pas ni ne célèbre la diversité. Et ces facteurs sont beaucoup plus lents à changer. Dans leur article, Ann Marks, Cathy Foley, Adriana Predoi-Cross et Nora Berrah présentent une vue d'ensemble des efforts visant à promouvoir

la participation des femmes en physique au Royaume-Uni, en Australie, au Canada et aux États-Unis, respectivement.

Au Canada, nombre de programmes et d'initiatives ont vu le jour au cours de la dernière décennie en vue d'attirer plus de femmes vers les carrières en physique et de les inciter davantage à y demeurer par le mentorat et une culture de travail positive, de relever le profil et redorer l'image des physiciennes, ainsi que de les préparer à une main-d'œuvre diversifiée. Ces efforts visent à créer un milieu inclusif et positif qui permette aux jeunes femmes de participer pleinement et équitablement aux professions connexes à la physique. L'article de Marina Milner-Bolotin « énumère les facteurs qui jouent sur les attitudes négatives des femmes face à la physique » au Canada et propose des méthodes pédagogiques susceptibles d'aider les professeurs de physique au secondaire à les engager en physique ». Ensuite, Marcia Barbosa brosse un tableau du système d'enseignement supérieur au Brésil et de la représentation des femmes en sciences exactes là-bas. Dans le dernier article du numéro spécial, un groupe d'auteurs de l'Iran et du Mexique, soit Dina Izadi, Nona Izadipannah, Masoud Torabi Azad et Cesar Eduardo Mora Ley, examine comment les méthodes artistiques et imaginatives favorisent la compréhension conceptuelle dans l'enseignement des sciences.

Faut-il donc que les femmes remportent deux prix Nobel pour se faire remarquer? Non. Et non, il ne faudra pas attendre un autre siècle pour que les femmes soient égales à la table. Non, ce n'est pas qu'un problème propre aux femmes – comme l'a souligné la professeure d'histoire des sciences à l'Université Stanford, Londa Schiebinger, au lieu de 'repenser la place des femmes' seulement, nous devons songer à 'repenser le système'. Et cela profitera non seulement aux femmes, mais à l'ensemble de la société et à l'économie en raison de la possibilité de doubler ainsi notre main-d'œuvre qualifiée. Nous avons fait un bon bout de chemin, mais il en reste encore beaucoup à parcourir. Un jour, espérons-nous, un numéro spécial sur les femmes en physique ne sera plus nécessaire. D'ici là, nous espérons que vous apprécierez cette série d'articles.

Adriana Predoi-Cross, Université de Lethbridge
Gillian Butcher, Université de Leicester
Shohini Ghose, Université Wilfrid Laurier
Rédactrices honoraires, *La Physique au Canada*

Les commentaires de nos lecteurs ou lectrices au sujet de cette préface sont bienvenus.

NOTE: Le genre masculin n'a été utilisé que pour alléger le texte.

RÉFÉRENCE

1. D. Kaminski and C. Geisler, "Survival analysis of Faculty Retention in Science and Engineering by Gender", *Science*, **335**, 864–866 (2012).



INTERNATIONAL CONFERENCES ON WOMEN IN PHYSICS (ICWIP)

BY GILLIAN BUTCHER, ADRIANA PREDOI-CROSS, AND SHOHINI GHOSE



Gillian Butcher,
<gib2@le.ac.uk>,
Space Research
Centre, Department
of Physics and
Astronomy,
University of
Leicester, University
Road, Leicester,
LE1 7RH, UK,

Adriana
Predoi-Cross,
<adriana.
predoiross@
uleth.ca>,
Department of
Physics and Astron-
omy, University of
Lethbridge,
Lethbridge, AB,
T1K 3M4 Canada,

and

Shohini Ghose,
<sgghose@wlu.ca>,
Department of
Physics and
Computer Science,
Wilfrid Laurier Uni-
versity, 75 University
Avenue West,
Waterloo,
ON N2L 3C5,
Canada

HISTORY OF ICWIP

The International Union of Pure and Applied Physics (IUPAP) was established almost one hundred years ago to assist in the worldwide development of physics and to foster international cooperation in physics. In 1999 at the Atlanta General Assembly a resolution was passed to create a Women in Physics (WiP) Working Group (WG), with the charge:

- to survey the situation for women in physics in IUPAP member countries,
- to analyse and report the data collected along with suggestions on how to improve the situation,
- to suggest ways that women can become more involved in IUPAP, including the Liaison Committees, the Commissions, the Council, and the General Assemblies,
- to report all findings at the General Assembly in 2002.

It was suggested that to carry out the charge, the WG should organise and convene an international meeting on women in physics. Thus the first IUPAP International Conference on Women in Physics (ICWIP) was held in Paris in 2002 and duly reported back to the General Assembly.

THE CONFERENCES

That first conference brought together 296 delegates from 65 countries over 3 days. Each country was invited to send a team which would report on the statistics and status of women in their country. The attendance of country teams is a unique aspect of the ICWIPs. The aim is to encourage teams to work together before the conference to obtain updated information on their country and to work after the conference to share their experience and good practice around the country. A limit to the

size of teams was introduced to ensure that the wealthier countries would not dominate. Another unique aspect of the conferences therefore is the number of developing countries represented, assisted by the distribution of full travel grants to enable delegates from those countries to attend.

The conferences encourage attendee participation, not only through the country reports, but through workshops. Attendees choose from a handful of workshop topics, attending the same topic over three sessions, hearing talks by several speakers and contributing to discussions. Workshop topics have included attracting girls into physics, attracting women into leadership, and gender studies. From these sessions, good practice and resources are shared, and each workshop aims to come up with a series of recommendations which it takes back to the final conference plenary session. There, all the recommendations are brought together, discussed and translated into resolutions to take to the IUPAP General Assembly. The resolutions could be recommendations for IUPAP member countries to follow, actions for IUPAP or actions for the WG to undertake. Examples of resolutions are that IUPAP sponsored conferences should provide an outreach activity associated with the conference and that member countries should be encouraged to have clear and transparent criteria for awards to ensure that women are nominated.

More recent conferences have responded to the growing understanding that while they might be about women in physics, they are not just for women in physics: this is for everyone, and to make progress, men need to be involved. Country teams are therefore encouraged to include at least one man. Every conference also provides opportunities for delegates to participate in outreach activities aimed at attracting more girls to physics. As physics is the activity that unites the participants, there are several plenary talks on physics, by prominent women physicists. These women are excellent role models, particularly when they include in their talk, as many do, background details of their personal life and how they got into physics. Opportunities are also created for networking, whether socially or through poster sessions. Thus collaborations have been established, role models made visible, inspiration shared and friendships made through the conferences.

SUMMARY

Since 2002 there have been five international conferences on Women in Physics. This paper looks at the history, the content and legacy of those conferences.

There is a real sense of the joy and privilege of doing physics and a strong sense of community and support, particularly for younger and/or isolated women. In addition, the papers presented in talks, poster sessions, and workshops are published in the conference proceedings, which serve as an excellent resource and record of the conferences.

HOSTING ICWIP

The conference has moved around the continents: Paris, France (2002), Rio de Janeiro, Brazil (2005), Seoul, South Korea (2008), Stellenbosch, South Africa (2011), and most recently, Waterloo, Canada (2014). The 5th IUPAP International Conference on Women in Physics (ICWIP 2014) in Waterloo was co-hosted by the Canadian Association of Physicists and locally organized by the Laurier Centre for Women in Science. It was attended by 215 scientists from 52 countries who celebrated the physics achievements of women throughout the world (Fig. 1). The theme of the meeting was Conversation, Connection, Change. Each country presented information about its activities to increase women's participation in physics, networking, gaining skills for career development, and the formation of active regional working groups to advance women in physics.

ICWIP 2014 opened with a public lecture by world-famous astronomer Jill Tarter. The conference featured plenary talks by distinguished speakers from around the world such as: Melissa Franklin, Harvard University; Silvia Torres-Peimbert, President Elect of the Executive Committee of the International Astronomical Union; Sabine Stanley, University of Toronto; Tsai-Chien Chiang, author of "Madam Wu Chien-Shiung:

The First Lady of Physics Research". Delegates were also thrilled to meet legendary Canadian physicist Ursula Franklin. A special panel on the many career opportunities that a physics degree can lead to was well attended by students.

The conference delegates participated in five different workshops on gender issues and developed a set of resolutions that were presented and approved at the General Assembly of the International Union of Pure and Applied Physics meeting in October 2014. The conference also featured a new initiative called "My STEM Story" (mystemstory.wlu.ca), which encouraged women physicists to share their experiences online in the form of personal stories, essays, poems, pictures and videos. A video featuring conference delegates called *HerStories*, filmed by the American Association of Physics Teachers, is now available online and has been watched thousands of times.

IMPACT

Statistics gathered from the conference proceedings^[1-4] show the spread of the impact of the conferences, with some 1175 delegates having attended (not taking into account persons attending more than one conference) over the 5 conferences from 89 different countries. All but 3 (out of 59) IUPAP member countries have been represented in at least one conference. As mentioned previously, efforts are made to secure the participation of developing countries and indeed, using the UN designation of Human Development Index (HDI), 14 countries participating have medium HDI and 13 have low HDI.



Fig. 1 The 5th IUPAP International Conference on Women in Physics held in Waterloo in August 2014 was attended by 215 scientists from 52 countries.

Most countries have a paper on the status of women in physics in their country (only 8 have not) in the conference proceedings, allowing fascinating comparisons of the cultural differences and similarities around the world. Indeed, while 9 countries have only one paper, 27 countries have papers published in all 4 existing proceedings, giving a unique view of progress over time. From the papers a wealth of information can be ascertained. For instance, in Europe 16 countries have national or regional working groups or networks, 12 of which were set up since the first ICWIP in 2002. One can find countries, such as Serbia, where the percentage of women who earned BSc degrees in physics is greater than the percentage of men, giving the lie to the notion that women are intrinsically not interested in physics. Many countries in their papers assess the impact of wider political events, with, for instance, Russia highlighting the effect of the fall of communism and of the fiscal crisis on women in physics, and Pakistan discussing the Taliban.

As well as the information that can be gleaned from the proceedings, the WG has commissioned several surveys of women physicists, conducted by the Statistical Research

Center of the American Institute of Physics (AIP). The first survey, in 2001^[5] and the second in 2005^[6], looked at common issues that women physicists face in their work and studies. The third survey was run in 2009-10, was translated into 8 languages and was sent to men as well as women^[7] (see also paper in this special issue). There were around 15,000 responses from 130 countries. Comparisons of responses between developed and developing countries have helped identify the differences and similarities in the issues faced by women in physics around the world, and inform the strategies and approaches taken by organizations and governments to improve the proportion of women in physics.

CONCLUDING REMARKS

The continued existence of the Working Group is requested from the IUPAP General Assembly every 3 years, and has been approved until 2017. As can be gleaned from the conferences and country papers, although progress is being made all round the world, there is still some way to go before there is no longer a need for the Women in Physics Working Group or for the ICWIPs to exist.

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IS THERE A LAND OF EQUALITY FOR PHYSICISTS? RESULTS FROM THE GLOBAL SURVEY OF PHYSICISTS

BY RACHEL IVIE AND SUSAN WHITE

Significant efforts to improve the situation of women in physics have been made in many countries^[1]. Everything from improving undergraduate education to funding university-level initiatives has been attempted in various countries. In spite of all the programmatic efforts, there are little to no international data documenting the specific areas in which efforts should be made. In this paper, we argue that one area of focus should be on the allocation of resources, such as funding and lab space, that are needed to contribute to the scientific body of knowledge. Another area of focus should be on the distribution of opportunities to present one's work and be acknowledged as a scientific colleague. Are scientific resources and opportunities distributed equally between women and men? Previous research suggests that they are not^[2]. In this paper, we look country-by-country to see where the inequalities lie.

Across the world, women are generally expected to take most of the responsibility for family and childrearing^[3–5]. Our previous research suggests that these expectations have negative effects on women's careers in physics, but that there are few effects on men's careers^[6]. Will we see these effects on women's careers in all countries?

To answer these questions, we use data from the Global Survey of Physicists (GSP), a multi-national collaborative effort arising from a series of international conferences of women in physics. These conferences were sponsored by the Working Group for Women in Physics of the International Union of Pure and Applied Physics (IUPAP).

HISTORY OF THE GLOBAL SURVEY OF PHYSICISTS

The first and second IUPAP International Conferences of Women in Physics sponsored surveys that were designed

to document the situation of women in physics. The first two global surveys of physicists were based on the notion that the situations of women in physics should be documented. The goal was to describe common problems that women in physics across the world face in their work and studies. The first two global surveys, therefore, were sent exclusively to women. More than 1,000 women from more than 50 countries responded to each of the two surveys^[6,7].

For the third International Conference of Women in Physics, held in Seoul, South Korea, in 2008, the IUPAP Working Group for Women in Physics decided to expand the scope of the surveys. First, men were included in the third survey to allow for comparisons between men's and women's experiences. In addition, the IUPAP working group decided to expand the languages of the survey; the first two surveys had been conducted in English only. With support from the Henry Luce Foundation, the survey was translated into seven languages other than English. These included all the UN languages (Russian, Arabic, Spanish, Chinese, and French), and Japanese and German. The Statistical Research Center of the American Institute of Physics, which had conducted the first two surveys, again undertook this project. We worked collaboratively with women's working group team leaders from the IUPAP countries to create the third survey, now called the Global Survey of Physicists (GSP).

Once the surveys were ready to be distributed, most of the team leaders distributed the web-based survey among their contacts. At the end of the survey form, respondents were encouraged to pass the survey on to other physicists, especially women, whom they knew. This created a snowball distribution. In some countries, physical societies distributed the survey to their members. The American and the German Physical Societies distributed the survey to random samples of their members, and the Japanese Physical Society distributed the survey to all its members.

The survey was available to respondents for one year, from October 2009 to October 2010. At the close of the survey, 14,932 physicists from 130 countries had responded, a dramatic increase from the 1,000+ who had responded to past surveys. Part of the reason for the huge increase in respondents was the addition of men. But the



Rachel Ivie,
<rivie@aip.org>, Associate Director,

and

Susan White,
<swhite@aip.org>, Research Manager, Statistical Research Center

American Institute of Physics, 1 Physics Ellipse, College Park, MD, 20740, U.S.

SUMMARY

A country-level analysis of the Global Survey of Physicists shows sex differences in the distribution of career-advancing resources and opportunities and in the relationship between family and careers.

distribution by physical societies, the addition of seven languages, and the participation of the team leaders no doubt contributed to the increase as well. In the end, 22% of the respondents were women, representing approximately 3,000 women, a significant increase over the number answering the first two women-only surveys. The analyses in this paper are limited to respondents who are not students and who have had a job that uses their knowledge of or skills in physics.

IMPORTANCE OF RESOURCES, OPPORTUNITIES, AND FAMILY RESPONSIBILITIES

There are many types of resources needed to advance a career in science, ranging from access to graduate students or employees to assist with research, to clerical support, research funding, and travel money. One study of social science faculty members in the U.S. found that mothers are less likely than fathers and childless professors to have access to resources, but this difference was entirely explained by mothers being more likely to work outside of research-intensive universities^[8]. Professional opportunities also are essential to career advancement for scientists. These include invitations to speak, serving on committees, and conducting research abroad. Results from the GSP have already shown that even controlling for sector of employment and age, women physicists have access to fewer career-advancing resources and opportunities than men. In turn, lack of opportunities and resources can mean that careers in physics advance more slowly^[2].

The effects of cultural expectations requiring women to take most of the child care and household responsibilities cannot be overlooked. These effects have been documented in the U.S. for academic women's career outcomes. One of the most cited studies found, among many other things, that mothers in the U.S. are 29% less likely to enter tenure-track positions than women without children. Furthermore, women who are full professors are much less likely to be married with children than men who are full professors^[9].

Previous results from the GSP focused on differences between respondents from very highly developed countries (as defined by the United Nations) and less developed countries. These results show the importance of resources and opportunities for advancing all careers in physics. The results also show the dampening effect of having children on women's—but not men's—careers. The results held true for respondents across the world, regardless of their age, employment sector, and their country's level of economic development^[2]. However, among countries with similar levels of economic development, there may be cultural differences that could affect the distribution of resources and opportunities within that country's scientific community. In addition, the effect of children on people's careers could be different in different countries. The purpose of this paper is to determine whether resources, opportunities, and children affect people's careers in physics differently at a country-by-country level.

ANALYSIS AND RESULTS

Although respondents from more than 130 countries answered the GSP, we conducted country-level analyses only for countries with at least thirty women respondents who were no longer students: Argentina, Canada, China, France, Germany, Italy, Japan, Spain, and the U.S. Recall that we drew random samples of the American and German Physical Societies, and that the survey was sent to the entire membership of the Japanese Physical Society. In all other countries, the respondents were asked to pass along the survey to colleagues, so the results are not necessarily representative of the entire population of physicists in those countries. However, the differences we found are statistically significant and merit further discussion.

In our results, statistical significance is indicated by the p -values shown in the tables. A p -value is a measure of the weight of the data against a specified (null) hypothesis. In our tests, the null hypothesis is that there is no difference between men and women. A p -value ranges between 0 and 1, and a smaller p -value indicates stronger evidence to reject the hypothesis. We set our cutoff for statistical significance to p -value < 0.10.

Limited Resources and Opportunities

To measure access to resources, we asked respondents whether they had enough of the following items to do their research: funding, office space, lab space, equipment, travel money, clerical support, and employees or students. To measure opportunities, we asked respondents whether they had done eleven different things such as given a talk as an invited speaker or served on various committees. (For a complete list of opportunities, see Table 2 in^[2].)

We measured the accumulation of resources and opportunities by summing the number of resources and then the number of opportunities that each respondent reported. Scores for the number of resources could range from 0 to 7, and opportunities from 0 to 11.

A simple approach to examine sex differences in the accumulation of resources and opportunities would be to look at the mean number of each for men versus that for women. However, we believe additional factors beyond the respondent's sex could affect his or her accumulation of resources and opportunities^[8]. For example,

- respondents with a longer work experience would be expected to have had more resources and opportunities by nature of having been in the workforce longer, and
- respondents working in different job sectors (government, post-secondary education, etc.) would be expected to have different resources and opportunities.

To account for these differences, we used ordinal regression models that included the respondent's age and employment

sector to test for differences in the accumulation of resources and opportunities. In these models, the value of the coefficient for sex (a 0 – 1 variable) can be interpreted as the difference between men and women. If it is statistically significant, there is evidence to suggest a difference between men and women. Our statistical tests were one-tailed tests because our alternative to the null hypothesis was that women would have fewer resources and opportunities than men.

While our data are not necessarily representative, the p -values are small enough to suggest that women accumulate fewer resources than men in Canada, China, Italy, Spain, and the U.S. In addition, our models show that women accumulate fewer opportunities than men in Argentina, China, France, Italy, Japan, and Spain (Table 1).

Relationship between Career and Family

In much of the world, women hold primary responsibility for taking care of the home and children^[3–5]. The first two IUPAP surveys of women physicists consistently document the effects of children on women's careers^[6,7]. In this section, we examine whether the relationship between career and family holds on a country-by-country basis.

The variable of interest in these models is binary (yes/no), so we used logistic regression models. Using the results of these models, we calculated the difference in likelihood for men and women. Our alternative hypothesis was that women would be more likely to be affected by the demands of balancing work and family, so our tests were again one-tailed tests.

We asked respondents whether their career had changed their personal life, such as decisions about marriage or children. For example, people may delay or avoid marriage or child rearing in order to focus on a career. In five countries—France, Germany, Japan, Spain, and the U.S.—women were significantly more likely than men to say that their career had affected their personal life. Because of the low p -values, we see that the evidence is the strongest in the U.S. and France (Table 2). Women in France, for example, are about three times as likely to say that their career had affected their personal life than are men – after accounting for age and employment sector. The differences were not statistically significant in Argentina, Canada, China, or Italy.

While focusing on a career may affect marriage and family decisions, the reverse could also be true. Becoming a parent, for example, may affect progress in a career, and this effect may be different for women and men. We asked respondents the degree to which they agreed or disagreed with the following statements:

- My work or career did not change significantly [after I had children].
- My career or rate of promotion slowed significantly [after I had children].

For the first question, we had enough respondents to analyze the data in eight of the nine countries analyzed above. (France is the exception.) In all eight countries, men were significantly more likely to say that their career did not change significantly after

TABLE 1
SEX DIFFERENCES IN THE ALLOCATION OF RESOURCES AND OPPORTUNITIES

Country	Resources			Opportunities		
	Average (Both Sexes) [†]	On average men have __ more*	p -value	Average (Both Sexes) [†]	On average men have __ more*	p -value
Argentina	2.83	—	ns [◇]	6.22	0.49	0.066
Canada	5.08	0.54	0.066	6.63	—	ns [◇]
China	4.52	0.51	0.068	5.66	0.69	0.023
France	4.58	—	ns [◇]	7.10	1.04	0.003
Germany	5.19	—	ns [◇]	4.82	—	ns [◇]
Italy	4.05	0.91	0.010	7.05	0.45	0.039
Japan	4.03	—	ns [◇]	6.43	0.59	0.005
Spain	3.98	0.45	0.052	7.23	0.41	0.023
United States	4.96	0.41	0.010	6.21	—	ns [◇]

[†] Averages should not be compared across countries since the data are not necessarily representative. Furthermore, each country has a different mix of men and women in a variety of employment sectors, and each employment sector offers different resources and opportunities.

* These differences account for respondent's age and employment sector.

◇ There is no statistically significant difference.

TABLE 2
SEX DIFFERENCES IN THE RELATIONSHIP BETWEEN WORK AND FAMILY

Country	Women more likely to say their career affects personal decisions		Men more likely to say their career NOT changed after having children		Women more likely to say rate of promotion slowed after having children	
	— times more likely than men*	<i>p</i> -value	— times more likely than women*	<i>p</i> -value	— times more likely than men*	<i>p</i> -value
Argentina ⁺	—	ns [◇]	5.57	0.002	2.79	0.031
Canada	—	ns [◇]	3.16	0.001	3.21	0.001
China	—	ns [◇]	2.05	0.024	5.18	0.000
France	2.98	0.005	Not enough respondents to perform tests			
Germany	1.53	0.012	7.85	0.000	Not enough respondents to perform test	
Italy ⁺	—	ns [◇]	4.30	0.000	3.71	0.001
Japan	1.53	0.042	14.44	0.000	3.62	0.000
Spain	1.42	0.056	4.32	0.000	3.99	0.000
United States	2.07	0.000	2.24	0.000	2.14	0.001
* These differences account for respondent's age and employment sector. + Because some employment sectors included either all men or all women respondents, the regressions for Argentina and Italy do not include every employment sector. ◇ There is no statistically significant difference.						

having children. The evidence is very strong that having children is more likely to change a woman's career than a man's in every country with enough respondents to test (Table 2). At a minimum, men were twice as likely as women to say their career had not changed after having children. In Japan – which was one of the countries where the survey was distributed through the national physical society – men were more than 14 times more likely than women to make that statement.

For the second question, about the rate of promotion, we had enough respondents to test the data in seven countries. In each—Argentina, Canada, China, Italy, Japan, Spain, and the U.S.—women were much more likely than men to say their career or rate of promotion slowed significantly after having children. France and Germany had too few women respondents with children to conduct the analysis. In all other countries, women are at least twice as likely to state that their rate of promotion had slowed after having children; in Japan, women are more than 33 times more likely to state that (Table 2).

Discussion

The GSP included nine countries with at least thirty women respondents who were no longer students. The nine countries included in these analyses are Argentina, Canada, China, France, Germany, Italy, Japan, Spain, and the U.S. For each of these nine countries, we examined sex differences in the accumulation

of career-advancing resources and opportunities while controlling for possible effects of age and sector of employment. With the exception of Germany, we found that in each country, women had either fewer resources, fewer opportunities, or both than men did. China, Spain, and Italy are the three countries where women physicists had both fewer resources and fewer opportunities than men. There were no countries in which women had more resources and opportunities than men.

In addition, we examined sex differences in the relationship between career and family, again controlling for age and sector of employment. In most countries, we found that women were more likely than men to say that their careers as physicists had affected their decisions about marriage and family. In every country in which there were enough women respondents with children, we found that, at a minimum, women were twice as likely as men to say that having children had slowed their rates of promotion. Similarly, in every country with enough respondents to test, we found that men were, at a minimum, twice as likely as women to say that having children had not significantly affected their careers at all. In some countries, these ratios were much higher than two times.

The question of why these relationships hold in some countries but not in others is beyond the scope of this paper. The reader should keep in mind that in only three countries (Japan,

Germany, and the U.S.) are the results representative of the memberships of the physics societies. Each of the countries in this paper has a unique culture, history, and economy that affect the distribution of resources and opportunities. These unique circumstances also affect the relationship between career and family. We welcome further research into the causes of the differences documented here.

IMPLICATIONS

One of the main problems with unequal distribution of scientific resources and opportunities is that it creates disadvantage for the groups or people with limited access. These disadvantages can have a cumulative effect^[10]. For example, a scientist with limited resources may not receive the recognition or opportunities that a scientist with more resources receives. Because of the limited recognition, the scientist who started out with limited resources may not be eligible for as many resources in the future. Lack of resources and opportunities can have long-term effects on people's careers.

In addition, constraints are placed on women's careers in science by the demands of parenting. These constraints also have cumulative effects. If a mother's rate of promotion slows, she may have access to fewer resources and opportunities in the future, so that the effects of parenting become cumulative over her career.

In the authors' opinion, resources and opportunities should not be allocated based on characteristics beyond one's control, such as sex. Science places importance on equity and taking an unbiased approach to its problems. Where possible, the values of fairness and objectivity should be applied to level the playing field for women in physics.

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AGAINST THE STEREOTYPE THREAT

BY ARUNDHATI DASGUPTA AND VÉRONIQUE PIERRON-BOHNES



Arundhati Dasgupta,
<arundhati.dasgupta@uleth.ca>,
Department of
Physics and
Astronomy,
University of
Lethbridge,
Lethbridge, Canada,
T1K 3M4

and

Véronique Pierron-Bohnes,
<veronique.pierron-bohnes@ipcms.unistra.fr>,
Département de
Magnétisme et Ob-
jets Nanostructurés,
Institut de Physique
et Chimie des
Matériaux de
Strasbourg, 67034
Strasbourg,
Cedex 2 France

The proportion of women in academic staff is considerably smaller in physics and mathematics than in the arts and social sciences. For example, women comprise 21.6% of physics faculty in French Universities^[1] and 22.1% of physics researchers in the French Center for Scientific Research (CNRS)^[2]. Only 12.4% of physics faculty in Canada are women^[3]. This is in contrast to social sciences and arts where women at the faculty level exceed 50%. Considerable research efforts have been devoted to understand this ‘imbalance’, and examine the root causes of why women do not pursue careers in natural sciences. Typically, hypothetical biological differences between the brain of men and women, social barriers, and existing prejudices are examined and assessed for their possible roles in the persisting gender disparity. However, recent research challenges the conventional assumptions based on genetic differences and highlights the influence of negative stereotypes.

In the present article, we examine ‘stereotype threat’, a psychological condition in which an individual is at risk of confirming existing negative biases about the individual’s group of identity. The concept was introduced in a paper by Steele and Aaronson in 1995^[4] to study the performance of African-Americans in biased conditions. The “stereotype threat” is rooted in the social, gender and racial identity of an individual, and is believed to be sufficiently influential in affecting the individuals performance in science. It invalidates the justification of women’s lack of appreciation of sciences as due to inherent “biological” constraints.

The present article describes selected experiments on scientific performance of women in math tests under the stereotype threat as reported in pioneering papers discussing this condition^[4–6].

SUMMARY

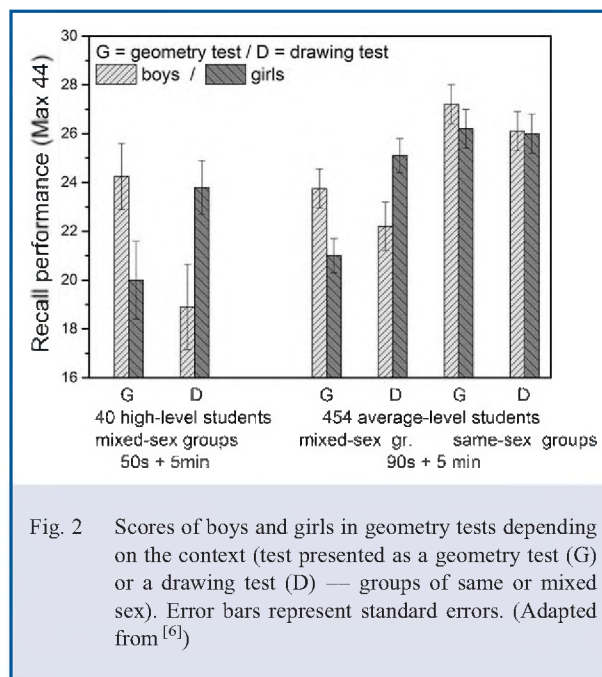
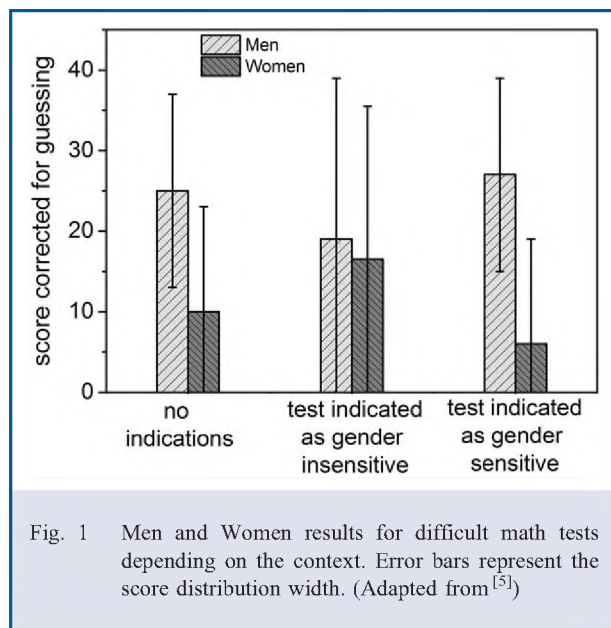
In this article, we discuss the nature of psychological influences which prevent women’s equal participation in science and suggest ways to create confidence instead.

PERFORMING UNDER THE STEREOTYPE

In the 1980’s Benbow and Stanley attributed the significant differences in performance in math observed at a very young age between boys and girls to intrinsic differences in mathematical ability^[7]. The conclusions of the study were later rebutted and attributed to social prejudice rather than inherent biological differences^[5,6]. In an important study, the concept of ‘stereotype threat’ and the methodology introduced by Steele and Aaronson to explain the performance of African-Americans^[4] were used by Spencer, Steele and Quinn (SSQ)^[5] to study gender differences in math tests in 1999. Their results are discussed briefly.

The SSQ investigation comprised three sets of studies with samples ranging from 28–36 men and a similar number of women from University of Michigan and State University of New York, USA. All participants had good qualification in math, including calculus. In study 1 the participants were given two sets of questions, an ‘easy test’ and an ‘advanced or difficult test’. Women scored significantly less than men in the advanced test. This test was done to confirm existing notions of women underperforming in difficult math tests. In study 2 the notion of gender difference was introduced. The participants were given two sets of questions. They were told that the performance outcome had previously shown a gender difference for the first set and no gender difference for the second set. For half of the participants the first and second sets of questions were reversed. The test results revealed that, when women were told that the test was unbiased, they performed significantly better, and equally as men, independently of the actual questions. Figure 1 (adapted from SSQ^[5]) shows the results of the studies.

The SSQ Study 3 was equivalent to Study 2 with easier questions. It further analysed the psychological stress level, the evaluation apprehension, self-efficacy and anxiety of each individual in the study. Based on the three studies, SSQ concluded that women were performing poorly because of the ‘stereotype threat’ (which might have been promoted by anxiety). When the ‘threat’ was removed, women’s performance equalled that of the other gender independently of the difficulty of the test. For the detailed account of the experiments and findings, the reader is referred to the original paper^[5].



Huguet and Régner^[6] conducted a series of studies to examine the effect of the ‘stereotype threat’ on young school pupils of a French public middle school, in an age group of 11–13 year olds. The test consisted in reconstructing by memory a complex drawing with different lines and figures. One half of participants were told that the test was a geometry test, whereas the other half, were told that the test was a drawing memory game.

In a first study, 20 girls and 20 boys with good math skills were tested. They had 50 seconds to memorise the figure and 5 minutes to reproduce it. The result was astounding (Fig. 2 left); in the test labelled as memory game, the girls significantly outperformed the boys whereas the result was reverse when the test was presented as a geometry test.

A second study involved 454 children (223 girls and 231 boys) with average math skills. They were divided into groups of 20 persons either of the same sex or with mixed sex members and given the same test as for study 1. The test was again specified as a ‘geometry test’ for half of the groups and as a ‘drawing test’ for the others. They had 90 seconds to encode the figure and 5 minutes to reproduce it. The results of Study 2 are presented in the right panel of Fig. 2. Again, in mixed groups, the girls significantly outperformed the boys when the test was labelled as a ‘drawing test’, replicating for a larger sample the observations of study 1. In the groups comprised of same-sex members, the scores were very good for both genders. These studies show that the stereotype threat influences the results of both girls (stereotype favouring boys in geometry ability) and

boys (stereotype favouring girls in artistic ability) in the mixed groups. Whereas in the same-sex groups the stereotypes are inhibited; the influence of role models (high ability persons of the same sex) can be useful in improving performance. Further details can be found in the original paper^[6].

A recent study^[8] used a similar test for 312 high school students in physics in USA. Three different stereotype threat conditions were assigned to different groups: They were (i) Implicit stereotypes (the students were not told about any gender notions), (ii) Explicit stereotypes (students were told that in the test boys outperformed girls), and (iii) Nullified stereotypes (The students were told that girls performed equally as boys). The results of this recent study^[8] confirmed the outcomes of the previous studies^[5,6]. The groups with implicit and explicit stereotype threat conditions showed disparity in the performance: boys performed better than girls. On the contrary, in the groups with nullified stereotype condition, girls and boys performed equally.

CONCLUSION

In conclusion, the notion that women would be weaker than men in their math skills, particularly in difficult math skills, persisted during the test of individuals and influenced their performance. The use of psychological manipulation to counter-influence the individuals against this bias clearly increased their performance level. The use of positive role models, e.g. the presence of girls with excellent math skills in the group, also increased the performance level of the group^[6]. Thus the existence of ‘stereotype threat’ is real, and like all

threats must be removed from the classrooms and educational centers of human knowledge as a beginning. However, the good performance of girls at exams is only a first step towards achieving gender balance in scientific careers. The next step is changing the negative stereotypes that have a strong influence on their career choices. Women with high scientific skills statistically prefer medical and social jobs to maths, physics and engineering jobs.

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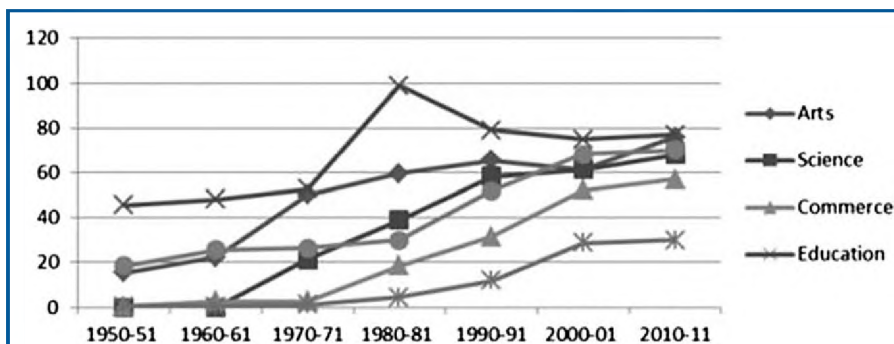
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WILL MENTORING BRIDGE THE GENDER GAP IN INDIAN SCIENCE?

BY ANITHA KURUP

Despite the steady increase in the number of women entering science, the gender gap persists, especially at higher levels in academic careers across the world. This phenomenon of attrition of women at progressively higher levels of professional careers has been described as the 'leaky pipeline'. In the Indian context, the number of women entering science at the undergraduate level has been on the rise (from almost nil in 1951 to close to 62 percent in 2010–11, as seen in the graph below). This is a very encouraging sign. However, this does not translate to increased numbers at the graduate and PhD level.



Graph 1 Enrolment of girls across Broad Disciplines between 1950–2011.

The “leaky pipeline” for India shows a distinct pattern. On one hand, India, like several developed countries, shows a persistent gender gap in specific disciplines like engineering, physics and mathematics. What is more interesting though for India is that the leaky pipeline across the STEM disciplines is with regard to the period beyond the doctoral degree. Notwithstanding the lower numbers of

women enrolling for PhDs in India, one of every four scientists in India is a woman, but the largest pool of women remain at the lower rungs of science. A study by Bal^[1] reports that even in the biological sciences, which are thought to have a relatively higher proportion of women, the number of permanent positions held by women ranges between 10–22% across biological departments of various universities and institutions in India. Women in the biological sciences are also limited to junior faculty positions, where their proportion ranges from 18–33%. Similarly, Kumar^[2] (2001) also compared the percentage of women across faculty levels in the

STEM discipline showing a growing gender gap as a result of prevailing organizational culture of scientific institutions. Thus, it is imperative to mention that women’s growing access to education is not translating into gender equity in scientific careers in India.

In an attempt to understand the leaky pipeline in the scientific careers of women in the STEM disciplines, a national survey was carried out by the National Institute

of Advanced Studies (NIAS), Bangalore, and the Indian Academy of Sciences (IAS), Bangalore, covering 568 women scientists who had a PhD in one of the STEM disciplines. 312 were engaged in Science research (WIR); 182 were not engaged in long term research (WNR) includes those in undergraduate/school level teaching, temporary research positions such as DST women scientists schemes and consultancy or administrative posts. The defining feature of the category was working on jobs that may not require training at the PhD level; and 74 were not working (WNW). In addition to representing the diversity among women, another unique aspect of the study was the inclusion of men scientists (161) as a comparative group.

The survey was conducted using a pre-coded questionnaire that contained approximately 100 questions regarding



SUMMARY

Mentoring and its inter-linkages with role models provide a useful lens in understanding the minuscule number of women in leadership in the STEM disciplines.

Anitha Kurup,
<bkanitha@gmail.com>,
Professor, National
Institute of
Advanced Studies,
Indian Institute of
Science Campus,
Bangalore 560012,
India

personal and family details, education, employment and organizational details, and research and productivity factors. In addition, qualitative data was collected through in-depth interviews with the respondents of the study. An analysis of the data revealed several factors at the personal and organizational level that were responsible for women leaving active careers in the STEM disciplines^[3]. The absence of mentoring as an important aspect of why women leave science was not directly alluded to in the survey. However, the interviews with WNR and WNW made indirect references to the absence of mentors, which was later corroborated by a closer analysis of the survey data^[4]. The responses of the women scientists about networking and lack of job opportunities is directly related to the absence of mentoring.

Who is a mentor? A mentor is an experienced and trusted advisor. A mentor is an individual, who gives another person help or advice over a period of time and also teaches them about the job. The National Academy of Sciences (197:2) defined mentoring as a process in which . “... a good mentor seeks to help a student or (protégé) optimize an educational (developmental) experience to assist the student’s (protégé’s) socialization into disciplinary (organizational) structure, and to help the student (protégé) find suitable employment”. If this is the operational definition of Mentor, what does the analysis of the NIAS_IAS study reveal?

MENTORING AND NETWORKING

The NIAS-IAS study examined the reasons why women did not take up jobs previously applied for. 66.6 % of WNW, 41.8% WNR and 28.2% of WIR reported that they did not get the job that they applied for. It is well established that the mentors play a significant role in providing information, recommendation and the much needed support for the new entrant into a career in science. The increasing percentage of WNW and WNR indicates the critical absence of mentoring support at a crucial stage of entry into the formal space of science practice.

A central factor accounting for success in professional careers is access to senior colleagues who are influential in the field. In the field of science, such influential members are more often than not members of professional organisations and academies. Being members of professional organizations can affect one’s career opportunities, as professional organizations are important sites of networking, through which one may be able to participate in collaborations, research projects, conferences and workshops, advisory committees etc., thereby gaining greater visibility.

A significant difference exists with respect to membership in professional organizations for sub-categories of women scientists. Among women in research, only **24 per cent** have reported **not being members of professional organizations**. The highest percentage of WNR (**47.3 per cent**) has reported that they were **not members of any professional organization**.

An equally high percentage of WNW (**41.9 per cent**) have also reported **not being members of professional organizations**. **The above data clearly reveal** the absence of mentoring among WNR and WNW at the organizational level.

Most professional organisations that are prestigious in the STEM disciplines need very strong recommendations or nominations from a senior scientist to become members of these professional bodies. In the absence of such recommendations, women scientists who do not belong to a family of scientists and, consequently, are unaware of the academic culture of science institutions, find it extremely difficult to make their way into professional organisations. Needless to say, membership in professional bodies provides the much needed networking and collaboration opportunities for career advancement in science.

Access to information about grants and scholarships for career advancement is critical for women as they progress in their career. Most often, information about opportunities for grants and scholarships is not well advertised and more often than not does not reach women scientists. This is true for women scientists who are not part of the active network of scientists and hence are denied the opportunity to avail themselves of these facilities. The low numbers of women scientists in the overall pool of scientists in India adds to the problem. The survey revealed that over 65% of WIR **have not received career grants from within or from outside the organization**. **The percentage not receiving grants was higher (over 75%) among WNR and WNW**.

The availability of opportunities to attend conferences and workshops fulfills an important function for the different groups – allowing women in scientific research and teaching to showcase their work and learn more about the work of colleagues and competitors. For those who are working indirectly in science, it is useful to help them keep in touch with science and topics of interest to them. More importantly, for those women scientists who are not currently employed, it provides an important mechanism for keeping in touch with science and with scientific networks, which can someday help them return to science.

There was no significant difference in the proportion of women or men with regard to attending conferences, which is very encouraging, despite the fact that women with families find it harder to leave young children and travel long distances. Attending conferences independently does not result in networking unless coupled with efforts to promote oneself. According to Nandini Rajamani Robin, a wildlife biologist with IndiaBioscience, there is a sense of discomfort with self-promotion among women. “Networking also involves consciously putting yourself out there and talking about your work, which is something women have to learn to be comfortable doing”. Despite being aware of the significance of attending conferences, the absence of active mentoring by senior

scientists in promoting and encouraging women scientists and linking them with potential collaborators has negatively impacted the career growth of several promising women scientists.

MENTORING AND ROLE MODEL INTERACTION

Scientific organisations have not systematically explored the potential for mentoring, particularly as a key support mechanism for women scientists. In order to develop a successful mentoring programme, there is a need to build a symbiotic relationship between organizational mentoring (more formal and part of the institutional process) and informal mentoring.

Organizational mentoring is a long term intervention, more likely to be sustainable and have a wider outreach, and hence a greater impact. Organizations aware of the potential of mentoring, often create opportunities for collaborative work within and outside the organization. Stanford University and MIT are cases in point. Incentives in several instances are built-in giving the signal that this is a valued practice within the organisation. Mentoring, as an outcome of this planned intervention, is allowed to evolve as a process providing flexibility to individuals to respond to differences amongst employees. Mentoring has a complex relationship with the culture of the organization. There is a wide variation in the organisational culture within and among organisations of different sizes. Thus, it may be important for the evolution of typical models of mentoring that may be suitable for small, medium or large organisations. This can be based on the experiences of individual organisations. The full participation of members of the organization is instrumental in the development of successful models of mentoring. Periodic reviews of the mentoring models need to be built-in to allow for mid-term corrections. Most international laboratories led by Nobel Laureates and other distinguished scientists are important sites for learning and understanding the development of successful models of mentoring.

On the other hand, informal mentoring, which is equally important, is observed more often in practice. It is true that mentoring is a complex process, and hence cannot be conducted as a tutorial class. However, informal mentoring plays a crucial role in advancing one's career, and hence needs to be given due recognition when considering the professional growth of women scientists. There is a need to create social spaces for networking and interactions. Shobhana Narasimhan, a theoretical physicist at JNCASR in Bangalore, says that when men tend to go for drinks after work, they are also creating informal but very significant spaces to network and share valuable information. "How to apply for grants, which journals to approach, which institutions to apply to—these are things that are otherwise hard to learn; no-one teaches you these things. Women are typically excluded from these circles" [5].

CHALLENGES AND OPPORTUNITIES

There is a general perception among most men scientists that women scientists are individual players. This perception held by the men scientists, leads them to believe that women scientists lack the skills for team-building and make very poor leaders. However, a closer interaction among successful women scientists during the survey revealed that many of them actually believe the contrary. In the absence of systematic mentoring and access to information regarding the availability of role models within the country, most women scientists believe that career advancement is a combination of intelligence, dedication and personal commitment. This is true for several women scientists from rural India, where the chance encounter with charismatic women science leaders continues to be very low. A combination of the above factors often creates serious roadblocks for potential leaders among women scientists to considering experimenting with mentoring as an important mechanism for their own professional growth.

It is widely believed that identifying a mentor from within one's own field of specialization can be advantageous on the professional front. However, given the nature of the field defined by intense competition, developing trust between the mentor and mentee can negatively impact the mentoring process. Interaction with women scientists in India revealed that among the very few who reported having a mentor, the mentors often belonged to different fields of specialization or were individuals in their own field but resident in different countries (based on the interviews with women and men scientists during the IAS NIAS Survey on "Trained Scientific Women Power: How Much are we Losing and Why?", 2010).

As discussed earlier, mentors need to be in positions of power and be members of important networks. The STEM disciplines have a large proportion of potential men mentors in the general pool in comparison to women. Cultural barriers, particularly in the Indian context, inhibit women from seeking mentors among men, where interaction with men is considered as a taboo. There is also a general perception among potential men mentors that women lack the commitment and drive required for a long term professional career, which further reduces the opportunities available for women. On the other hand, some women scientists shun mentors because of the fear of being patronized by men. Unfortunately, in several instances the fine line between mentorship and patronizing is often forgotten.

Men constitute the majority of potential mentors in a profession like science and engineering, since they occupy the majority of the decision-making positions within the formal science space. Hence, there is the possibility of perceived shared values; skills of networking derived from the historical advantage of accessing the public sphere throughout the growing years when compared with women. The shared common experiences among men lead to a natural bonding of mentor-mentee among men. On the other hand, the presence

of fewer women in decision-making roles and the pressure to learn to operate in this space, predominantly occupied by men, often leave women scientists with little time or opportunity during the initial years to reach out to their younger women colleagues. However, research studies have pointed out that when the number of women in these decision-making bodies reaches a critical mass, women are more likely to mentor younger women scientists. (Kurup.A., 2010 based on the interviews with women and men scientists during the IAS_NIAS Survey on “Trained Scientific Women Power: How Much are we Losing and Why?”).

Negotiating skills in the formal space of science practice are critical as one advances in one’s career. Women scientists have little opportunity to observe, learn and master the skills of negotiation. It is often difficult for women to be assertive with regard to equitable distribution of administrative and academic responsibilities and opportunities. Mentors play a key role in providing useful tips in building such skills.

CONCLUSION

Although it is little contested that mentoring plays a key role in the professional advancement of any individual, there is a lack of systematic study that explores the differential patterns of mentoring that operate in different professional fields. Many researchers have concluded that women are not well integrated into mentoring systems^[6–8]. The absence of mentoring opportunities, both within formal and informal spaces, has been the single most important factor among others responsible for the slow pace of career advancement of women scientists to decision-making roles and leadership positions. Women scientists pay a huge price in failing to acknowledge the need for mentoring of any form as integral to career advancement and thus it is often forgotten and goes unrecognized as part of the reality of organizational and professional lives^[9]. There is an urgent need to carry out systematic, large-scale and long-term research studies on mentoring if we are serious about providing support and retaining women in the STEM disciplines.

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TOWARDS GENDER EQUITY IN PHYSICS: GENDERED AND GENDER-NEUTRAL INTERVENTIONS

BY PRAJVAL SHASTRI

Gender disparity in the physics profession is a world-wide phenomenon^[1]. Increasing recognition of the issue led to, inter alia, the constitution of a Working Group on Women in Physics by the *International Union of Pure and Applied Physics* in 2000. This Working Group has been conducting international conferences every three years since 2001 to deliberate on the problem. While gender disparity exists in all the natural sciences, the disparity in physics is the highest, with the fraction of women physicists rarely exceeding 30%. And it is unlikely that this disparity will simply correct itself with time. To quote Londa Schiebinger,

"There is a sense that nature takes its course—that, given time, things right themselves. The history of women in science, however, has not been characterized by a march of progress but by cycles of advancement and retrenchment"^[2].

EXPLAINING THE GENDER GAP

The disparity or gender gap in the sciences has been attributed to multiple factors. They include lack of interest in science among girls, discriminatory familial responsibilities and discrimination in the workplace^[3]. Several efforts to address the gender disparity in developed countries have focused on the first two factors, viz., lack of interest in science among girls and the discriminatory familial responsibilities that women encounter in their personal lives. Several empirical studies have, however, shown that, in addition to these factors, there is also discrimination in the workplace that is rooted in gender stereotypes^[4]. The National Science Foundation, USA has found that, after correcting for age, experience and education, discrimination remains the only explanation for women's poor positions in the sciences^[2].

SUMMARY

The gender gap in physics is seen world-wide and has been attributed to multiple factors. The applicability of these factors is explored in the context of physics practice in India, using available empirical investigations and theoretical insights from gender studies.

In India, the first factor appears not significant. Girls traditionally do as well as or outperform boys in high school, and they do seem to be as attracted to science as boys. Sixty per cent of the fellowships given under the "Innovation in Science Pursuit for Inspired Research" (INSPIRE) instituted by the Department of Science & Technology (DST) of the Government of India are girls. Available data on enrolment in physics at the college level, although somewhat dated, indicate that female enrolment was well above 30%^[5]. One might therefore expect that in India the disparities in the profession, i.e., post-PhD, would be much lower relative to the situation in the developed nations, where the proportion of women in post-PhD positions is under 20%. If, on the other hand, a gender gap exists at that level, then it must be attributed to the other factors outlined above. Policies to redress the gap must then reflect this understanding.

In this paper, we will explore the following in the Indian context:

1. The extent of the gender gap in the physics/science profession,
2. The current attempts at redress and their limitations, and
3. The way forward.

THE GENDER GAP IN THE PHYSICS/SCIENCE¹ PROFESSION IN INDIA

The gender disparity in the sciences as a whole in India is known to be declining. Statistics published by the DST show that ~30% of the INSPIRE faculty-level fellowship recipients have been women, ~30% of the principal investigators of science projects funded by DST are women. The female fraction in science faculties in higher education institutions has reached 43%^[6]. However, it is known that the situation in physics faculties is not as good. E.g., the female fraction of physics faculty in the University of Hyderabad is 30%^[7]. Furthermore, representation of women among scientists in the country's elite institutions, among senior governance positions and academy membership remains dismal^[8].

1. For India, physics-specific data are sparse, so we often use data for all of the sciences instead.



Prajval Shastri,
<prajval.shastri@gmail.com>,
Indian Institute of
Astrophysics,
Bangalore
560034, India

The Government of India has recognized this gender gap in the Indian science profession. To quote Kapil Sibal, who was the Minister for Science & Technology in 2008:

"It seems to me that we have developed in science and technology, a stratified system in which men are favoured with career advancements at the expense of women."^[9]

POLICY INTERVENTIONS: REDRESSING OR STEREOTYPING?

Several policy measures have been initiated or proposed by the government to address this gap. They include:

- A three-year career-break fellowship for women by the DST, intended to have them re-enter mainstream research. 223 fellowships have been awarded in the physical sciences as of 2014. A significant fraction of them have subsequently got tenured positions.
- A flexible work hour policy for women has been proposed, though not implemented so far.
- Workshops, almost exclusively for women scientists, have been organized by both the DST and the University Grants Commission, to sensitize them to "legal/ethical" issues and "enhance" their research skills.
- The DST has also proposed a "mobility scheme" to address constraints faced by women scientists subjected to relocation due to family reasons.
- The government has a generous child-care leave policy for all women employees (two years per child for a maximum of 2 children over their career), though this does not include "stopping the tenure/promotion clock".

The implicit assumption behind these policies² is that external discriminatory familial responsibilities impose a professional handicap that will result in a productivity deficit. That a large number of women have utilized the career-break fellowships lends credence to this assumption. The Global Survey of Physicists found that for India, though a minority of women respondents were parents or in a long-term relationship, as many as 77% of female physicists reported that their career changed their personal decisions about marriage or children, as opposed to 53% of the male physicists (67/126)^[10], again lending credence to the assumption.

The problem with policies that focus on women, however, is that they reinforce the gender stereotyping to which women are subjected. For instance, the career-break fellowship is seen by men as an unfair benefit given to women^[11]. If it were a career-break fellowship for men and women, then it would signal that men are expected to take equal responsibility for caregiving, and would also be more on par with other gender-neutral fellowships. While men who have taken primary responsibility for the caregiving of their families and have

therefore taken career breaks are hard to find, their numbers are slowly increasing.

The same argument applies to child-care leave and flexible work hours. Rather than viewing the family as a handicap factor only for women, there should be a shift in orientation of family leave and career-break policies towards work-life balance of men and women.

Similarly, the funding of women-only skill-building workshops rests on the highly gendered idea of "fixing the women", whereas the data demonstrates that the women who do make it into the profession are, if at all, better qualified than the men^[12]. In other words, measures envisaged to address gender inequity ought to be those that result in reduction in the salience of gender^[13].

THE BIGGER FACTOR: DISCRIMINATION IN THE WORKPLACE

Unfortunately, the "Familial Handicap" is far from the full story. Although the female fraction of science faculty in higher education in the country has increased from ~30% (1985) to ~43% (2012), and the fraction of female principal investigators of science research projects funded by the DST increased from 18% in 2005 to over 30% in 2012^[6], the fraction of women fellows of the prestigious Indian Academy of Sciences has climbed from 3% in 1995 to a mere 7% today. This fraction is much lower than the fraction in the pool, a clear indicator of discrimination^[14].

Surveys have shown that, on average, women scientists come from a more socially advantaged class of society than the men^[12,15], and that they were also better qualified relative to the men scientists^[12]. Clearly women need to have a head start relative to their male counterparts in order to get into science. More importantly, however, analysis of data gathered via questionnaires administered to a sample of 117 physical scientists (56 women and 61 men matched on the basis of age) across the country in both universities and national laboratories has shown that there was no significant correlation between gender and productivity (measured using scholarly publications), but there was a correlation between gender and position in the hierarchy. The mean age of women who were professors (or equivalent) was significantly higher than that for men. The investigator Neelam Kumar concluded:

"Women's status in the institutions depends on factors other than competence, indicating that particularism in the form of gender discrimination exists here."^[14]

Indeed it has been argued that organizational hurdles outweigh so-called family constraints, and furthermore, that unequal treatment and subtle discrimination against women scientists in interpersonal relations also prevail^[16,17]. In one not-so-subtle case, a woman scientist was not offered the directorship of an institute because of perceived interference by her familial

2. The DST also awards substantial support to Women's universities (the CURIE programme). We do not analyze the impact of women's universities here, however, due to paucity of data.

responsibilities^[7]! Clearly, discrimination against women is strong, and shows that scientists are as influenced by gender stereotyping as in the rest of society, and they bring these values into their functions in the science workplace.

While discrimination in the workplace is clearly a major factor in bringing about the gender gap, it is often difficult to recognize, even by the targets themselves. In the words of Megan Urry, astrophysicist and Director of the Yale University Centre for Astronomy:

"Discrimination isn't a thunderbolt, it isn't an abrupt slap in the face. It's the slow drumbeat of being under-appreciated, feeling uncomfortable and encountering road-blocks along the path to success..."^[18]

It should be noted that both men and women are susceptible to holding gender stereotypes, and therefore, perpetrate discrimination. An indication of the gender stereotyping that is prevalent is the drumbeat of casual comments that are typically heard by women scientists/students^[11]. Anecdotal evidence of sexual harassment also exists in both university settings and elite institutions, although data to gauge the extent of the problem are scarce.

In some sense, the finding that culturally driven discrimination is a major factor in Indian science is not surprising, given the strong gender bias in societal relationships that persist in Indian society, of which, after all, the scientists, both men and women, are products. As Ridgeway and Correll have said:

"There is increasing consensus among gender scholars that gender is not primarily an identity or role that is taught in childhood and enacted in family relations. Instead, gender is an institutionalized system of social practices for constituting people as two significantly different categories, men and women, and organizing social relations of inequality on the basis of that difference."^[13]

Therefore, gendered measures to address gender inequity such as the governmental policies listed above will be limited in their effectiveness and indeed only reinforce gender stereotypes.

GENDER STEREOTYPING AND DISCRIMINATION: MEASURES NEEDED

In order to address this discrimination and stereotyping, it is important to keep in mind the back-drop of gender stereotypes that are prevalent. The descriptive stereotypes perceive women as less competent as men, and as primarily care-givers. Furthermore, men are perceived as primarily breadwinners and incapable of caregiving. The prescriptive stereotypes suggest that women should focus on parenting, be "nice" and cooperative in the workplace, and dress in certain ways.

Cognitive shortcuts are used to evaluate a person by the perceived group that she/he belongs to (in this case women or men) rather than as a person with individual scientific merit and other institutional capabilities. In a video titled *Minimizing Gender Biases in the Workplace*, Shelly Correll points to strategies to combat gender bias in the workplace based on the concept of cognitive shortcuts^[19].

Training Workshops to Combat Gender Bias

Clearly, then, an important need of the hour is gender training workshops for *all* scientists, especially those in the decision-making roles of science practice, that bring to the fore the various cultural sources of gender bias. The workshops should include training for search committee members in recognizing unconscious bias in recruitment, including the types of questions allowable in an interview: questions should focus on job-related issues and should avoid questions of a personal nature such as marital or family status^[4]. They should also train all scientists in how to run meetings fairly and how to implement a zero-tolerance policy towards offensive comments.

Such workshops would be far more effective in changing the science workplace into a gender-healthy one, rather than workshops that merely give skills to women who are already highly skilled. Furthermore, spreading best practices through workshops makes the environment better for everyone, not just women.

Transparency and Accountability in Institutional Governance

Making governance of scientific institutions transparent and accountable makes institutions healthier, and of course helps all scientists independent of gender. However, it has been argued that transparent governance also addresses gender bias and makes for a gender-healthy workplace, because it implies checks and balances against individual biases of decision makers. Transparency and accountability would include clear guidelines for hiring and promotion, robust redressing of sexual harassment and open advertisement of leadership positions.

Monitoring the Gender Audits and Tracking the Impact of Interventions

Funding agencies such as the DST and the UGC should be required to publish their gender fraction data at all levels of the institutional hierarchy and to list measures that they have initiated to address gender inequity. Constant monitoring is extremely important to ensure effectiveness of the interventions.

CONCLUSIONS

Available data and studies of the gender question in Indian physics/science practice clearly show that the gender gap is caused not only by the discriminatory familial responsibilities that women encounter in their personal lives, but also by

gender-discriminatory attitudes in the scientific workplace. Although the Government of India, which is the major funder of scientific research and higher education in India, has acknowledged the gender gap and initiated several measures to address it, these measures also come from a gendered perspective, and therefore will be limited in their long-term effectiveness. Policy measures must address the gender discrimination in the workplace as well in order to achieve gender equity.

Ironically, there has been very little (though slowly increasing) discussion of the gender issue in formal circles within the Indian physics community^[8], and even within scientific institutions there is very little acceptance that the gender gap is due to gender discrimination rooted in cultural stereotypes. This is probably because of:

1. A belief in immunity to prejudice: Physicists believe that by being scientists they are automatically and completely driven by reason alone, just as physics itself is.
2. The physicists' disconnect: Physicists study things other than the society around them and are therefore likely to be

less aware of the societal forces and processes that they are situated in.

3. Fear: Women physicists probably worry that raising the gender issue will undermine their positions within the institution, and do not wish to be seen as rocking the boat.

However, scientists, and especially physicists, are clearly culpable, and urgently need to collectively reflect on the problem of gender inequity in their workplace.

ACKNOWLEDGEMENTS

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AN ECLECTIC HISTORICAL PERSPECTIVE ON ADVANCING WOMEN IN PHYSICS

BY BEVERLY KARPLUS HARTLINE, MILDRED S. DRESSSELHAUS, AND JUDY FRANZ

Women have contributed to physics since the origin of the field. But throughout most of history, they have been very scarce. Until the 1970s, moreover, the scarcity was rarely questioned, and the women were often relegated to volunteer or low-paid roles, making extraordinary contributions, nonetheless. Examples include Marie Curie, Lise Meitner, Marietta Blau, Cecilia Payne-Gaposchkin, Maria Goeppert Mayer, C.S. Wu, Rosalyn Sussman Yalow, and Sulamith Goldhaber. When the late Yalow could not get a position in nuclear physics after earning her doctorate in 1945, she found employment at a hospital, started the field of nuclear medicine, and shared the 1977 Nobel Prize in Physiology or Medicine for developing the radioimmunoassay technique.

In the United States, the severe underrepresentation of women was not due to a lack of capability or interest, but rather to a lack of opportunity, an abundance of barriers, and a difficult climate. Many leading physics departments were in universities that did not admit women, keeping women off the fast track to doctoral study. The culture of physics was highly competitive and actively discouraging to females. Nepotism policies, gender-based inequalities, and discounting—even discrediting—of women's abilities all took their toll. In the 1940s and 1950s, for instance, women employees at some Ivy League Universities were not allowed to enroll in and get academic credit for graduate courses, like their male peers could.

Starting in the early 1950s, more women were completing physics doctorates and entering careers. These pioneers include Cecile DeWitt-Morette, Vera Rubin, Mildred Dresselhaus, Myriam Sarachik, and Margaret Kivelson—all of whom have made truly extraordinary contributions to physics and/or astronomy.

SUMMARY

Some innovative interventions over a half century have helped overcome significant barriers to the full participation of women in physics. Yet more work remains.

Unlike chemistry and engineering—fields in which the entry-level credential is a bachelor's degree—for physics the doctoral degree is required for a professional career. Looking at trends in doctoral attainment, one can see growth in women's participation (see Rachel Ivie's paper in this issue for more details). In 1966 only 1.9% of the PhDs granted in the USA in physics were earned by women. Only nineteen women received physics doctorates across all U.S. universities.

Fast forward to 2012. As a result of decades of effort, the percentage of physics doctorates to women had increased by an order of magnitude to 19.4% (363 degrees). Even with this significant growth, women are still seriously underrepresented. Moreover, non-Asian minority women are even scarcer, with the 15 doctoral recipients representing less than 1% of the total.

Among university physics faculty, where visible women can be inspiring role models for undergraduates, graduate students, and prospective K-12 teachers, progress can also be seen. But the percentage of women on the faculty is still abysmally low: only 14% across all departments that award degrees at the bachelor's level or higher. This presence can be viewed positively only in contrast with the past. In 1985 less than 2.5% of the faculty in physics were women, and more than half of the PhD-granting departments in the USA had no female faculty. Yet even today, among the 9,000 physics faculty at all US colleges and universities, fewer than 75 are underrepresented minority women!

We present here some of the strategies used in the United States over the past 40 years to increase the numbers, visibility, and advancement of women in physics. We describe the key role of professional societies, highlight three successful interventions, and provide a vignette from one subfield: condensed matter and materials physics. Finally, we discuss the role of the International Union of Pure and Applied Physics (IUPAP) in fostering networking, data-gathering, and sharing of best practices toward improving the participation and success of women in physics and related fields around the world. Useful references are provided in the bibliography.



Beverly Karplus Hartline,
<bhartline@
mtech.edu>,
Montana Tech,
Butte, MT, USA,

Mildred S. Dresselhaus,
<millie@mgm.
mit.edu>,
MIT, Cambridge,
MA, USA,

and

Judy Franz,
<franz@aps.org>,
Retired, Huntsville,
AL, USA

CATALYZING CHANGE IN THE UNITED STATES

The low participation of women is a serious problem for physics and for society. Without women, physics can only tap half of the brainpower in the population. It cannot build on the ideas and insights the missing women could have contributed. Imagine the course of physics even world history—without Marie Curie, Lise Meitner, and C.S. Wu. Most likely their discoveries would have been made by someone by now. But when and where?

In the United States, the physics community began to question the low participation of women by the early 1970s. Possibly the publication of gender-disaggregated data by the National Science Foundation's (NSF) statistics group was a factor in focusing attention on the demographic imbalance. Perhaps departments aspired to increasing enrollments and saw women students as a source of additional majors. Likely there was a very strong influence from the enactment in June 1972 of Title IX, which prohibits sex discrimination in any educational program or activity which receives financial support from the federal government.

In any case, in the early 1970s, the APS and American Association of Physics Teachers (AAPT) began to take an interest in understanding the low participation of women and girls and in exploring effective means to encourage them in the field at all levels. Both women and men physicists contributed to this effort.

Professional Societies as Agents of Change and Support

In the USA, professional organizations contributed significantly to giving the issue attention, to developing interventions, and to fostering the nationwide networking needed to overcome the isolation experienced by the few women present. The first action they took was to establish a committee focused on women to engage a few of the organization's members, thereby raising the visibility of the issue and stimulating ideas and interventions. By 1980, leading physics professional organizations in the USA had founded such committees.

The APS (www.aps.org) founded its **Committee on the Status of Women in Physics** (CSWP, <http://www.aps.org/about/governance/committees/cswp/index.cfm>) in 1972 to encourage and promote the career development of women physicists. The CSWP has nine appointed member volunteers, including a few men. To date, of the 101 people who have served as APS president, five (5%) have been women, including the first female APS president, C.S. Wu in 1976, and co-author Dresselhaus in 1984.

Throughout its history, CSWP has been an active sponsor of studies, programs, publications, and sessions at the major annual APS research meetings to focus attention on the issue and foster women's participation and advancement. Among its

initiatives are career development workshops to help students, early career physicists, and mid-career physicists cope with career challenges and advance to the next level; studies of the climate for women in physics departments; efforts to increase the nomination of women for APS fellowship and awards; and financial fellowships to help women re-start their physics careers after a break. After her term as APS president, Dresselhaus requested appointment to CSWP to emphasize the important role of CSWP in enabling women's success.

The AAPT (www.aapt.org) focuses on physics education and teaching. To date, nine women (11%) have been among the association's 79 presidents, including its first female president, Melba Phillips in 1966–67, and co-author Franz in 1990–91 (shortly before she became Executive Officer of APS).

By 1980, the AAPT launched its **Committee on Women in Physics** (<http://www.aapt.org/Directory/women.cfm>). The mission of this committee is to seek means to recruit and retain women in physics classes and careers and to aid women in their physics career development. This committee has organized and offered numerous workshops over the years at AAPT's conferences. Popular topics address career success (including negotiation and working with difficult colleagues), classroom climate, outreach, recruiting, and retention.

Because non-Asian minorities are so underrepresented in physics, two additional physics-focused professional societies formed more recently to promote the wellbeing, networking, recognition, and professional development of minority physicists and physics students. The **National Society of Black Physicists** (NSBP, www.nsbp.org) was founded in 1977. The **National Society of Hispanic Physicists** (NSHP, www.hispanicphysicists.org) formed in 1995. For both organizations, the inclusion and advancement of women physicists have been a priority since their inception. The NSBP committee on Women in Physics organizes sessions on survival skills for women, monitors and disseminates statistics, reaches out to young girls, and maintains a list of Black Women in Physics (www.nsbp.org/bwip/).

Tackling the Difficult Climate

Among the most innovative and effective interventions has been the departmental **climate site visit** program. This program resulted from a resolution approved in 1990 at a meeting of physics department chairpersons. This resolution urged all physics department heads to do more to encourage the full participation of women and minorities in physics. The group requested the assistance of both APS and AAPT, which engaged their respective committees on women. The committees decided to initiate a program of visits to universities to investigate the climate for women in the physics departments, to identify systemic problems and best practices, and to suggest improvements.

A pilot set of visits to a few campuses was initiated with support from APS. Then a more formal program was designed, including more site visits and a national survey on climate issues to be administered to undergraduate and graduate physics students. A proposal led by Judy Franz—AAPT president at the time—and Mildred Dresselhaus—chair of the APS/CSWP—was funded by the NSF to support the visit program. Bunny Clark at Ohio State was added to create a three-member leadership team. The group engaged many more women physicists as visiting team members, including co-author Hartline.

The initial climate project visited 15 departments—many of them at major universities. These visits revealed that on most of the campuses, women suffered repeated indignities, including: seeing lewd and nude pictures in offices, women students being asked to substitute for secretaries, being called “honey,” and frequent assumptions that women obtained rewards only because they were women—not because they were qualified.

As a result of the site visit program, a compendium of best practices was assembled. These best practices include an environment that is respectful of all students, good communication from the chair, intolerance of unacceptable behavior, inclusion of women seminar speakers, social events, having several women faculty members, department facilities for students (e.g. lounge, computers, and study space), and good TA training programs. When these best practices^[1] were implemented, the environment improved for both men and women.

The site visit program remains a staple offering of CSWP, and it has expanded beyond universities to national laboratories. The program has also expanded beyond evaluating the climate for women to doing so, in collaboration with the APS Committee on Minorities (COM), also for underrepresented minorities, if requested by the inviting department. Over the past 20-plus years, climate site visits have been an effective driver of change in physics departments—both those which had visits and others, whose faculty or chairs simply read and acted on the insights included in various published reports or site-visit-focused sessions at major conferences.

APS 100th Anniversary Celebration

In preparation for its 100th anniversary in 1999, the APS initiated several projects, including a series of historical posters. Each poster featured the top physicists and discoveries from one of the ten decades of APS history. When it became evident that very few women would be mentioned in these posters, Nina Byers (UCLA) contacted CSWP (chaired by Hartline) to propose incorporating an additional effort that Byers would oversee, to develop a web-based collection of scientific and personal biographies of women, who had contributed in significant (but mostly invisible) ways to physics during the century.

Many physicists—both male and female—submitted profiles of women physicists. Each profile included information about the woman’s science and personal life—including examples of the many challenges she needed to surmount to participate in the science she loved. Biographies of 83 amazing women, who made significant contributions to physics can be found at <http://cwp.library.ucla.edu/>.

With support from the Alfred P. Sloan Foundation—long a champion and enabler of women and minorities in science—Byers subsequently assembled 41 of these scientific and personal mini-biographies with the help of their authors into chapters for the book, *Out of the Shadows: Contributions of 20th Century Women to Physics*^[2].

Conferences for Undergraduate Women in Physics (CUWiP)

When female students, themselves, take the initiative to improve the situation for others, truly great things can happen. The **Conferences for Undergraduate Women in Physics (CUWiP)** originated in this manner. CUWiP are three-day regional conferences held over the Martin Luther King holiday weekend for undergraduate physics majors.

The first Conference for Undergraduate Women in Physics was organized by graduate students at the University of Southern California (USC) in 1996, supported by a grant from the NSF. The 1997 conference, also hosted by USC, included individual undergraduate women, mostly from the west, and also small delegations of students with a faculty member from other campuses, such as Yale, which were interested in cloning the experience and hosting it in their regions.

Held annually since they started, the conferences have become a suite of regional meetings (eight are planned for 2015) held concurrently. In some cases two or more venues share particularly noteworthy keynote speakers, who appear in person at one of the conferences, but are broadcast to others, using internet video technology.

The CUWiP agendas feature workshops, professional development sessions, plenary talks, presentations of research by the student attendees, along with abundant networking and mentoring opportunities for the undergraduates with several speakers, faculty, and graduate students. In 2012, the APS became the institutional home for CUWiP, assisted by a national organizing committee including representatives of previous conference hosts, upcoming hosts, and other stakeholders. More information is available at <http://www.aps.org/programs/women/workshops/cuwip.cfm>. Barbara Whitten has published^[3] useful strategies for increasing the numbers and success of undergraduate women in physics.

Materials Physics: A Case Study of Women’s Advancement

Today materials physics constitutes one of the largest Divisions of the APS, and it includes women in unusually high

numbers. However, it was not a popular subfield in the 1950s, when co-author Dresselhaus was a graduate student. She was attracted to this field both for a deep interest and because she liked the idea of table-top physics from a practical standpoint. At that time only 2% of physics PhDs went to women. What helped her career was the occurrence of Sputnik in 1957 and the start of the US space program, both of which increased research funding in the USA.

With the small number of women, even standard amenities were a problem, such as finding a restroom in the physics building on a winter day. Since women students were scarce, and there were even fewer female faculty nationwide, it was difficult for women students to be taken seriously. The first goal for women interested in physics was simply having *any* opportunity to do physics. When the number of women in an academic department increased from one to two, their productivity more than doubled.

This non-linear amplification of impact also was emphasized by the climate-visits committees (described above). And it was quantified and publicized nationally by Nancy Hopkins, a faculty member in the Biology Department at MIT. She compared her experiences with somewhat isolated women faculty in other MIT science departments, discovering and documenting that the women faculty had systematically less space, resources, and other advantages, compared with their male peers^[4]. She and Robert Birgeneau—a leading physicist then serving as MIT's Dean of Science—were instrumental in the national movement to gain equality for women in both education and careers, including in physics.

CATALYZING CHANGE INTERNATIONALLY

The International Union of Pure and Applied Physics (IUPAP) was established in 1922 with 22 member countries, and it has grown to 60 member countries worldwide. Its mission is “to assist in the worldwide development of physics, to foster international cooperation in physics, and to help in the application of physics toward solving problems of concern to humanity.” The IUPAP endorses international conferences, engages through committees and commissions in many subfields and issues, and conducts its business at triennial General Assemblies, attended by delegations from its member countries.

At the 1996 General Assembly (Uppsala, Sweden) only three of the 80-plus delegates were women: one each from the USA (co-author Franz), France, and Italy. While the total absence of women would likely have been unremarkable, the extreme gender ratio was noticeable and therefore the subject of some discussion.

Behind the scenes conversations transpired before the next General Assembly (1999, Atlanta, USA). At this meeting, the

Swedish delegation offered a resolution proposing to establish the IUPAP Working Group on Women in Physics (WGWIP). Several delegates opposed the idea. However, the presence of women had nearly doubled to five. They argued strongly that such a working group was both needed and appropriate. The 1999 General Assembly approved its establishment with the mandate to survey the situation for women in physics in IUPAP member countries; to analyze and report the data along with suggestions for improvement; to suggest ways that women can become more involved in IUPAP; and to report its findings in 2002.

At that time, Nobel Laureate Burton Richter (USA) was the incoming IUPAP President. He asked Franz, in her role as IUPAP Secretary General, to find members for the WGWIP and to get it going. After consulting with physicists internationally and obtaining Richter's approval, Franz recruited to the working group nine women (including Hartline) and three men from around the world. Marcia Barbosa (Brazil) was the chairperson. Franz served as IUPAP Liaison.

The APS administratively hosted the WGWIP, which held its first meeting in 2000 at APS headquarters in College Park, Maryland. The group decided to hold an international conference on women in physics. It then met in 2001 at CERN outside of Geneva, Switzerland, to finalize plans for the conference. The first IUPAP International Conference on Women in Physics took place in March 2002 at UNESCO headquarters in Paris.

Over 300 physicists—about 85% female—from 65 countries attended. As a result of successful fundraising, the working group could fully support the travel of three-member delegations from about 20 developing countries. At that point, IUPAP only had about 45 member countries. The strong engagement of women and men from many developing countries inspired IUPAP to devise a broader pathway to membership for developing countries, which can now also host IUPAP-sponsored conferences.

Richter and several IUPAP, EU, and UNESCO dignitaries (many of them male) addressed the Paris conference and became convinced that the dearth of women in physics was a problem and that they could be part of the solution. This realization gained the WGWIP considerable support in IUPAP going forward.

The conference proceedings were published and distributed widely, and the unanimous resolution approved at the Paris conference was formally adopted as Resolution 5 by the IUPAP General Assembly (Berlin, Germany) that fall. IUPAP has continued the WGWIP, which has to date organized four more triennial International Conferences on Women in Physics (ICWIP) in Brazil (2005), Korea (2008), South Africa (2011), and Canada (2014). Each conference has produced a resolution,

which has been submitted to IUPAP and endorsed at the General Assembly immediately following. Conference proceedings^[5–8] are available free online.

In 1999 no women were IUPAP Council members or Commission chairs; today about 25% are, including the immediate past IUPAP President, Cecilia Jarlskog (Sweden). More women now serve on liaison groups, on organizing committees, and as

invited speakers at IUPAP-sponsored conferences. Physics participation data are also now monitored in many countries.

Equality is still far in the future. But considerable global progress has been made in the 15 years since IUPAP focused on the issue of women's participation in physics. And the trends continue upwards. The IUPAP working group's web site (<http://wgwip.df.uba.ar/>) provides numerous useful resources and links.

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GIRLS AND PHYSICS: FOUR CONTRASTING NATIONAL SITUATIONS

BY ANN MARKS, CATHY FOLEY, ADRIANA PREDOI-CROSS, AND NORA BERRAH



Ann Marks,
<ann.marks@liverpool.ac.uk>, WIPG Institute of Physics, UK, and University of Liverpool, Liverpool, UK

Cathy Foley,
<cathy.foley@csiro.au>, CSIRO, Lindfield, New South Wales, Australia

Adriana Predoi-Cross,
<adriana.predoi-cross@uleth.ca>, University of Lethbridge, Lethbridge, Alberta, Canada

and

Nora Berrah,
<nora.berrah@uconn.edu>, University of Connecticut, Storrs, Connecticut, USA

The situation regarding the participation of girls in physics varies from country to country. Therefore the 2014 International Conference on Women in Physics (ICWIP) was an excellent opportunity to make comparisons between the situations in the 51 countries which were represented. The abstracts for their country papers are available on the ICWIP website [[http://icwip2014.wlu.ca/docs/ICWIP Printable Abstract book.pdf](http://icwip2014.wlu.ca/docs/ICWIP_Printable_Abstract_book.pdf)]. In a few, the proportion of girls studying physics post-16 is in the region of 50% of the up-take. Examples showcased were India and Iran. In other countries, for example Northern Europe, Northern America and Australia, the physics year groups aged 16 to 18 include only approximately 20% girls. Several of the 51 countries run special programmes aiming to increase the up-take of physics by school-aged girls. In this paper, examples of these activities in Australia, Canada, UK and USA are described with links to websites of materials and resources.

The point can be made that increasing the number of girls following physics careers benefits national economies and that this may prompt politicians to fund action at a national level. While not all girls who study physics become physicists, providing an education in physics for girls from a young age has wider benefits as it enable them to become informed members of society able to grapple with problems such as energy shortages and climate change.

REPORTS

Australia

In Australia since 2010, there has been little progress in increasing the number of women and girls participating in physics as a subject in school and tertiary education, and

as a profession. Over the period from 2007 to 2013, Australia had an increase in the number of women in many senior roles in its wider society, including their first woman Prime Minister, Governor General and President of the Australian Academy of Science. However since 2013, the number of women in these most senior roles has decreased to virtually zero. The early progress in increasing the number of women in senior roles had been based on a fragile level of support, often from male champions. When their support was removed, the participation of women in these highest levels quickly fell away. This trend has also been reflected in the number of girls undertaking physics and mathematics subjects at high school.

In 2013, 31% of boys and 8.4% of girls in New South Wales, a state of Australia, studied physics in their final year at high school. The number of girls who studied two sciences in their final two years of high school (a strong indicator of transition to studying Science, Technology, Engineering and Mathematics (STEM) courses at university^[1]) has decreased significantly. In the period of 2001 to 2011, the number of girls studying physics and one or more other science subjects in their final year at high school decreased by 9% while the number of boys undertaking these subjects increased by 30% over this time period. This trend was recognised by the Prime Minister's Science, Innovation and Engineering Council in 2013 as is reported in a STEM Country Comparison study undertaken by the Australian Council of Learned Academies at the request of the Australian Chief Scientist^[2]. Furthermore, the number of women working as physicists in Australian universities and government research laboratories has remained static at $20 \pm 5\%$.

The number of young girls who do **not** choose to study science and mathematics in the final years of high school has been increasing. The participation of girls in a least one mathematics subject and one science subject after year 10 (age 16 years) has been dwindling since 2001. The proportion of girls who elect to study **no mathematics** subjects whatsoever in their final two years at high school has tripled from 7.5% in 2001 to 21.5% in 2011. The corresponding proportion of boys also tripled but from a much lower base level, from 3.1% to 9.8%. Australia is introducing a new national science curriculum and efforts have been made to address gender appropriateness in this

SUMMARY

The 2014 International Conference on Women in Physics (ICWIP) was an opportunity for country representatives to showcase activities to increase the participation of school-aged girls in physics. This paper focuses on the situations in Australia, Canada, the UK and the USA, providing examples of the issues and initiatives.

new curriculum, such as consideration of the topics used to demonstrate physical phenomena, and introducing a stream in the curriculum on “science as a human endeavour” for each section that may be more relevant to both genders. The impact of this new curriculum on attracting girls to enrol in physics in their final years in high school is still to be determined. At this stage there is no study on why these trends are occurring. Some possible influences may be (1) that Australian universities have changed their requirement from a “prerequisite” to “assumed knowledge” for eligibility to study a subject, and (2) league tables reporting comparative performance of schools may lead to the encouragement of students to choose “easier” subjects to boost the schools overall performance. The Australian Government has committed an extra \$12 million in the 2014–15 Budget to restore the focus on STEM education with a view to achieving an increase in student uptake of science, technology, engineering and mathematics subjects in primary and secondary schools across the country. Initiatives include STEM summer schools and improved career advice [<http://www.studentsfirst.gov.au/restoring-focus-stem-schools-initiative>].

Canada

In the past decade Canadian society witnessed an upward trend in the number of short term or year-long activities which aim to increase the interest and involvement of girls in science and in physics in particular. A carefully planned school curriculum or extra-curricular activities, rich hands-on demonstrations, practical examples and applications may also spark girls’ interest in physics. It is too soon to know the impact of these efforts but data concerning girls who study physics post-16 for years up to 2000, indicate that up-take is likely to vary from one province to another^[3].

The outreach initiatives are targeting girls at a young age, starting in elementary schools (5 to 11 year olds). One such example is Local and Regional Science Fairs. Science Fairs also have a Science Olympics component where the enrolment of girls exceeds that of boys. In a few cases girls were up to 75% of the total number of participants. In addition, scientists make visits to schools in their district and through clear language communicate their love and enjoyment of physics to students and their educators. The teachers are also invited to visit the academic physics units, meet and interact with faculty members and jointly develop outreach activities that, among other things, contribute to attracting female students to physics. The *Innovators in the Schools* program available in British Columbia for students aged 11 to 18 years aims to address the province’s need for more scientists, engineers, technologists and technicians, to promote students’ interest in these areas and to inspire students with exciting, in-school presentations by real scientists. The *Canadian Association for Girls in Science* [<http://www.cagis.ca/>] is an organization that “promotes, educates and supports the interest and confidence in science, technology, engineering and mathematics among pre-teen girls” through a variety of diverse, fun activities such as “the physics of music, or the chemistry of cooking”.

Many universities across Canada organize science summer camps for school girls aged 5 to 11 years, with a fraction of these camps being “girls only”. Teenage girls enrolled in the *Techsploration* [<http://techsploration.ca/>] program in Nova Scotia interact with and are mentored by female role models working in areas of science, trades and technology. Also teenage girls are targeted by the *Operation Minerva* [<https://www.aws.com/operation-minerva-calgary-1>] a program available nationwide that is a one day job-shadowing/ workshop for 14 to 16 year-old girls with interest in science, mathematics, engineering or technology careers. The outreach team of the Perimeter Institute [<http://www.perimeterinstitute.ca/outreach>] promotes the power and fun of physics to students and the public. Examples of their activities are *EinsteinPlus Teacher Workshops*, an *International Summer School for Young Physicists* and an award-winning documentary. *Let’s Talk Science* is an award-winning, national, charitable organization that delivers science learning programs and services to children and teenagers.

Overall, in formal or informal ways, institutions and non-profit organizations across Canada are supporting local schools in their efforts to attract girls to physics through activities that develop their analytical skills, independent thinking, and boost the girls’ confidence in their abilities to pursue physics related courses and activities.

United Kingdom

In the UK, over the last 30 years there has been a considerable amount of science and engineering outreach to both schools and the public with some, such as the WISE programme, specifically for girls. Despite these activities, the percentage of girls in the cohort studying physics post-16 decreased from 23% to 21%, in contrast to increases in other science subjects targeted. Even taking into account other changes, such as requirements for medicine, there is concern. To combat the shortage, the Institute of Physics (IOP) has developed resources such as: *Girls in the Physics Classroom: A teachers’ guide for action* in 2006; *Engaging with Girls: An action pack for teachers* in 2010, which includes guidance on Action Research teaching resources; and *Science: It’s a people thing*, enabling discussion workshops with girls aged 11 to 16. These were successful when the quality of teaching improved and in long-term, whole-school programmes [http://www.iop.org/education/teacher/support/girls_physics/resources-and-guidance-for-teachers/page_63821.html].

The recent IOP study *It’s different for girls*, 2012, reports on progression to post-16 physics in different types of schools for boys and girls, finding that girls were more likely to study physics in single-sex schools than in co-educational schools and more likely in fee-paying schools than state-funded schools. Worryingly, almost half of state-funded co-educational schools sent no girls to study physics post-16^[4]. Significant differences were found between boys’ and girls’ experiences of physics in the various types of schools, suggesting that

gender-specific cultural influences may be causing gender stereotyping of pupils' expectations.

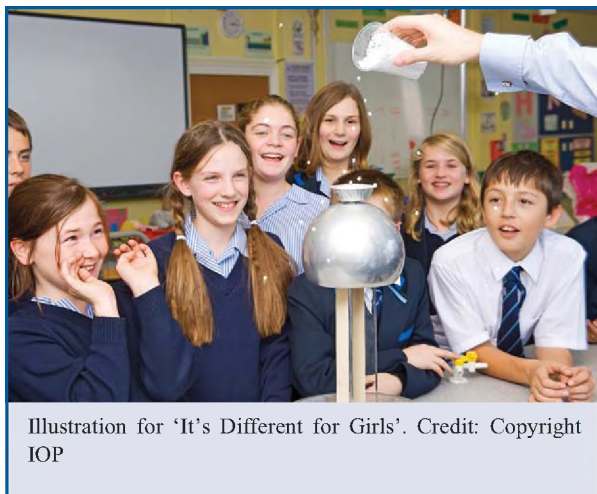


Illustration for 'It's Different for Girls'. Credit: Copyright IOP

The *Closing Doors* report, 2013, found that in co-educational state-funded schools the gender balance in progression to A-level physics correlates strongly with that for the other 'gendered' subjects investigated. Therefore factors limiting the progression of girls to post-16 physics may depend on the whole-school environment and whole-school measures will be required to counteract gender stereotyping. It is hoped that practices used by schools, identified as successfully counteracting gender stereotyping, can be applied widely [http://www.iop.org/education/teacher/support/girls_physics/reports-and-research/page_63816.html].

New projects 2014 onwards: first, the UK Government has provided substantial funding for the *Opening Doors* project, which will be facilitated by the IOP and take a whole-school approach to develop a code of practice on gender equity for schools. Secondly, *Improving Gender Balance* is a three-year, Department for Education funded, IOP and Science Learning Centres pilot project to develop the teaching and learning of physics in secondary schools. The project includes trials of three distinct interventions and aims to identify the most effective approaches to encouraging more girls to continue with physics post-16. Additionally, the IOP has been awarded private Drayson funding for a three-year pilot project, aiming at combating gender stereotyping as well as increasing the confidence of female pupils to continue physics post-16 [http://www.iop.org/education/teacher/support/girls_physics/current-projects/page_63825.html].

In parallel, the Government has recently funded the major 'Your Life' [<http://www.yourlife.org.uk/>] national campaign, to inspire more young people, particularly girls, to study STEM subjects.

Finally, after recognition that many children make career decisions before the age of 11, interest in working with schools for children aged from 7 to 11 is increasing. Resources for

exciting the interest of this age group are freely available [e.g., the presentations at <http://www.iop.org/pips/>]. Pupils aged 16–19 can have free special membership in the IOP, which provides them with information and opportunities [http://www.iop.org/education/student/youth_membership/page_41684.html].

It is hoped that application of findings from all these projects will change the culture throughout schools so that the number of girls inspired to choose careers in physics increases.

USA

In the US, efforts to increase the number of women in physics have largely been at the level of universities and colleges and not at the level of middle schools or high schools. In 2007 the American Physical Society (APS) Committee on the Status of Women in Physics (CSWP started in 1972) hosted a national workshop, *Gender Equity: Strengthening the Physics Enterprise in Universities and National Laboratories*. This initiative was funded by the National Science Foundation and the Department of Energy Office of Science. Recommendations for improving gender equity at physics departments/national laboratories/funding agencies can be found at <http://www.aps.org/programs/women/workshops/gender-equity/upload/genderequity.pdf>. However, this workshop did not focus on the recruitment of girls from high schools.

In order to significantly augment the number of women bachelors in physics from the present $\sim 20\%$ to parity, we need to reach out to school-girls so that more high-school girls opt to study physics (16 to 18 year olds). The Extending Your Horizon conferences, which are organized by volunteers and are celebrating their 40th anniversary, are for girls only and aim to excite the interest of many thousands in STEM fields, but do not focus on physics [<http://www.eyhn.org/#!about-main/c1glg>]. There are also several state and local outreach programs to middle and high schools to expose both boys and girls to the wonders of STEM fields. The APS also has an outreach program which aims to excite interest in physics and, although not girl-specific, should reach girls through activities with schools. However, we do not yet have evidence that this program increases the number of women in physics [<http://www.aps.org/programs/outreach/guide/index.cfm>]. In addition, the APS has one effort called K-12 (for ages 6 to 18): *Physics Quest* and the associated *Spectra* comic book series <http://www.physicscentral.com/explore/comics/>. The protagonist in *Spectra* is a teenage girl. There is no specific agenda with this comic book series other than outreach about why physics is interesting or cool. It is hoped though that the role-model played by the protagonist will dispel biases regarding girls/women and physics. The comic book often has themes relating to the experiments sent by Physics Quest, which is a story-based learning adventure that consists of a free activity kit sent to physical science teachers of 6–9 year old pupils. The Physics Quest program was established in 2005 as part of the World Year of Physics celebrating the centenary of Einstein's "miracle year".



These programs have been around for less than ten years but we do not see yet a significant change in the number of women majoring in physics from colleges and universities. According to the APS/Source: IPEDS Completion Survey^[5], in 2002 the percentage of women who obtained US bachelor's degrees in physics was 23.0% whereas in 2012 the percentage was 19.6%.

Thus, although the actual number of women graduating with a bachelor's degree in physics has increased in the past 10 years, the proportion has decreased. Whereas, across STEM the proportion of women graduating with degrees is greater, it changed only from 37.0% to 36.4%. In the US we need both a *social culture change* in addition to *national concerted programs* targeted to increase the number of girls in *physics* from *middle and high schools (12–17 years old)* because, sadly, physics remains so far a boy- and male-dominated field.

CONCLUSIONS

Numerous successful women physicists have demonstrated that girls can become physicists. From ICWIP Education Workshops it appears that those countries with a high proportion of girls taking physics post-16, have cultural expectations that girls study physics. In order to increase the number of women in physics, the aim in many countries has been to encourage girls to study physics rather than study the factors which deter girls from physics. Now UK research demonstrates that overcoming gender stereotyping, deterring girls from physics, requires both societal and whole-school cultural change.

Canada has developed a large number of well-planned and varied activities to attract girls into physics, over the last ten years. However, in the UK many years of initiatives to encourage girls to study physics have resulted in little change in the proportion studying physics beyond the age of 16. By comparison, in the same period, there have been increases in the proportion of girls studying other science subjects. In the USA there have been few initiatives to encourage young girls to follow physics careers and the proportion graduating in physics has decreased. Australia recently had women in many senior roles. However, after allowing a reduction in the level of the support for encouraging girls to study physics, the number of girls who do not choose physics is increasing.

This situation in Australia provides a cautionary note, highlighting the need to maintain efforts towards gender equality until it is truly embedded. The governmental responses to the situations in Australia and the UK have been to inject substantial funding. On the other hand, the report from the USA explains that their efforts are concentrated on university students and urges more national action in schools.

The paper describes a wide variety of activities being implemented with the aim of increasing the participation of girls in physics, but it is clear that there is still **much** to be done. By sharing, the whole picture is enhanced and a spotlight shone on the complex situation.

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INCREASING GIRLS' PARTICIPATION IN PHYSICS: EDUCATION RESEARCH IMPLICATIONS FOR PRACTICE

BY MARINA MILNER-BOLOTIN



Women's underrepresentation in physics is a worldwide phenomenon^[1-6]. According to the recent study by the American Institute of Physics, in the US women currently earn just 21% of physics bachelor's degrees and only 17% of the PhDs. In Canada women are also "an exception" in the physical sciences both in academia and in the industry^[3]. As a result of this gender imbalance, women are still scarce in scientific and technical leadership positions^[7]. As Sheryl Sandberg has pointed out, this underrepresentation has important social, political and economic implications:

A truly equal world would be one where women ran half our countries and companies and men ran half our homes. I believe that this would be a better world. The laws of economics and many studies of diversity tell us that if we tapped the entire pool of human resources and talent, our collective performance would improve.^[7] (p. 8)

In order for industry and academia to have access to the entire talent pool, we should ensure that girls elect to study advanced physics and mathematics courses at secondary schools, which is rarely the case^[8,9]. For example, in Canada the number of students of both genders completing grade 11 and 12 advanced mathematics and science courses is declining^[10]. In 2010–2012, less than 50% of Canadian youth chose to complete these courses^[10]. This development underscores the importance of raising the profile of advanced secondary physics courses through changing students' attitudes about physics and physics-related careers^[11,12]. Making these courses more appealing to girls requires a collaborative effort from teachers, parents, school councillors, and administrators^[13,14]. This will not be achieved unless we educate physics teachers capable and willing to inspire both boys and girls in physics studies^[8,9,15,16].

SUMMARY

The paper identifies factors affecting girls' negative attitudes toward physics and suggests pedagogical approaches that can help secondary physics teachers to engage girls in physics.

This paper describes a number of research-based pedagogies effective at engaging girls (and other underrepresented students) in secondary and post-secondary physics courses^[17]. However, before discussing how we can engage girls in physics, we need to uncover possible reasons for their disengagement. This will be done in the following section.

RESEARCH-BASED EVIDENCE FOR THE REASONS BEHIND GIRLS' DISENGAGEMENT FROM PHYSICS

There is an extensive body of research investigating the reasons for girls' alienation from secondary physics and mathematics courses^[8,9,12,18]. According to Zohar and Bernshtein^[9], these reasons include:

- a) **Different gender-dependent socialization patterns:** Boys are "socialized into physics" and girls are "socialized out of physics". This socialization is related to the lack of women role-models, inequality in educational opportunities, biased school guidance (girls are often discouraged from taking technically challenging subjects), reduced parental and teachers' expectations of girls' success, and lastly, family-unfriendly and unappealing prospects of physics-related careers^[9,19].
- b) **Different gender-dependent attitudes, interest levels and self-efficacy about physics:** Girls often exhibit more negative attitudes about physics than boys^[12,19]. This is also reflected in their lower physics self-efficacy (one's belief in one's ability to complete specific tasks or achieve certain goals) as compared to boys, which results in girls' lower achievements^[20]. Girls' low self-efficacy in physics learning is expressed as their lack of confidence in their ability to succeed at understanding physics and excelling in it. It has been documented that even when boys and girls perform at the same academic achievement level, the girls have a lower confidence in their ability to do physics or mathematics than the boys. This also applies to undergraduate students^[17]. As a result, girls become more frustrated and less persistent in their studies, consequently having lower academic achievement and failing to fulfill their potential.

Marina Milner-Bolotin,
<marina.milner-bolotin@ubc.ca>,
Department of Curriculum and Pedagogy,
University of British Columbia,
Vancouver,
V6T 1Z4, Canada

- c) **Different effects of the classroom culture on boys and girls:** Girls are more likely to experience aversion to the highly competitive and non-collaborative culture found in many physics classrooms^[9,16]. Since girls represent a minority in most physics classrooms, and many of them feel uncomfortable and silenced in competitive male-dominated groups, girls often feel alienated and excluded. While contemporary physicists rarely work alone, collaborative pedagogies, such as Peer Instruction^[21] and PeerWise^[22] are still uncommon in secondary schools.
- d) **The lack of appeal of traditional physics curriculum and assessment strategies to girls:** Traditional physics curriculum is intentionally abstract, reinforcing the masculine conceptualization of science as a male-dominated field. It is often disconnected from the social, historical, and environmental concerns making it less appealing to girls. Boys and girls differ in the ways they learn and understand physics: while it is important for girls to be able to put a physics concept into a broader context relevant to them in order to understand it, the boys often view the value of physics in its internal coherence^[23]. Thus, the boys' ways of physics learning might be more aligned with the traditional teacher-centered abstract physics curriculum. The issue of apparent disconnect of abstract physics curriculum from students' lives and interests has become a significant obstacle for girls' engagement at both secondary and post-secondary levels^[16]. Meredith and Redish conducted an investigation of undergraduate physics curriculum for life-science majors (most of whom are women)^[24]. They highlighted the differences in the world view of the two disciplines and asserted that in order to engage life-science students, physics courses for these audiences should be reinvented. They also pointed out that while reimagining physics curriculum, we also have to reconsider how we use assessment in physics courses. Research indicates that traditional physics assessment that puts a sole emphasis on the final product, while ignoring the process, is unfavourable for girls^[25]. Considering that girls often have low self-efficacy about physics, the high-stakes exams that emphasize the ability to arrive at the correct answer in a very short period of time only reinforce these feelings and diminish girls' chances for success.
- e) **Teachers' beliefs about girls' ability to succeed in physics and teachers' lack of awareness of the reasons for girls' disengagement:** Good teachers support and inspire each and every student. They are also aware of their own beliefs, attitudes and expectations from the students which have a profound effect on the classroom learning environment^[25]. However, few physics teachers (males and females) believe that the low participation of girls in physics courses is a problem^[9]. Even fewer teachers are prepared and

willing to deal with this problem both at K-12 and undergraduate levels^[17]. The good news, however, is that there are research-based pedagogies that can help teachers address this problem. There is also ample research evidence that the pedagogical approaches that are effective for engaging girls in science are also beneficial to other students^[23]. The following section will discuss some of these research-based pedagogies.

RESEARCH-BASED PEDAGOGIES FOR INCREASING GIRLS' ENGAGEMENT WITH PHYSICS

Research-Based Pedagogies for Engaging Girls with Physics

At first glance, the obstacles for girls' disengagement from physics look insurmountable. However, a closer examination reveals that while some of them are located outside of teachers' control, there is a lot teachers *can* do to alleviate the problem. For example, Daly and Grant^[16] identified six areas of good practice in a physics classroom that promote positive girls' attitudes about physics. They include: (1) **Pedagogy:** teaching and learning physics in a way that is accessible and engaging for girls; (2) **Classroom management:** engaging and supporting girls; (3) **Careers:** emphasizing the value of physics and physics-related careers; (4) **Progression:** making physics relevant for girls (and boys) in secondary and postsecondary education; (5) **Workforce:** girls (and boys) have access to good physics teaching; (6) **Culture and ethos:** Physics is for everyone – developing a positive perception of physics (p. 10). Zohar and Bronshtein^[9] produced a similar list of pedagogical approaches aimed at engaging girls with physics:

1. **Promoting student active engagement inside and outside of school:** Using group projects dealing with real life problems, Peer Instruction, real life data collection and analysis.
2. **Focussing on developing students' metacognitive strategies:** Helping them learn how to study physics effectively and become confident learners; engaging students in critical reflection, helping them acquire better learning skills, modeling problem solving and thinking using cognitive apprenticeship approaches.
3. **Using modern technologies to make physics relevant to students' lives and to their future aspirations:** Using real life data collection and analysis with sensors, video analysis, etc.
4. **Using history & philosophy of science to build a more realistic picture of science and scientists:** Uncovering the process of discovery, showing that science is not an individual pursuit, emphasizing the roles women played in science.
5. **Introducing female role-models and mentoring:** Connecting students with women scientists, engineers, and high-tech leaders.

6. **Providing continuous constructive feedback on students' progress:** Using formative assessment to help students learn physics, utilizing technology and collaborative pedagogies.
7. **Using multiple ways to assess student understanding:** Tests and quizzes, projects (group and individual), lab practical, etc.
8. **Emphasizing collaborative nature of science:** Using collaborative projects, activities, encouraging girls' participation. Modeling collaboration and mutual support.
9. **Raising teachers' awareness of their beliefs and attitudes about girls' engagement with physics:** Discussing with the girls how they feel in class, encouraging them, focusing on their successes, while acknowledging what we learn from failures.

Making practicing and prospective physics teachers aware of the factors affecting girls' disengagement from physics is the first step in addressing the problem. The second step is equipping physics teachers with the relevant pedagogical approaches that can help address these issues. In the last decades a number of research groups studied how to implement these approaches in secondary and post-secondary physics classrooms. In the following section we will briefly outline four specific research-based pedagogies that will illustrate how the approaches described above can be implemented into practice.

Four Examples of Research-Based Pedagogies for Engaging Girls with Physics

This section outlines four inter-related pedagogical approaches that can help physics teachers engage girls and boys with physics. The first one is **Peer Instruction**^[21]. With the proliferation of smart phones and other mobile devices, Peer Instruction is slowly gaining ground in secondary schools. It utilizes clickers, mobile devices, or flashcards to solicit students' responses to multiple-choice conceptual questions^[26]. The first element of Peer Instruction is using conceptual questions that emphasize physics ideas, their everyday life applications, and conceptual reasoning^[27]. Its second element is group question discussions that follow the polling results. These discussions help students build reasoning skills, promote ownership of physics concepts, and increase their engagement. Having an opportunity to articulate their reasoning supports the development of students' meta-cognitive skills and helps them view science as a process. Peer Instruction can be taken to the next level through the use of **PeerWise** online collaborative software^[22]. PeerWise allows students to author multiple-choice questions, solve and comment on the questions authored by their peers and improve their conceptual understanding through online discussions. The second pedagogical approach focuses on helping students

relate physics to everyday life through using **data collection technology**, such as Logger Pro^[28]. This technology helps students see everyday life physics applications through collection and analysis of real-life data. For example, students can video-record interesting phenomena inside or outside of the classroom and then use Video Analysis^[29] to explore them. They can also use data sensors to collect real-life data and test their physics understanding^[30]. This brings us to the third strategy which focuses on **encouraging student collaboration** on long-term projects where they have a chance to express their creativity and multiple talents. Project-Based Instruction is rarely used in secondary physics classrooms, yet it has the potential to engage students in solving meaningful problems, devising authentic solutions and sharing their findings with peers^[31]. Project-Based Instruction also opens opportunities for connecting students with external experts (both men and women). Having women mentors and role-models for these projects is especially beneficial as it helps students see successful female scientists in the "real world". The last strategy focuses on making assessment a positive and meaningful learning experience through conducting exams that **promote collaborative learning**^[32]. For example, at the University of British Columbia, many undergraduate courses implement two-stage exams in which "... students first complete and turn in the exam individually, and then, working in small groups, answer the exam questions again" (p. 51). The final exam grade combines the individual and the group marks.

To enact these strategies successfully, physics teachers have to believe that girls can succeed in physics. This will create an ideal learning environment where continuous encouragement, intellectual stimulation and high expectations from all students are the norm.

CONCLUSIONS

In order to increase girls' participation in physics-related careers, we need to engage them in secondary physics courses. Therefore, changing teachers' attitudes about girls' engagement with physics and equipping teachers with effective pedagogical strategies to address the problem should become one of the top priorities of the physics education community. This paper highlighted research literature on the reasons for girls' disengagement from physics and suggested four research-based pedagogies that can help teachers to address this problem. As a physics education community, we have to support physics teachers in this process. Unless physics classrooms can be made welcoming to all students, the issue of girls' disengagement from physics will not be resolved and women-scientists, such as Dr. Fabiola Gianotti (the first female head of CERN), will remain a rare exception worthy of world-wide news coverage.

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EDUCATION IN BRAZIL

BY MARCIA C. BARBOSA



The participation of women in professional life in Brazil has been increasing in the last decades. Today within the 20 most competitive careers, women are the majority in graduation in 15 of them. Women are also the majority of undergraduate students and half of the professors in the universities^[1]. This situation is still far from representing equity between genders. Female students are not present in all fields. In particular, the percentage of female students in the exact sciences is small. In addition, in all fields, the percentage of women decreases at each step of the career ladder. For example, in physics the percentage of female researchers at each career level not only decreases^[2–5] as the position is more senior, as illustrated in Fig. 1, but is the same for the last ten years^[2]. This situation is very similar in other countries of Latin America^[6]. This suggests that either no change is happening in this field or the change is so slow that a ten-year analysis is not enough to perceive it. Naturally, this raises the question of the origins of this absence of females in the exact and physical sciences. The answer to this question is quite complex and involves not only global factors, such as a lack of role models, but also cultural and educational aspects. A description of the evolution of the educational system in Brazil is provided below and an analysis of the current system is provided as a framework for understanding the under-representation of women in the power structure of exact science.

HISTORICAL BACKGROUND

Basic education in Brazil started at the end of the sixteenth century when the Portuguese administrators established themselves with their families in the new continent. The education of the offspring of this elite was under the supervision of the catholic priests. During this period the Jesuits, whose mission was to evangelize, also provided basic education for Indians and workers under

the agenda of getting them under the supervision of the church. Education was focused on humanities and, in particular, on Latin, philosophy and arts. The girls either were kept illiterate or were trained by nuns to read and write and perform basic domestic affairs. Teaching was only for three years and reading was restricted to religious texts.

The increasing power of the church, and the illuminist ideas that were becoming quite popular in intellectual circles in Europe, led the king of Portugal in the eighteenth century to select the Marques do Pombal as the minister of economy. He revolutionized the economy of Portugal and modernized the city of Lisbon during a very centralized period of Portuguese administration. In order to achieve his economic goals he had to control the political arena, and consequently oppose the church. He created the public school system and expelled the Jesuits from the colonies. The new school system included science and modern languages and excluded some of the topics explored by the Catholic schools. The schools were still separated by gender and the girls' schools did not cover the scientific topics explored in the boys' schools. This idea, based in a vision of a more modern and developed Portugal, faced the problem that at that time Portugal did not have enough teachers to replace the priests. In Brazil the situation was more dramatic because of the absence of people properly educated to take over the task of teaching to the children of the Brazilian elite^[4]. After the period of the Marques do Pombal in power, the Catholic schools returned to operation and Brazil developed a dual system in which private and public schools operated in parallel. The ideas of the Marques do Pombal, of having a more illuministic and scientific education fortunately survived^[7,8].

In the nineteenth century the royal family of Portugal moved to Brazil in a self inflicted exile due to the invasion of Napoleon. Teaching expanded, with preceptors being brought from Europe. In 1827 a more formal education at the fundamental level was formalized. While the boys studied grammar, geometry and sciences, the girls were restricted to languages and arts. In addition, the girls were allowed to study only until the 5th grade^[9]. Women that had the desire of studying further had to go to schools outside Brazil which restricted this group to a small number of girls coming from rich families.

SUMMARY

An overview of the Brazilian educational system is presented with the main focus on the lack of representation of women in the exact sciences and minorities in higher education.

Marcia C. Barbosa,
<marcia.barbosa@ufrgs.br>,
Instituto de Física
da Universidade
Federal do Rio
Grande do Sul,
Bento Gonçalves,
9500, Caixa Postal
15051, 91501-970,
Porto Alegre, RS,
Brazil

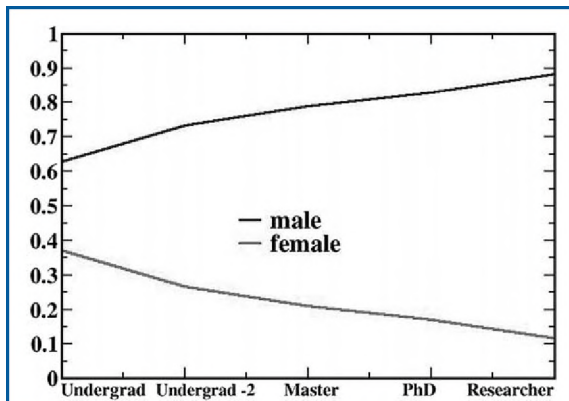


Fig. 1 Percentage of male (upper line) and female (lower line) at each academic level in physics in Brazil in 2012 [Source: CNPq]^[10].

The middle schools, as a consequence of the Pombal versus Jesuits fight were divided into schools with focus on humanities, in order to become a medical doctor called Schools of Classical Studies or “Clássico”, and schools with technical topics, named Schools of Scientific Studies or “Científico”. A separate set of high schools were also dedicated to training teachers for the fundamental levels, called “Normal” Schools.

The higher education system was created at the end of the nineteenth century. No university existed at that point aside from isolated medical and law schools. Women, however, were not allowed to enter these colleges. In 1879, thanks to a decree from the Emperor D. Pedro II, women were granted permission to enter the schools of medicine and law. The idea of allowing women in higher education was generated because the daughter of a friend of the Emperor, Maria Luiza e Albino Augusto Generoso Estrela, had to do her studies in the United States. After 1879 a few women ventured into the colleges of medicine and law. Unfortunately, most of them never worked because the population did not accept female professionals.

In exact sciences, the first woman to graduate was Edwiges Maria Becker in 1919, as an engineer. The next was Carmen Portinho. She got her degree only in 1926. The first woman to graduate in physics in Brazil was Yolande Monteux in 1937 more than a decade later when compared with the engineers, and more than three decades later when compared with the first medical doctors.

The reason for women’s arrival in the exact sciences has many roots. One important ingredient is related to the division of the middle school into Classical and Scientific studies. Since Classical studies were considered more suitable for girls, more girls’ schools were devoted to Classical than Scientific specialties.

This division of the high school system persisted until the 1970’s, when three complementary changes were made: the

schools for only girls and only boys were abolished, the Classical and Scientific schools were combined in one single system of high school, and the public school system was expanded to cover the entire population. The mixed schools, where all the disciplines were taught, gave rise to an expansion in women’s participation at the universities.

In parallel to the lack of representation of women in the educational systems, the black population was also excluded from it. Slavery was abolished only in 1888 and most of the slaves did not know how to write or read, and over the years played the role of servants in this white male dominated society. This population had access to the fundamental and high schools in a more massive way only in the 1970’s when the school system experienced an expansion. Unfortunately, this was followed by a decrease in quality of the public school system.

AFFIRMATIVE ACTION POLICIES

The end of the 20th century and the beginning of the 21st century brought a new perspective for the country. The stabilization of the currency, and consequently of the economy, brought a perspective of steady growth that required a massive number of highly trained professionals. Until the end of the 20th century higher education was a privilege for the higher and middle classes, which was not enough for the projected increase of industry. Realizing that, the government implemented two complementary policies to increase the number and diversity of the students at university. First, in 2009, a four-year program established an expansion by 30% in the public federal universities. This program led to the creation of new majors and an increase in the number of accepted freshmen students in the already implemented courses. In a continental country this implied the creation of new campuses in remote areas. In addition to the increase of the public sector higher education, tuition at private universities was paid for students coming from low-income families.

Realizing that the students at the public universities came from upper and middle class families, and that the proportion of white students was disproportionate, an affirmative action policy was put in place. This new policy imposes that by the year 2016, 25% of the entrances at the federal universities will be restricted to students coming from low-income families and 25% of the entrances will be restricted to self-declared black low-income students. The consequences of the policies of affirmative action and expansion are still not clear. However, it is expected that a few years from now the higher education system will be more racially balanced and the percentage of educated people in the country will be substantially increased.

The need for more engineers in the country, and the fact that the percentage of female students in engineering courses is rather small, led the granting agency, CNPq, and the secretary of Women’s Affairs to propose new programs to attract

high-school girls to exact science. The consequences of this large-scale program will be observed in the next five years.

CONCLUSIONS

The educational system in Brazil has suffered from being a colony, from having an economy based on slavery and later on

commodities, which surely delayed its expansion and universalization. Currently, the country is in a process of broadening the entrance to the higher educational system by women and minorities, which, in the near future, will create a more diverse working atmosphere, and consequently sustainable and humanistic development.

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IMAGINATIVE METHODS IN SCIENCE EDUCATION

BY DINA IZADI, NONA IZADIPANAH, MASOUD TORABI AZAD, AND CESAR EDUARDO MORA LEY

Getting students to study effectively, even under difficult circumstances, is one of the most important challenges in our real world. Indeed, what motivates our young generation to learn sciences is a puzzle and researchers are trying to find the best models in education. Students' interests and attitudes are critical aspects of science education. Curriculum and instruction should guide learning toward (1) understanding and fulfilling basic human needs and facilitating personal development; (2) maintaining and improving the physical environment; (3) conserving natural resources^[1]. Teaching should be viewed as an art to motivate students to look around themselves carefully in order to find the reason behind each phenomenon that happens in nature. University and high school students often have conceptual difficulties in understanding and learning basic sciences so we should try to make science more approachable, and linking the arts with basic sciences is one of the most attractive models which may help to solve these issues. By learning arts, students can transfer science concepts into environments which engage them in active learning with innovative ideas.

Imagination is a key to bringing dreams into reality, and in science education it is necessary to ask students to try to make imagination deeper. Painting, sculpture or photography can help them to show their dreams out of their minds, but mixing with scientific ideas can help them to build or even invent something that can be used in research projects.

SUMMARY

Art and imaginative methods in science education promote conceptual understanding. These methods are attractive and students can improve their imaginations to help them make science more approachable. Based on these findings, the benefits associated with imagination in science education and student's achievements have been identified as: learning in an interesting environment; developing drawing and designing skills, communication and practical skills, conceptual understanding; transforming drawing and designing into industrial models.

ART IN SCIENCE EDUCATION (ASE)

We believe that education, creativity, and empathy strengthen any community. During recent years, new pedagogical approaches and computer-based tools for analyzing data have been developed in science education. Multimedia learning modules as web-based pre-lecture assignments in a calculus-based introductory electricity and magnetism course have resulted in a large improvement in students' understanding of basic physics concepts^[2]. Physics and basic sciences are in our everyday lives in devices such as solar cells, Mp3 players, microchips and transistors in toys, phones, computers, lasers in CD players, surgical instruments, telecommunications equipment. etc. According to scientific forecasts, the 21st will primarily be the age of information. As a result of the rapid development and wide-spread use of information technologies, a huge amount of various types of information, including scientific and educational, will become available practically to every learner^[3]. Thus, our students should take an active role in both their own development and that of those around them. A way to include project-oriented learning combined with art can help their scientific imagination and strengthen it. By constructing mental images and building models they will overcome difficulties in the construction of long-lasting science knowledge. Students should learn to design their own model related to the scientific concepts and draw from their imaginations. To investigate the effects of changing the variables in scientific laws they can be encouraged to provide animations of 3D models in order to simulate the problems and create a virtual environment. Then they are instructed to make predictions about the relationships between these variables. Bill Gates was recently speaking in Washington, D.C. at the American Enterprise Institute, and said that within 20 years, a lot of jobs will go away, replaced by software automation. He said: "20 years from now, labour demand for lots of skill-sets will be substantially lower"^[4]. Then in this new economic climate we should strive to find a way to progress from science and technology to innovation as the way to ensure a prosperous future. Today, more than ever before, the future depends on students' abilities to apply the knowledge they learn in the classroom to the solution of real life problems such as climate change, air pollution, waste disposal, energy generation, world poverty and food production. In the incessantly changing world, students of the 21st century are very different from the students of the past^[5]. Schools that want to improve their



Dina Izadi,
<dina_idus@yahoo.com>,
Department of Physics, National Polytechnic Institute, IPN, Mexico City, Mexico

Nona Izadipannah,
Islamic Azad University North Tehran Branch, Tehran, Iran

Masoud Torabi Azad,
Islamic Azad University North Tehran Branch, Tehran, Iran

and

Cesar Eduardo Mora Ley,
The Research Center for Applied Science and Advanced Technology, National Polytechnic Institute, Mexico, Mexico city

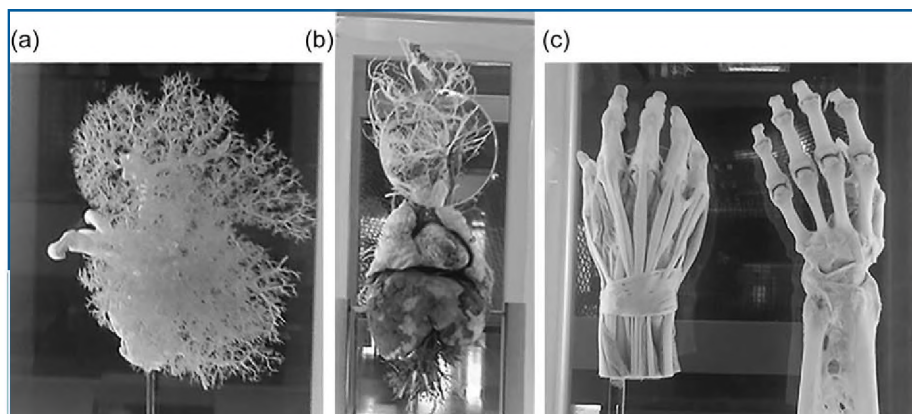


Fig. 1 Photo by D. Izadi, International Conference of Young Scientists, ICYS 2012, Radboud University Nijmegen.

climate typically should choose an approach to shape the future of education which is filled with the spirit of creative innovators who can change the world of science and industry. To maximize students' potential and empower them to be the best, we need to create a balance between art and science. What is the main purpose of education? Finding a boring job in future or making a job that can be enjoyed. Supporting methods of bringing art and science together will develop innovative practices in science education. Through arts programming in schools, students' motivation, concentration, confidence, and teamwork can be improved.

Art in Biology is very attractive, too (Fig. 1). Biology is a science that relates perfectly to art through graphics, drawings, images, sculpture, even music inspired by genetic information. Julian Voss-Andreae is a sculptor who developed a model of cutting and pasting one-dimensional objects to recreate the inner organization of biological macromolecules, mostly proteins. Protein music is based on the linearity of genetic information encoded in protein sequences, i.e., a sequence made of any numbers of 20 amino acids, the alphabet of protein structures^[6]. All these new ideas in combination with physics, with its complicated laws, make Biophysics more beautiful.

Thus, the inclusion of Art in Science Education (ASE) offers a new model for 21st century teaching and learning which will help the shift from human labour to mechanical labour based on human imagination and novelties. ASE is not an end in itself. It provides a solution to finding what is missing in public education today.

Building Toys and Science Education

Building toys in an educational framework can help students to express their ideas on observed phenomena and compare them

as the starting point in building their scientific knowledge. Encouraging students to build toys and explain the science behind them in a cooperative atmosphere can lead to innovation and will help to create new industries in the future.

A toy such as the Tippe top was a physics puzzle that fascinated at least two Nobel Prize Winners and one of the Allies' greatest strategists in World War II. Tippe tops are round tops that, when spun fast enough tip sideways and eventually turn upside down so that they are spinning on their thin handles. To do this, the tops have to actually lift their bodies up, off the surface they're spinning on. How does a lateral spinning

motion push a top upwards? This question absorbed several brilliant and famous minds. Niels Bohr, who helped figure out the structure of the atom, and Wolfgang Pauli, best known for the Pauli Exclusion Principle, both famously studied the Tippe top to figure out what made it flip itself (Fig. 2). The Tippe top displays the unexpected result of inverting itself when it is spun upon a flat surface. In the process its centre of mass rises. Several explanations of this behaviour have been offered in the literature^[7]. Although the physics behind it is very complicated, designing Tippe tops in several colors and forms can explain the composition of colors, symmetrical or unsymmetrical motions, moments of inertia and several other parameters in physics.



Fig. 2 (L-R): Pauli; Niels Bohr, demonstrating 'tippe top' toy at the inauguration of the new Institute of Physics at Lund, Sweden. Photograph by Erik Gustafson, courtesy AIP Emilio Segre Visual Archives, Margrethe Bohr Collection.

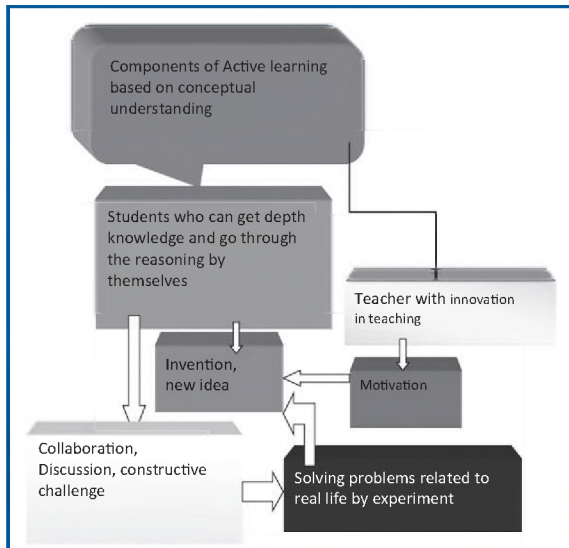


Fig. 3 Active learning diagram in ALIT.

To build a toy, students are asked to design their models by drawing on paper. Then mathematics and geometry with computer programming will improve their models. The science behind these artistic models is very important because these toys are going to be used in solving real problems in science. Imagination and creativity along with the study of the art in designing these toys are intimately correlated with problem-solving skills.

Psychologists have shown that toys are crucial for the development of high-level skills such as decision-making, socialization, and creativity. Students can be educated to make their own models for toys by learning analog skills in conceptual drawing and prototyping.

ASE and Imaginative Methods in AYIMI

Active Learning by Innovation in Teaching (ALIT), as a new model in education, offers students different approaches in solving problems and investigating suggested science topics (Fig. 3). By using ALIT conceptual understanding in several basic sciences, specifically in physics, can be improved.

Students are encouraged to solve more practical problems by combining theoretical and experimental approaches to extend their scientific abilities^[5].

Ariaian Young Innovative Minds Institute (AYIMI) as a scientific institute in Iran (www.ayimi.org) follows the ALIT model by inviting students to participate in physics or other basic science tournaments. With open-ended problems, students are asked to invent by themselves and suggest the scientific solutions and procedures. The educational objectives of these tournaments are divided into: a) doing research on open-ended problems, b) bringing out their ideas about the phenomena, c) making a bridge between simulation environments and meaningful learning, d) finding real interest behind these simulations, e) finding verified conjunction of Math, computer programming and image processing in solving problems and f) increasing the depth of students' skills concerning their knowledge and imaginations (Fig. 4).

ASE as a branch of ALIT inspires students to look carefully, to think

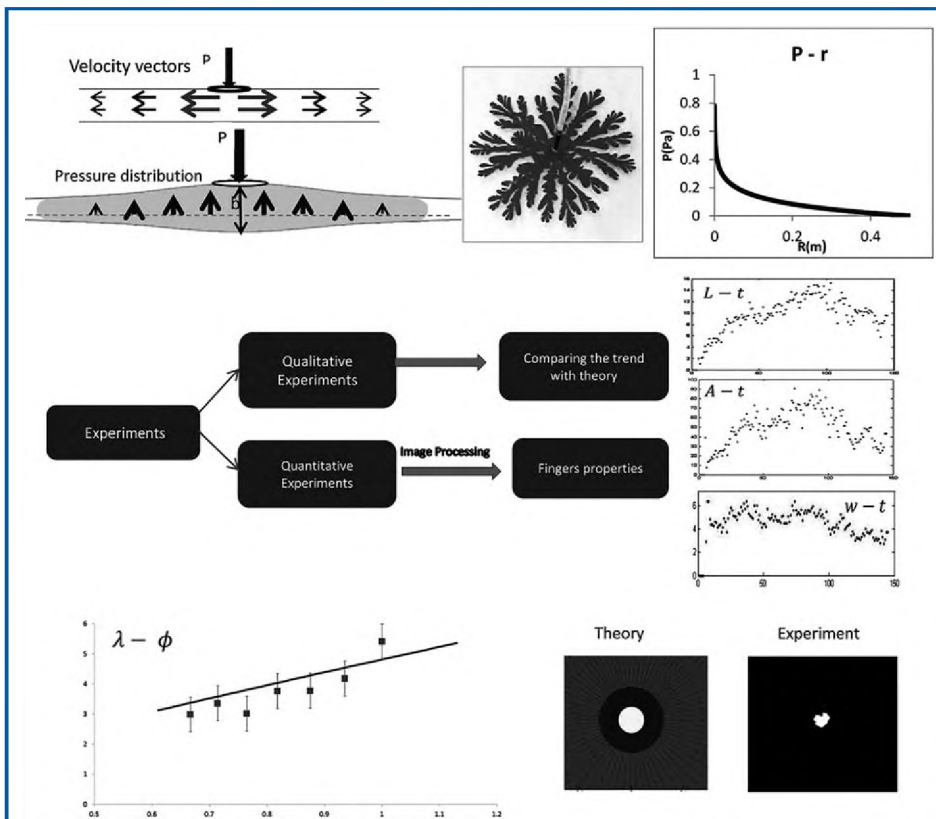
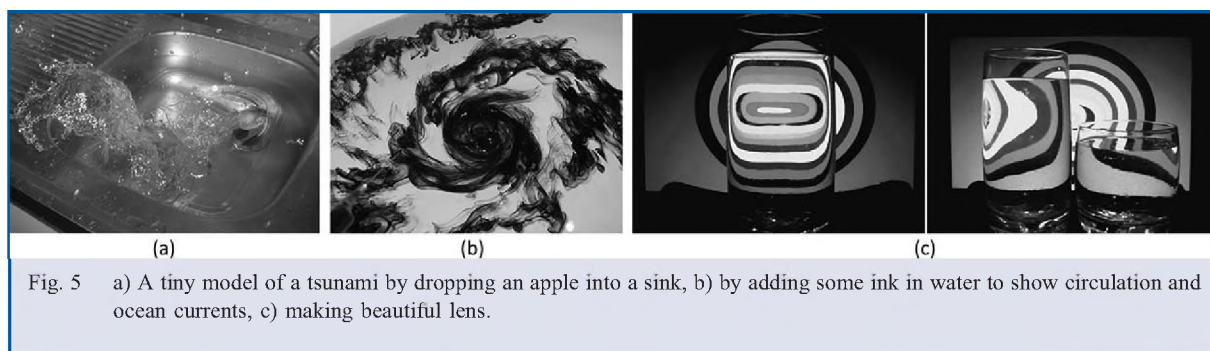
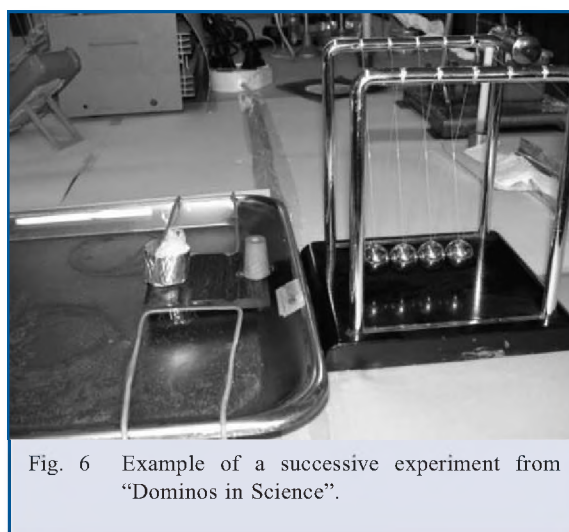


Fig. 4 By Filling a thin gap between two large transparent horizontal parallel plates with a liquid and making a little hole in the center of one of the plates, students should investigate the flow in such a cell, if a different liquid is injected through the hole (PYPT/IYPT 2012, physics tournament).



deeply and to design a model such as “Physics in Nature” (Fig. 5a, b & c).

“Dominos in Science,” which began in 1999 in Iran can empower students’ imagination as one of the best activities in experimental learning. Students can find the relationships among different laws, formulas, and equations in Physics, Chemistry and Biology without it being boring. In “Dominos in Science” different experiments follow each other. For example, students can start their dominos with a pendulum hitting a body on a surface in low or high friction with different gradients. Then it will move and give its energy to a boat that will start to move on a water surface. . . , and it will be continued^[8]. These dominos in a limited time show the novelties in designing easy to complicated and successive experiments. An example is displayed in Fig. 6. To build these machines, imagination, design and innovation support each other.



CONCLUSION

Supporting methods of science learning that are connected to imagination and artistic process can change the world of science and industry in future. Implementing such methods in interactive learning, can extend and develop innovative practices in science education. Imaginative methods in science

education, by focusing on conceptual understanding, can inspire students to look carefully, to think deeply and to design their own models which direct them to get more capacity in creating meaningful ideas and improve their decision-making, socialization, and creativity.

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PETER EGELSTAFF (1925–2015)



Peter Alfred Egelstaff, Past President of the Canadian Association of Physicists, 1987–88, died January 18, 2015, in Waterloo, Ontario, following a lengthy illness with Alzheimer's disease. Peter was Canada's leading physicist in liquid state research and was preeminent worldwide in this

field and in the general field of neutron scattering. He was a University Professor Emeritus at the University of Guelph.

Peter was born on December 10, 1925 in Middlesex, England, the third of five children. At age 10 he decided he wanted to be an experimental nuclear physicist. He completed high school at age 17 in 1943 during WWII. Being too young for the armed services and unable to afford attending university, he took full time scientific employment at High Duty Alloys Ltd at Slough, Buckinghamshire (now Berkshire), starting as a production line chemist analyzing metal alloys intended for military aircraft production, later transferring to more urgent work in the physical metallurgy laboratory. On reaching the age of 18, he wanted to join the RAF but his employer felt he was too valuable in the laboratory and obtained a military exemption for him. During his period (1943–47) at High Duty Alloys Ltd he worked evenings on courses to obtain an undergraduate degree by correspondence from the University of London. First year examinations on site at the University of London were memorable due to the rocket attacks on London at that time (June 1944). Because of logistical problems caused by the war he took his degree in mathematics rather than physics, and was awarded a B.Sc. with honours in 1946 at age 20. His employer immediately raised his salary by one third. In 1947, at age 21 he was then old enough to enter the Civil Service Commission competition for future government scientists, obtained a high grade, and was awarded a position of Scientific Officer to the Ministry of Supply, which he held at the Atomic Energy Research Establishment (AERE, Harwell). He joined the Nuclear and Reactor Physics Division, then headed by Otto Frisch, where he spent the next 10 years. He and his wife Joy were married in 1947. During the period 1951–54 he also worked evenings at Harwell on his own research and obtained a Ph.D. (external) from the University of London in 1954. His official supervisor was then Division Head Egon Bretscher. Most of his employment research up to this point was classified as secret. From 1955 to 1957 his position at Harwell was Principal Scientific Officer. In

1955 he was an AERE representative to the UN Atoms for Peace Conference at Geneva, which abolished secrecy regarding nuclear reactors. In 1957 he moved to Canada and in the period 1957–59 he was a Group Leader at Atomic Energy of Canada, Chalk River. He returned to Harwell for the period 1959–70 with a Special Merit Senior Appointment. The last of his UK–Canada alternations occurred in 1970 when he came to the University of Guelph where he remained for the rest of his career.

At Harwell Peter's initial project was to measure the neutron scattering and absorption cross sections to give data needed for reactor design. This work started with the arrival of the BEPO reactor in 1948 and culminated a decade later with work on scattering from water at the much higher flux NRU reactor at Chalk River. By about 1960 a data set more than adequate for reactor design had been produced by groups at Harwell, Argonne, Oak Ridge and Brookhaven. Peter then turned his attention to using neutron scattering to study the structure and dynamics of liquids. Neutron diffraction by crystals had been proposed in 1936 by Elsasser and demonstrated in the same year by two groups using a radium-beryllium source of neutrons, and the first diffractometer for the much higher flux neutron beam from a nuclear reactor was constructed at Argonne National Laboratories in 1945. An important step toward structural studies by neutron diffraction was taken in 1947 by Fermi and Marshall who determined the nuclear scattering lengths for about 20 elements, and by the end of the decade structural studies on solids, liquids and dense gases began to appear. The theory of inelastic neutron scattering by solids was initiated in 1944 by Weinstock, and in 1951 Egelstaff demonstrated inelastic scattering using various crystalline samples. In the period 1952–54, Placzek, Van Hove and others developed the general theory of inelastic neutron scattering from solids, liquids and gases. Using in particular the Van Hove result for the dynamical structure factor to analyze their experiments, Bert Brockhouse at Chalk River and Peter Egelstaff became the leading practitioners for the experimental study by neutron scattering of the dynamics of solids (Brockhouse) and liquids (Egelstaff). Many have expressed the opinion that Peter's work in this area was of Nobel class. Peter was a strong advocate of the use of neutron scattering techniques in all branches of condensed matter physics, and in his later years at Harwell he encouraged collaborations with many university researchers. The first of these was with Gordon Squires at Cambridge. Gordon's early students, Malcolm Collins, Gerald Dolling, David Price, Sunil Sinha, Gordon Peckham and Roger Pynn, all worked with neutron

facilities that Peter had developed before going on to stellar careers in the field.

At Chalk River his group made the first comprehensive measurements of the thermal neutron “scattering law” of reactor moderator material, and this work was used in optimizing the CANDU reactor design. His work on the Van Hove dynamical structure factor arose directly from this work on neutron moderation. During his Chalk River period he became good friends with Brockhouse. Peter, and probably others, nominated Brockhouse for the Nobel Prize for his work on neutron scattering, and when Brockhouse was awarded the prize in 1994, Peter and his wife Joy joined the Brockhouses in Stockholm for the celebration.

At Guelph, on arrival Peter became the second Chair of the fledgling Physics Department, and the excitement he brought with him was palpable. There was an endless stream of distinguished visitors. All were subjected to leading a round table discussion on a topic of their choice which could go on for several hours. Interactions with this force of nature were always interesting, often exhilarating, and sometimes exhausting. In the case of Chris Gray, it stimulated a change in research direction. One of the early visitors was Keith Gubbins who was planning to spend part of his sabbatical leave from the University of Florida with Peter at Harwell and who decided to come to Guelph instead when Peter left Harwell for Guelph. Peter alerted Gubbins and Gray to areas of liquid state research where there were unsolved theoretical problems, and this eventually led to new theoretical and computer simulation methods being developed for molecular liquids. Kenji Suzuki of the University of Sendai also changed his sabbatical leave plans to join Peter in Guelph in 1970, and Wolfgang Glazer came from Munich for a leave period somewhat later. Peter guided the department with wisdom through five formative years and was responsible for some crucially important appointments. He was one of the instigators of the Guelph–Waterloo graduate program in physics, which developed into the Guelph–Waterloo Physics Institute. He strongly supported the undergraduate biophysics program and the formation of the Biophysics Interdepartmental Group for graduate studies. Peter had a number of outstanding graduate students and postdoctoral fellows, for example Sow-Hsin Chen (Harwell), Shen Wang, Bob Hawkins, Albert Teitsma, David Winfield, Dan Litchinsky, Alan Soper, Alan Denton, Jim Sullivan, John Root, Joe Salacuse, Chris Benmore and Bruno Tomberli. Typical of their reactions on learning of Peter’s passing is that expressed by former graduate student John Root (Ph.D. 1986), currently Director, Canadian Neutron Beam Centre, Chalk River Laboratories: “My experience with Peter was very positive. I found him to be a person of high energy, creativity, and a strong outcome-orientation. He seemed

a boundless source of marvellous scientific ideas, well articulated. I could have chosen a number of the paths he suggested, being certain to find a rich scientific experience along the way. I am so grateful for the trust he placed in me as a graduate student. I always felt respected, empowered, and carefully mentored by a man with great vision and wisdom.”

Peter published about 180 papers in refereed journals, including 16 memorable reviews, on liquids, dense gases, related topics, and neutron scattering, and was in constant demand as a keynote speaker at conferences in these fields. In the 1982–89 period alone he gave about eight invited talks per year. He was very active scientifically up to the age of 75.

An important milestone was the publication of his book *An Introduction to Liquid State* (first edition 1967), which was a landmark in the field and has been cited extensively. There were three earlier research monographs in the English language devoted to the modern statistical mechanical theory of liquids, and chapters in a few books, for example in the volume of review articles by various authors edited by Peter titled *Thermal Neutron Scattering* (1965), but Peter’s book was the first modern true textbook. It was based on graduate student lectures given at the University of Reading and at Harwell. It dealt with the whole field, experiment and theory, equilibrium and nonequilibrium properties, with admirable physical clarity and brevity (236 pages), and dispelled Landau’s pronouncement that liquids were too complicated for a quantitative molecular theory. Until the late 1950s, the main theory used was that of van der Waals from the 19th century for the equation of state, which was semi-molecular and qualitative. With the development of nonlinear integral equation based theories solvable numerically by computers then becoming available, and computer simulation methods (Monte Carlo and molecular dynamics), for simple atomic liquids in thermal equilibrium such as argon one could now calculate the liquid pair correlation function and make testable predictions starting from an intermolecular force model like the Lennard-Jones potential. Peter discussed all this, with specific applications of the theory to the calculation of equilibrium properties such as the equation of state and the static structure factor measured in neutron and x-ray diffraction experiments. The modern theories for nonequilibrium properties were based then, as now, on the rigorous time-correlation function expressions derived in the 1950s by Van Hove for the dynamical structure factor, and by Melvin Green, Kubo and others for the diffusion coefficient, viscosity, thermal conductivity, and other linear response properties. Peter discussed these properties mainly phenomenologically using semi-macroscopic arguments from hydrodynamics and elasticity, as true molecular theories for nonequilibrium

properties were a few years away. The discussions throughout Peter's book were mainly classical but a chapter was devoted to the quantum corrections to the dynamic structure factor, a topic on which Peter had published a research paper in 1961 and one to which he repeatedly returned in later years. The last two chapters contained brief discussions of the liquid-gas critical point (pre-renormalization group), and fully quantum liquids such as helium-4 and helium-3. A second edition (1994), based on a graduate course given at the Guelph–Waterloo Physics Institute, omitted the last two chapters as the subjects discussed had now developed into autonomous fields, but covered later developments such as additional integral equations, perturbation theory (which finally made the old van der Waals theory fully molecular and quantitative), the theory, simulation, and experiments for molecular liquids such as nitrogen and water, an extended discussion of quantum corrections for both equilibrium and nonequilibrium properties, and, for nonequilibrium properties, statistical mechanical / molecular theories such as the generalized Langevin equation with memory function friction, generalized kinetic theory, generalized hydrodynamics, and mode coupling. Peter also coauthored a book *Experimental Neutron Thermalisation* (1969) with M.J. Poole.

His rapid comprehension and versatility were legendary. Peter was equally at home with experiment and theory and while at Harwell he collaborated with theorist Peter Schofield. Egelstaff was one of the very few scientists who could explain Placzek's theory for the inelasticity effect in neutron diffraction experiments using an understandable notation, and he extended the theory to include molecular systems. At Guelph he published theoretical papers with faculty and postdoctoral fellows, and he was one of those first responsible for obtaining and maintaining state of the art computer simulation facilities for the University. For example, in the late 1970s a consortium at Guelph including Peter obtained NSERC funding for the first Array Processor (AP) in Canada available for simulations. This powerful machine, built by Floating Point Systems, had been used for geophysical prospecting but a group at Cornell University, including Ken Wilson, had recently written software to convert it to a very high performance / relatively low cost general number cruncher. The Guelph group was made aware of the AP through its ongoing collaboration with Keith Gubbins, then at Cornell, as Gubbins and Wilson had obtained one through an NSF grant. As another example of Peter's versatility, in 1960 he and three colleagues at Harwell published a study of the frequency shift of light caused by acceleration of the source or receiver. They put a Mossbauer gamma ray source at the centre of a rotor and a Mossbauer detector on the rapidly rotating rim. The measured shift agreed with that predicted by general relativity from time dilation in a gravitational field; they invoked the Einstein

equivalence principle and assumed the centrifugal field experienced by the detector is equivalent to a gravitational field. They pointed out that the shift can also be calculated from special relativity using the transverse Doppler effect. At about the same time a conceptually similar experiment was carried out at Harvard University by Rebka and Pound. These workers put the gamma source at the top of a 22 metre tower and the detector at the bottom. They also found a frequency shift in agreement with the prediction from general relativity. The latter experiment is the one usually cited in textbooks.

There is insufficient space to review in detail Peter's many specific contributions to the physics of liquids, dense gases, clays, glasses, and biological systems, and to the techniques and instrumentation of neutron scattering, but there are some particular highlights. He pioneered the technique of inelastic neutron scattering to study the dynamics of liquids, and improved the neutron diffraction techniques to study static (or equilibrium) properties of liquids; specific studies include collective modes in liquids, orientational correlations in molecular liquids, three-body potential effects in atomic fluids, quantum effects in water and other liquids, metastable phases of very low temperature water, and the structure of collagen. As regards instrumentation and other specific techniques, Peter was a pioneer in the development of time-of-flight methods using high speed rotating collimators (choppers) made of a magnesium-cadmium alloy that had a high strength-to-weight ratio. The frequency and phase of these choppers were tightly controlled so that multiple choppers could be used in series and so that choppers could be phased with a pulsating neutron source. This was central to the development of spallation neutron sources. Major such facilities now exist with ISIS at Harwell, SNS at Oak Ridge and JParc in Japan. Another groundbreaking work was showing that it was feasible to operate a liquid hydrogen source of cold neutrons within a nuclear reactor. Use of such sources is now standard at major neutron scattering facilities. He developed the isotope substitution method to extract the individual pair correlation functions in liquid mixtures and heteronuclear molecular liquids from neutron diffraction data, a method now standard for extracting individual pair correlation functions in ionic solutions. Isotopes were also introduced in diffraction work for the study of quantum effects in liquid structure, including the hydrogen-bonding structure in liquid water. He started with an innovative in-house gamma-ray diffractometer at Guelph with an Americium-241 source, and later used high flux synchrotrons at Grenoble and Hamburg; he paved the way for the development of high precision x-ray diffraction techniques at third generation synchrotrons. He improved the precision by factor of 5–10 for diffraction by the design and construction of an advanced type of neutron diffractometer at the NRU reactor, Chalk River. He designed and

built a rotating crystal time-of-flight spectrometer on the University of Toronto electron linac which he used as a pulsed neutron source; designers in the US and UK used this as a prototype. He was at the forefront in using computer simulations for the study of liquids; in particular, he collaborated on the first use of a minicomputer (a Data General NOVA 2 at Guelph, 1976) to do liquids simulations (Monte Carlo for linear molecules), and later helped promote large scale supercomputing facilities for researchers at Guelph and elsewhere. In collaboration with Jens-Boie Suck (Chemnitz), Fabrizio Barrochi (Florence) and others, Peter pioneered the use of neutron Brillouin spectroscopy to study the phonon-like excitations in dense gases, liquids and amorphous solids.

Peter served on the editorial boards of the journals *Molecular Physics* and *Journal of Physics and Chemistry of Liquids*, and on a vast number of other boards and committees including being a member and Chair of NSERC research grants and scholarships committees, management boards for nuclear reactor facilities (Argonne-Los Alamos Joint Program Committee for Pulsed Neutron Sources, McMaster University, Canadian Institute for Neutron Scattering), NSERC and Ontario supercomputer access committees, Royal Military College Awards Committee, Royal Society of Canada Physics Committee, Board of Governors of the University of Guelph, and Chair of the Polanyi Prize Committee.

Honours received by Peter include the Canadian Association of Physicists Medal for Lifetime Achievement in Physics (1983), election as a Fellow of the Royal Society of Canada (1980), Fellow of the Institute of Physics

(London), Honorary Doctorate from the University of Waterloo (1992), Researcher of Distinction for the first 25 year period of the University of Guelph (1989), Spiers Memorial Medal of the Faraday Society / Royal Society of Chemistry (1978), and the Guelph Sigma-Xi award for excellence in research (1980). In honour of his 65th birthday a symposium, International Symposium on the Structure and Dynamics of Liquids and Gases in Honour of Peter Egelstaff, was held in 1991 at Wadham College, Oxford University. The invited speakers came from Canada, UK, US, France, Germany, Austria and Japan.

It is impossible to express the loss felt by friends and colleagues of Peter. He lived life to the fullest, with deepest love for his family, dedication to his profession, and joyfulness in all activities. It was fun to be with him no matter what the occasion.

Peter is survived by his wife of 67 years, Joy, and by their five children: Robert in the UK, Richard in Australia, Paul in Toronto, Janet in Australia and Katy in Waterloo. He also leaves 17 grandchildren.

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Chris Gray
University Professor Emeritus, Department of Physics
University of Guelph

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INTERVIEW WITH MARIO PINTO, NSERC PRESIDENT, ON FEBRUARY 19, 2015 BY BARBARA FRISKEN, CAP DIRECTOR OF ACADEMIC AFFAIRS

PREAMBLE:

Dr. B. Mario Pinto has recently been appointed President of the Natural Sciences and Engineering Research Council of Canada. Previously, Dr. Pinto served two terms as Vice-President, Research at Simon Fraser University. He is a pioneer in the field of chemical biology, and an active researcher in the areas of drug and vaccine design. He is a Fellow of the Chemical Institute of Canada and the Academy of Sciences of the Royal Society of Canada. He recently presented NSERC's Draft Strategic Plan for 2015–2020 for advice and comment. You can read about the plan on the NSERC website: http://www.nserc-crsng.gc.ca/NSERC-CRSNG/NSERC2020-CRSNG2020/index_eng.asp.

Barbara: First I'd like to congratulate you on your appointment and thank you for participating in this interview.

Mario: Thank you very much, Barbara. It is a pleasure to speak with you today.

Barbara: One of the first strategic goals articulated in the plan is to foster a science culture in Canada. What do you think that physicists can do to help build a culture of science in Canada?

Mario: First, I think they can join other natural scientists and engineers in promoting the message that science is essential and all around us, and I really do believe that until we foster a science culture with the general public that we are not going to make the strides that we want in terms of investment in science and engineering. So whatever you can do to work with the general public from K to 12 all the way up to your Members of Parliament to educate them about what is being done in the universities. Now, you are already doing a lot in terms of outreach activities and I think that is very good because through the students you will educate the parents. I think that is the critical part of the exercise.

Barbara: What can we do to increase understanding of the importance of research in areas of foundational knowledge?

Mario: This is a good question. Let me tell you what I have learned since I took over as President and this is what I have been communicating to different groups in my trips across the country. In March and April I'll cross the country yet again to talk about the NSERC 2020 plan and to get feedback on the plan, but also to take the occasion to share these insights.

In my encounters with the different sectors: academic, business, and government, the importance of discovery research is appreciated and there is a growing understanding of investment in research where results may be unanticipated.

Two nights ago, we celebrated the top NSERC research awards at Rideau Hall, the Governor General's residence. At the event, Minister of State for Science and Technology, Minister Holder, spoke about the importance of discovery-driven research and the value of scientific inquiry.

Everybody must realize that we shouldn't create an artificial distinction between pure and applied research. Let's focus instead on doing excellent research. But this is not to say that we should not keep up the pressure to spread that culture among the general public, the business community, and parliamentarians, and that's what I am in the process of doing.

As far as Discovery Grants go, I'd like to emphasize that investments have increased (15%) over the last decade and funding has steadily gone up every year. If I look at the overall NSERC budget, 66% of the funding pie is dedicated to discovery-driven research, while the rest supports strategic partnerships and innovation. Of that 66%, 13% is in Scholarships and Fellowships, and 13.5% is in CRCs (Canada Research Chairs) and CERCs (Canada Excellence Research Chairs), also doing foundational research. So the bulk of our money goes into discovery research.

The importance of foundational research is well recognized and we have to accept that it is part of our fabric, part of our foundation. We need to celebrate it more and this is what you will see in the new plan, but with the understanding that, when inventions do arise, we have the responsibility to provide the tools to develop these inventions to create innovation for societal and economic impact.

What NSERC does through the partnership programs, is to add value and de-risk the scientific invention for further investment. This investment takes different forms, some of which are supported by other funding organizations. But what we are doing at NSERC is discovery research, adding value, and de-risking. That's it. Commercialization requires the involvement of many more players in the innovation ecosystem. This is our space. What I am doing is defining our role for the academy, for the business community and for parliamentarians.

Barbara: One of the things people are wondering about is the continuum between university research, NRC, and industry.

Mario: You bring up a very interesting point. There are many, many players in the space of research and innovation. We have to look at the other partners.

NSERC is trying to provide some coordination and collaboration between the different organizations to leverage respective strengths, working with NRC IRAP, MITACS, etc. to try and reduce the administrative burden and provide one access point.

Discovery is our cornerstone and our foundation, but when invention needs to be developed further, we will partner with industries and other agencies to take those inventions forward and build them into true innovation.

It takes a whole ecosystem. The important thing is to do it well, whether one is doing discovery-type research or partnership-type research with industries, to do it rigorously with a high caliber of excellence in both those endeavors.

What I maintain is that the distinction between discovery and partnership research and what we call innovation is really moot, because it depends very much where I draw my boundary conditions what makes research of a discovery nature or an innovation nature. But one thing is clear, the entire system profits from the dynamic interaction between the two.

Barbara: There is a practical distinction – if you are moving towards the partnership area you need a partner.

Mario: There is, and then you have to ask very different questions. You have to look at the measures of rigour appropriate to that partnership. You can't use the measures of rigour you would use in a pure scholarly inquiry in the partnership precinct. If you are going to encompass partnerships, you have to use other measures as well, appropriate to industry standards, for example.

We should not be preoccupied with this distinction and just do excellent research and innovation, and that will be key.

Barbara: One of the things physicists have found challenging about the strategic areas is that they have become very defined. People don't feel they fit.

Mario: There are broad research priorities and sub-priorities in the Science Technology and Innovation Strategy and really they provide enough latitude to encompass most initiatives. I recently presented this to the Evaluation Groups as part of the discovery merit-review process. Allow me to outline the research priority areas and sub-priority areas because it may be instructive to your community:

- **Environment and agriculture** – water, health, energy, security, biotechnology, aquaculture, sustainable methods of accessing energy and mineral resources from unconventional sources, food and food systems, climate change and technology, disaster mitigation
- **Health and life sciences** – neurosciences, mental health, regenerative medicine, health in an aging population, biomedical engineering, medical technologies
- **Natural resources and energy** – arctic, responsible development and monitoring, bioenergy, fuel cells, nuclear energy, pipeline safety
- **Information and communications technologies** – new media animation and games, communications networks and services, cyber security, advanced data management and analysis, machine to machine systems, quantum computing
- **Advanced manufacturing** – automation, including robotics, lightweight materials and technologies, additive materials, quantum materials, aerospace and automotive

These areas are broad and offer many opportunities to the physics community. Here are a couple of examples that I can

speak to: Jeff Dahn at Dalhousie University has been well supported and is very successful. He taps into a lot of partnership programs in the area of battery technology. Karen Kavanagh at Simon Fraser University has just received an Engage Grant to work with Parkside Optical Inc. That's just the beginning of the relationship. There are many other examples of physicists working in Strategic Partnerships, Collaborative Research Development programs, and Industrial Research Chair programs.

Barbara: The CAP-NSERC Liaison Committee has found that physicists' participation in partnership programs is low as compared to some other disciplines. There will be a session about this at the CAP Congress in June.

Mario: Physicists are at the core of many of the strategic areas. I don't see many restrictions because of the chosen strategic areas. You can work on sensor technologies, nanotechnologies, wireless communications, quantum materials, optical spectroscopy, and the list goes on. Physicists are well positioned.

Start with an Engage Grant, it's the "first date", the first exposure of a researcher to a company and possibly first exposure of a company to the brain trust. This will set up the network for further development.

In the past five years, one in five Engage Grant partnerships have gone on to more mature relationships like Collaborative Research Development grants, and Industrial Research Chairs. And one in six of students involved have gone on to be employees of the companies. There are lots of opportunities, not just for physicists, but you have a privileged position as you are at the core of many of these activities, as I see it.

What we can do better, which is part of the NSERC 2020 strategic plan, is to be the matchmaker and provide access to these companies for the academics, and vice versa. We can develop an asset map of the different strengths of academics to offer to potential industrial partners.

Barbara: I think that would be helpful. Is there a particular type of industry that is more likely to become involved in partnership programs?

Mario: NSERC funded researchers are working with 3,000 companies through partnerships. We are primarily a land of small and medium enterprises and we might as well embrace this ideology and ethos and run with it. And many people are: 3,000 companies is quite significant. There are some large companies: we have for example IBM and 3M working with us. Overall, there is a significant Canadian industry presence and we work with them.

The testimonials I have heard from these business partners are just outstanding. They value the brain trust so much that it is overwhelming. Scientists and engineers shouldn't underestimate their contributions.

Generally, the Engage Grants are taken advantage of by small companies, the Collaborative Research Development grants are more mature relationships taken advantage of by medium companies. Industrial Research Chairs are exploited

by large companies. We can see the progression and their maturing as a function of company size.

Barbara: IRCs is another area where I have noticed that physicists are under-represented.

Mario: I think this is very much dependent on the institution. I will say that Industrial Research Chairs are a great way to bring in new talent. I'd like to see all institutions occupy this space because it is a great way to add new faculty without bearing the cost, at least for five years.

There are a total of 180 Chairs across the country, and they are particularly well represented in Alberta, Ontario, and Quebec. Of these, 11 are held by physicists.

Barbara: We only have a few more minutes, I wondered if you could comment on how we can build on the potential of academic institutions of all sizes?

Mario: Absolutely. The second goal of NSERC 2020 is to take advantage of the diversified, competitive research base in Canada. We have to admit that we have great diversity in research and innovation, ranging from the colleges and polytechnics, to the universities, small, medium and large, each with a different mandate and a different clientele. We have to embrace that diversity.

That means we may have to be flexible. By that I mean, when judging the productivity of a researcher from a primarily undergraduate university, we should admit that they are working with undergraduates and so the productivity and the type of research project is going to be geared to this base. So perhaps we should be flexible in evaluating their contributions in the training of undergraduates.

Similarly, the colleges, polytechnics, and institutes have their place, mostly on the innovation side. NSERC's plan is to embrace this diversity. This diversity extends to populations as well. We need more women in science and engineering, and we need more aboriginals in science and engineering. We have to recognize that we have a diverse culture, embrace it and figure out how we can leverage these various strengths to generate a

robust research and innovation ecosystem. Through diversity we can generate strength. But, research excellence has to be the overriding criterion with the assessment of university contributions. This is what we propose in our new strategy, to embrace the contributions of the different types of institutions so that we are inclusive to all parts of the population.

Barbara: Have you looked at having different programs for primarily undergraduate universities as they do in the US?

Mario: In my first round of consultations with the community, I asked this question of researchers at small universities, and was surprised that a strong majority of them wanted to be evaluated in the same competition. They did not want a separate allocation; rather they wanted to be evaluated with their peers. But they wanted some consideration for the training environment. We offer similar flexibility with early career researchers.

Barbara: How can people provide input on the draft NSERC 2020 Strategic Plan?

Mario: There is a free-format survey on our website: http://www.nserc-crsng.gc.ca/NSERC-CRSNG/NSERC2020-CRSNG2020/index_eng.asp. We have asked two specific questions and comments are welcome. I will look forward to meeting with researchers across Canada this spring where I will hold in-person sessions looking for input. I look forward to the feedback and interacting with the community. This is a cogent strategy but we want to make sure that the community has an opportunity to fine tune it and that you will help us realize this strategy because it has to be a team effort.

Barbara: The plan presents a more optimistic view than I have heard for a while, and it is quite refreshing.

Mario: Thank you Barbara. If you can't be optimistic it is not going to happen. We, as a community, have to believe in the plan. We have to stop dividing the pie and instead grow the pie. The other objective is to present a coherent front. We need to move forward together to harness the potential of scientific discovery and innovation.

ENTREVUE ACCORDÉE PAR MARIO PINTO, PRÉSIDENT DU CRSNG, LE 19 FÉVRIER 2015, À BARBARA FRISKEN, DIRECTRICE — AFFAIRES ACADÉMIQUES DE L'ACP

PRÉFACE

B. Mario Pinto est depuis peu président du Conseil de recherches en sciences naturelles et en génie du Canada. Il a auparavant été vice-recteur à la recherche à la Simon Fraser University durant deux mandats. Ce pionnier de la biologie chimique a fait activement de la recherche dans le domaine de

la conception de médicaments et de vaccins. Il est membre de l'Institut de chimie du Canada et membre de l'Académie des sciences de la Société royale du Canada. M. Pinto a récemment présenté la version provisoire du Plan stratégique de 2020 du CRSNG (période 2015–2020) afin de recueillir des avis et des commentaires. Pour en savoir plus sur ce plan,

consultez le site Web du CRSNG à http://www.nserc-crsng.gc.ca/NSERC-NSERC2020-CRSNG2020/index_fra.asp.

Barbara : Tout d'abord, j'aimerais vous féliciter pour votre nomination et vous remercier d'avoir accepté de nous accorder cette entrevue.

Mario : C'est moi qui vous remercie Barbara. Je suis ravi de parler avec vous aujourd'hui.

Barbara : L'un des premiers objectifs stratégiques énoncés dans le plan consiste à favoriser une culture scientifique au Canada. À votre avis, quelles mesures les physiciens peuvent-ils prendre pour aider à instaurer une culture scientifique au pays?

Mario : Tout d'abord, ils peuvent à mon avis s'associer aux autres chercheurs des sciences naturelles et aux ingénieurs pour faire passer le message que la science est essentielle et qu'elle se trouve partout autour de nous. Tant que nous ne favoriserons pas une culture scientifique auprès du grand public, nous ne ferons pas les progrès souhaités en matière d'investissement dans les sciences et le génie. J'en suis convaincu. Alors, il faut que vous fassiez de votre mieux pour sensibiliser le public, depuis les jeunes de la maternelle, du primaire et du secondaire jusqu'aux parlementaires, afin de les renseigner sur les travaux accomplis dans les universités.

Je sais que vous faites déjà beaucoup d'activités de sensibilisation. Et, à mon avis, c'est très bien, car vous renseignez les parents par l'intermédiaire des élèves. Je pense que c'est un volet essentiel de la démarche.

Barbara : Quelles mesures pouvons-nous prendre pour mieux faire comprendre l'importance de la recherche dans les domaines de la connaissance fondamentale?

Mario : C'est une bonne question. Permettez-moi de vous dire ce que j'ai appris depuis que je suis président du CRSNG et c'est d'ailleurs le message que je livre aux différents groupes que je rencontre un peu partout au pays. En mars et en avril, je ferai une nouvelle tournée nationale pour parler du Plan stratégique de 2020 du CRSNG. En plus de recueillir les commentaires, je profiterai de l'occasion pour communiquer ces observations.

Quand je rencontre les représentants des différents secteurs, c'est-à-dire le milieu universitaire, le monde des affaires et le secteur public, ils me disent que les gens sont conscients de l'importance de la recherche axée sur la découverte et qu'ils comprennent de plus en plus l'investissement dans la recherche prometteuse. Avant-hier soir, à Rideau Hall, la résidence du gouverneur général, nous avons décerné les prix les plus prestigieux du CRSNG rendant hommage à des chercheurs. L'honorable Ed Holder, ministre d'État (Sciences et Technologie), a alors souligné l'importance de la recherche axée sur la découverte et l'utilité de l'investigation scientifique.

Tout le monde doit comprendre qu'il ne faudrait pas créer une distinction artificielle entre la recherche fondamentale et la recherche appliquée. Attachons-nous plutôt à viser l'excellence en recherche. Mais cela ne veut pas dire qu'il

faut relâcher les efforts que nous déployons pour propager cette culture auprès du grand public, des gens d'affaires et des parlementaires. Et c'est ce que je fais à l'heure actuelle.

En ce qui concerne les subventions à la découverte, j'aimerais souligner que les investissements se sont accrus de 15 % au cours des 10 dernières années et que le financement n'a cessé d'augmenter d'année en année. Lorsqu'on examine le budget global du CRSNG, l'enveloppe de financement est affectée à hauteur de 66 % à la recherche axée sur la découverte. Le reste appuie les partenariats stratégiques et l'innovation. Sur ces 66 %, les bourses représentent 13 % du financement et les subventions de Chaires de recherche du Canada et de Chaires d'excellence en recherche du Canada 13,5 %. Or, les titulaires qui bénéficient de ce financement font eux aussi de la recherche fondamentale. La majeure partie de nos fonds est donc consacrée à la recherche axée sur la découverte.

L'importance de la recherche fondamentale est largement reconnue et nous devons admettre qu'elle fait partie intégrante de notre tissu social, de notre assise. Nous devons la souligner davantage, comme vous le constaterez en prenant connaissance de notre nouveau plan stratégique. Mais il est entendu que nous avons la responsabilité de fournir les outils voulus pour perfectionner les inventions propres à stimuler l'innovation sur le plan social et économique.

Grâce à ses programmes de partenariat, le CRSNG apporte une valeur ajoutée aux inventions scientifiques et atténue les risques qui y sont associés pour attirer des investissements supplémentaires. Ces investissements prennent différentes formes. Certains sont financés par d'autres organismes subventionnaires. Mais ce que nous faisons au CRSNG, c'est de la recherche axée sur la découverte en apportant une valeur ajoutée et en atténuant le risque. Voilà ce qui en est. La commercialisation met à contribution de nombreux autres acteurs de l'écosystème de l'innovation. C'est notre univers. Ce que je fais, c'est de définir notre rôle à l'intention du milieu universitaire, des gens d'affaires et des parlementaires.

Barbara : L'un des aspects sur lesquels les gens se posent des questions, c'est le continuum entre la recherche universitaire, le Conseil national de recherches Canada et l'industrie.

Mario : Vous soulevez un point très intéressant. Il y a de très nombreux acteurs dans la sphère de la recherche et de l'innovation. Nous devons tenir compte des autres partenaires.

Le CRSNG s'efforce d'assurer une coordination et une collaboration entre les différentes organisations pour tirer parti de leurs points forts respectifs, en travaillant de concert notamment avec le Programme d'aide à la recherche industrielle du Conseil national de recherches Canada ou avec MITACS. On souhaite ainsi réduire le fardeau administratif et offrir un seul point d'accès. La découverte est pour nous une pierre angulaire et une assise. Mais lorsque vient le temps de perfectionner une invention, nous nous associons à l'industrie et à d'autres organismes pour la faire progresser et la transformer en une véritable innovation.

Il faut un écosystème tout entier. L'important, c'est de bien faire les choses. La rigueur et l'excellence sont essentielles, tant pour la recherche axée sur la découverte que pour la recherche menée en partenariat avec l'industrie.

D'après moi, la distinction entre, d'une part, la recherche axée sur la découverte et la recherche menée en partenariat et, d'autre part, ce que nous appelons « l'innovation » est vraiment discutable. Cette distinction varie grandement selon le point où on établit la frontière qui détermine si la recherche est axée sur la découverte ou l'innovation. Mais une chose est claire, le système tout entier bénéficie de l'interaction dynamique entre les deux.

Barbara : Il y a une distinction pratique – si l'on va du côté des partenariats, il faut un partenaire.

Mario : Vous avez raison. Et on doit alors poser des questions très différentes. Il faut se pencher sur les mesures assurant la rigueur qui conviennent au partenariat concerné. On ne peut pas appliquer dans le contexte d'un partenariat les mesures que l'on prendrait dans des travaux d'érudition en recherche fondamentale. Pour tenir compte des partenariats, il faut utiliser d'autres mesures, par exemple, des mesures conformes aux normes de l'industrie.

Nous ne devrions pas nous préoccuper de cette distinction. Il faut viser l'excellence en recherche et en innovation. C'est l'essentiel.

Barbara : Les domaines stratégiques sont maintenant très définis. C'est l'un des aspects que les physiciens trouvent difficiles. Ils ont l'impression de ne pas y trouver leur place.

Mario : La stratégie en matière de sciences, de technologie et d'innovation établit de grandes priorités et des sous-priorités de recherche, qui laissent assez de latitude pour englober la plupart des initiatives. J'en ai récemment parlé aux groupes d'évaluation dans le cadre de l'évaluation du mérite pour les subventions à la découverte. Permettez-moi de souligner les priorités et les sous-priorités de recherche, car cette information peut être utile à votre milieu :

- **Environnement et agriculture** – eau, santé, énergie, sécurité, biotechnologie, aquiculture, méthodes durables pour accéder aux ressources énergétiques et minérales tirées de sources non conventionnelles, alimentation et systèmes alimentaires, recherche sur les changements climatiques et technologie connexe et atténuation des catastrophes;
- **Santé et sciences de la vie** – neurosciences et santé mentale, médecine régénératrice, santé chez une population vieillissante, génie biomédical et technologies médicales;
- **Ressources naturelles et énergie** – Arctique : exploitation et surveillance responsables, bioénergie, piles à combustible, énergie nucléaire et sécurité des pipelines;
- **Technologies de l'information et des communications** – nouveaux médias, animation et jeux, réseaux et services de communication, cybersécurité, analyse et capacités avancées de gestion des données, systèmes machine à machine et informatique quantique;

- **Fabrication de pointe** – automatisation (notamment la robotique), matériaux légers et technologies connexes, matériaux additifs, matériaux quantiques, aérospatiale et secteur de l'automobile.

Ce sont des domaines vastes qui offrent de nombreuses possibilités au milieu de la physique. Je me permettrai de vous citer deux exemples : Jeff Dahn, de la Dalhousie University, a obtenu un solide appui financier et ses travaux sont très fructueux. Il participe à de nombreux programmes de partenariats et connaît beaucoup de succès dans le domaine de la technologie des piles. Karen Kavanagh, de la Simon Fraser University, vient tout juste d'obtenir une subvention d'engagement partenarial pour collaborer avec Parkside Optical Inc. Ils en sont au début de leur relation. On pourrait citer bien d'autres exemples de physiciens qui bénéficient des programmes de partenariats stratégiques, de recherche et développement coopératifs et de professeurs-chercheurs industriels.

Barbara : D'après le Comité de liaison ACP-CRSNG, les physiciens participent moins aux programmes de partenariats que les chercheurs de certaines autres disciplines. Une séance sur le sujet est d'ailleurs prévue au congrès de l'ACP en juin.

Mario : Les physiciens sont au cœur de bon nombre des domaines stratégiques. À mon avis, il n'y a pas beaucoup de restrictions découlant du choix des domaines stratégiques. Les physiciens peuvent travailler à différentes technologies comme les capteurs, la nanotechnologie, les communications sans fil, les matériaux quantiques, la spectroscopie optique et ainsi de suite. Ils sont bien placés.

Commencez par la subvention d'engagement partenarial, c'est la « première rencontre », le premier contact d'un chercheur avec une entreprise et peut-être le premier contact d'une entreprise avec le groupe d'experts. Elle permet de mettre sur pied le réseau qui poursuivra le développement.

Au cours des cinq dernières années, un cinquième des partenariats appuyés par une subvention d'engagement partenarial ont débouché sur une relation plus étroite appuyée, par exemple, par une subvention de recherche et développement coopérative ou une subvention de professeur-chercheur industriel. De plus, un sixième des étudiants participant à un partenariat ont par la suite été embauchés par les partenaires industriels. Il y a beaucoup de possibilités, et non seulement pour les physiciens. Toujours est-il que vous occupez une place privilégiée, car d'après ce que je vois, vous êtes au cœur d'un grand nombre de ces activités.

L'amélioration que nous pouvons apporter, comme le prévoit le Plan stratégique de 2020 du CRSNG, c'est d'assurer un jumelage et de faire en sorte que le milieu universitaire ait accès à ces entreprises et vice versa. Nous pouvons créer un inventaire des différentes compétences que les chercheurs universitaires ont à offrir aux partenaires industriels éventuels.

Barbara : Je pense que ce serait utile. Y a-t-il un type d'industrie en particulier où les entreprises sont plus enclines à participer aux programmes de partenariats?

Mario : Les chercheurs appuyés par le CRSNG collaborent avec 3 000 entreprises dans le cadre de partenariats. Comme

les petites et moyennes entreprises occupent une place prépondérante au Canada, autant adopter cette idéologie et cette mentalité et en tirer parti. Et c'est ce que font bien des gens : 3 000 entreprises, ce n'est pas rien. Loin de là. Il y a aussi certaines grandes entreprises : par exemple, IBM et 3M travaillent avec nous. Dans l'ensemble, l'industrie canadienne est très présente et nous collaborons avec elle.

Ces partenaires industriels ont livré des témoignages impressionnants. Ils apprécient les groupes d'experts à un point tel que c'en est bouleversant. Les chercheurs et les ingénieurs ne devraient pas sous-estimer leur apport.

De façon générale, les subventions d'engagement partenarial donnent lieu à des partenariats avec des petites entreprises, tandis que les subventions de recherche et développement coopérative sont à l'origine de relations bien établies avec des moyennes entreprises. Les chaires de recherche industrielle rallient les grandes entreprises. Nous pouvons constater la progression et l'évolution en fonction de la taille des entreprises.

Barbara : J'ai remarqué que les physiciens sont sous-représentés également dans le Programme de professeurs-chercheurs industriels.

Mario : Je pense que ça varie beaucoup d'un établissement à l'autre. À mon avis, les chaires de recherche industrielle sont un moyen formidable d'attirer de nouveaux talents. J'aimerais que tous les établissements s'en prévalent, parce que c'est une excellente façon d'augmenter le nombre de professeurs sans en assumer le coût pendant au moins cinq ans.

On compte 180 chaires à la grandeur du pays et elles sont particulièrement bien représentées en Alberta, en Ontario et au Québec. Sur ce nombre, 11 sont détenues par des physiciens.

Barbara : Il ne nous reste que quelques minutes. Nous diriez-vous comment nous pourrions exploiter le potentiel des établissements universitaires de toutes tailles?

Mario : Bien sûr. Le deuxième objectif de CRSNG 2020 consiste à tirer parti de la base de recherche diversifiée et concurrentielle en place au Canada. Nous devons reconnaître la grande diversité dans les sphères de la recherche et de l'innovation, depuis les collèges et les écoles polytechniques jusqu'aux universités de toutes tailles, qui ont chacune une clientèle et un mandat différents. Nous devons appuyer cette diversité.

Cela signifie que nous pourrions avoir à faire preuve de souplesse. J'entends par là qu'au moment d'évaluer la productivité d'un chercheur d'une université offrant principalement des programmes de 1^{er} cycle, nous devrions reconnaître qu'il travaille avec des étudiants de 1^{er} cycle. Cette particularité aura une incidence sur la productivité et le type de projet de recherche. Nous devrions peut-être nous montrer flexibles lorsque nous évaluons leur contribution à la formation d'étudiants au niveau du baccalauréat.

De même, les collèges, les écoles polytechniques et les instituts ont leur place, principalement dans la sphère de l'innovation. Le plan d'action du CRSNG consiste à appuyer cette diversité. La diversité s'étend aussi aux populations. En sciences et en génie, nous avons besoin de plus de femmes et de plus d'Autochtones. Il faut reconnaître que nous avons une culture diversifiée, l'accepter et trouver des moyens d'exploiter ces points forts pour obtenir un solide écosystème de recherche et d'innovation. La diversité favorise la vigueur. Mais l'excellence en recherche doit être le critère primordial pour évaluer les contributions des universités. C'est pourquoi nous proposons dans notre nouvelle stratégie d'appuyer les contributions des différents types d'établissements pour intégrer tous les segments de la population.

Barbara : Avez-vous envisagé d'avoir des programmes différents à l'intention des universités qui offrent principalement des programmes de 1^{er} cycle comme cela se fait aux États-Unis?

Mario : Au cours de ma première série de consultations auprès du milieu, j'ai posé cette question à des chercheurs de petites universités. À ma grande surprise, une grande majorité d'entre eux souhaitent que l'on évalue leurs demandes dans le cadre du même concours. Ces chercheurs ne veulent pas une enveloppe de financement distincte. Ils souhaitent plutôt que leurs demandes soient évaluées avec celles de leurs pairs, mais en tenant compte du milieu de formation. Nous offrons une souplesse similaire dans le cas des chercheurs en début de carrière.

Barbara : Comment les gens peuvent-ils exprimer leur opinion sur le Plan stratégique de 2020 du CRSNG?

Mario : Il y a un questionnaire de sondage à format libre dans notre site Web à http://www.nserc-crsng.gc.ca/NSERC-CRSNG/NSERC2020-CRSNG2020/index_fra.asp. Nous posons deux questions précises et nous invitons les gens à formuler des commentaires. J'ai hâte de rencontrer les chercheurs un peu partout au Canada ce printemps lorsque je tiendrai des séances de consultation en personne pour connaître leur opinion. Je suis impatient de recevoir leur rétroaction et de discuter avec les membres du milieu. Notre stratégie est pertinente, mais nous voulons nous assurer que le milieu a la possibilité de la peaufiner et que vous nous aiderez à la mettre en œuvre. Un travail d'équipe s'impose.

Barbara : Le plan stratégique présente un point de vue plus optimiste que ce que j'entends depuis un certain temps. C'est très rafraîchissant.

Mario : Merci Barbara. Pour progresser, il faut faire preuve d'optimisme. En tant que milieu, nous devons croire au plan stratégique. Au lieu de fractionner l'enveloppe de financement, nous devons l'augmenter. L'autre objectif consiste à faire front commun. Nous devons aller de l'avant ensemble pour exploiter le potentiel de la découverte scientifique et de l'innovation.

OPEN LETTER TO DR. B. MARIO PINTO, PRESIDENT OF THE NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL OF CANADA, APRIL 27, 2015

This spring, NSERC's President went on a cross-country tour of Canadian universities and colleges to get input from academics on the NSERC 2020 Strategic Plan. (Details of the plan are available on NSERC's web site: <http://www.nserc-crsng.gc.ca/>.) This letter is in reaction to Dr. Pinto's visit to the Université de Montréal on 13 April.

Dear Dr. Pinto,

I attended your presentation at the Université de Montréal and would like to articulate some thoughts which were brewing in my mind, but which had not yet surfaced during your presentation and the question period which followed.

I was very pleased to hear you describe "discovery" as the foundation—a necessary but not sufficient condition, as you put it—of "innovation", and also that you emphasize its importance when you meet with politicians and policy-makers. (I put the terms in quotation marks because they do not resonate with me, as I will explain below.)

As you gathered from the question period, many of those in attendance at the meeting (myself included) have the perception that discovery is viewed (by NSERC or the Government, or both) as subservient to innovation, so your words were to some extent reassuring. Nonetheless, this perception seems to be reinforced, and indeed embodied, in NSERC's vision as stated, among other places, in the online survey soliciting feedback from the research community on NSERC 2020. The statement is: *NSERC's vision is for Canada "to be a global leader in strengthening the discovery-innovation continuum for the societal and economic benefit of Canadians."* This certainly

makes it seem as though the ultimate goal of NSERC is economic benefit, and that discovery and innovation are two components of how to get there. (Incidentally, that is why I didn't fill in the survey when I first became aware of it: the two questions in the survey presuppose that I am in favour of that vision, which is not the case.)

You encouraged your audience at the beginning of the question period to be blunt, and I will allow myself to be so in this letter. Of the 12,000 researchers with NSERC grants, I strongly suspect that the majority of them would consider themselves wholly interested in discovery and only very slightly interested (if at all) in innovation. It therefore strikes me as unsurprising that NSERC's vision does not resonate with its clients, the researchers. Perhaps this explains, in part, why relatively few researchers have filled in the survey.

I have not yet explained why the terms "discovery" and "innovation" do not resonate with me. I remember being uncomfortable when, more than a decade ago, NSERC's research grants program was renamed "discovery grants". I didn't make much of it at the time, but I always wondered if it was merely a name change or if there was more to it than that. As the word "innovation" crept into the vocabulary of politicians, policy makers and NSERC, I began to wonder if the renaming was not in fact a subtle first step—perhaps taken unconsciously—in a sort of retooling of NSERC from a research funding agency to something else. The more I think about it, the more I agree with this assessment.

I feel that NSERC, and/or the Government, views discovery and innovation as components of research, so naturally they fall under the purview of NSERC. I have a very different view, one that is, I suspect, shared by many, if not most, of your clients. In my view, discovery, rather than being a component of research, IS research, while innovation is a completely different activity, one largely concerned with taking scientific discoveries and other ideas and developing useful products out of them. The researcher studies thermodynamics; the innovator develops the toaster. Thus, innovation is in my mind more a synonym of product development than a component of research.

The "R" in "NSERC", of course, stands for research. If, as I contend, innovation is not research, should NSERC



Richard MacKenzie, P. Phys. (richard.mackenzie@umontreal.ca), Professeur titulaire, Département de physique, Université de Montréal, Montréal, QC H3C 3J7

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therefore get out of the innovation business? I do not necessarily think so, but only for pragmatic reasons: in a hypothetical world with NSERC focusing entirely on (curiosity-driven, pure) research with another Council focusing on innovation, I would fear that research would inevitably suffer at the expense of innovation. This is because most politicians, notwithstanding their verbal support of research/discovery, are more interested in the short-term benefits to the economy implied by innovation than in the long-term benefits to which a solid research foundation would give rise. In addition, given that some

researchers also engage in innovation, I would certainly not wish on them the additional burden of having to write separate grant applications to separate funding agencies for their two activities.

Thus I thank you for supporting discovery, or research, or whatever it is called, and I strongly urge you to continue to do so. However it is hard for me to accept that NSERC truly values research for research's sake when innovation and economic benefits figure so prominently in its vision.

**CAP MEMBER BRIGITTE VACHON
FROM MCGILL UNIVERSITY
SELECTED BY THE WOMEN'S Y
FOUNDATION AS 2015 WOMAN
OF DISTINCTION IN THE SCIENCE
AND TECHNOLOGY CATEGORY**

***BRIGITTE VACHON DE L'UNIVERSITÉ
MCGILL ET MEMBRE DE L'ACP A
ÉTÉ SÉLECTIONNÉE PAR LA FONDATION
DU Y EN TANT FEMME DE MÉRITE
2015 DANS LA CATÉGORIE SCIENCE
ET TECHNOLOGIE***

On May 5, 2015, Anne Mezei, President of the Women's Y Foundation, and Louise Poirier, President of YWCA Montreal, unveiled the winners of the 2015 Women of Distinction Awards. These 13 exceptional women will be officially honoured at a ceremony to be held on September 29 at the Palais des congrès de Montréal.

Among the awardees is CAP member, and member of the CAP Foundation Board of Directors, Brigitte Vachon from McGill University. The award citation can be found in the Community News section of the CAP's website—www.cap.ca.

The Women of Distinction Awards is a celebration of women and their remarkable achievements and contributions to our society. Over the years, these awards have played a vital role in recognizing women's leadership. For 22 years, more than 240 women have received this honour. These inspiring women have, each in their own way and in their own field, opened new doors for women and girls.



Dr. Brigitte Vachon,
McGill University

Le 5 mai 2015, Anne Mezei, présidente de la Fondation du Y des femmes de Montréal et Louise Poirier, présidente du Y des femmes de Montréal, ont dévoilé les noms des lauréates des Prix femmes de mérite 2015. Ces 13 femmes d'exception seront officiellement honorées lors d'une soirée en leur honneur, le 29 septembre prochain au Palais des congrès de Montréal.

Parmi les lauréates, Brigitte Vachon de l'Université McGill, membre de l'ACP et membre du conseil d'administration de la Fondation de l'ACP. La référence à l'annonce de ce prix est affichée dans la section Nouvelles de la communauté sur le site web de l'ACP—www.cap.ca.

Les Prix femmes de mérite représentent une célébration des femmes et de leurs remarquables accomplissements et contribution à notre société. Au fil du temps, ces prix sont devenus des incontournables dans la reconnaissance du leadership au féminin. Depuis 22 ans, plus de 240 femmes ont reçu cet honneur; des femmes inspirantes qui ont su, chacune à leur façon et dans leur domaine, ouvrir des voies pour les filles et les femmes.

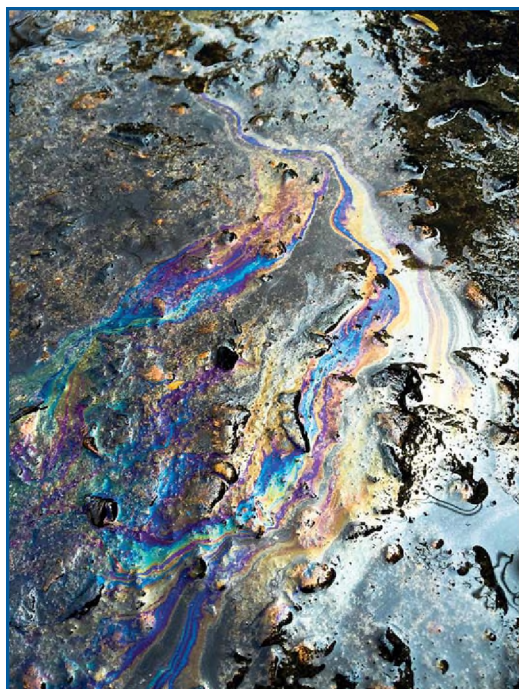
2015 ART OF PHYSICS COMPETITION

CONCOURS L'ART DE LA PHYSIQUE 2015

The Canadian Association of Physicists launched the first Art of Physics Competition at their 1992 Annual Congress in Windsor, Ontario. The aim of the competition is to stimulate interest, especially among non-scientists, in some of the captivating imagery associated with physics. The challenge is to capture photographically a beautiful or unusual physics phenomenon and explain it in less than 200 words in terms that everyone can understand. The winning entries, plus some selected entries from previous years, will be displayed annually at the CAP Congress.

To celebrate the 2015 International Year of Light (IYL2015), a special themed category was added to this year's competition.

RESULTS OF THE 2015 COMPETITION



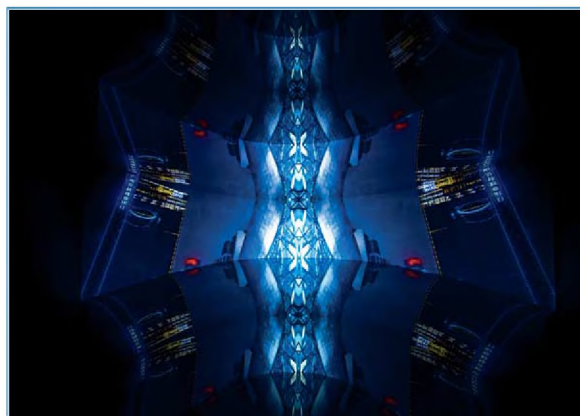
"Gas, Water, and Light" by Davis Jian Kun Zhu,
St. George's School, Vancouver, British Columbia

1st prize, High School/CÉGEP Individual Category /
1^{er} prix, Catégorie projet individuel au niveau
secondaire ou CÉGEP.

L'Association canadienne des physiciens et physiciennes a lancé son premier concours, l'Art de la physique, lors de son congrès annuel de 1992, à Windsor, Ontario. Ce concours cherche à intéresser les gens, spécialement les profanes, à la fascinante imagerie de la physique. Le défi est de photographier un phénomène physique époustouflant, ou particulier, et de rédiger un court texte explicatif, de moins de deux cents mots, en termes très simples, à la portée de tous. Les soumissions gagnantes, et quelques soumissions des années passées, seront exposées au congrès annuel de l'ACP.

Pour célébrer l'année internationale de la lumière 2015 (IYL2015), une catégorie à thème spécial a été ajoutée au concours cette année.

RÉSULTATS DU CONCOURS 2015



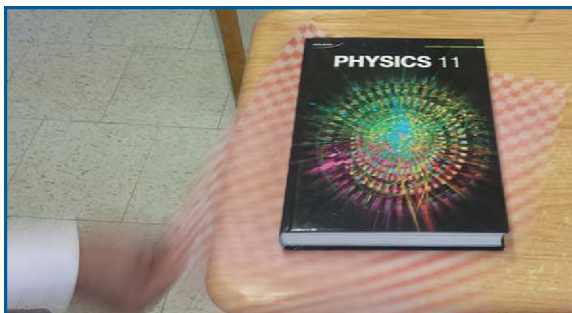
"Spaces and Dimensions" by Davis Jian Kun Zhu,
St. George's School, Vancouver, British Columbia

2nd prize, High School/CÉGEP Individual Category /
2^e prix, Catégorie projet individuel au niveau
secondaire ou CÉGEP.



“Spring Melt Icicles” by Muhammed Kurkcü, Nile Academy, Toronto, Ontario

3rd prize, High School/CÉGEP Individual Category /
3^{pr} prix, Catégorie projet individuel au niveau secondaire
ou CÉGEP.



“Inertia in real life” by Muhammed Emin Yilmaz, Nile Academy, Toronto, Ontario

Honourable Mention, High School/CÉGEP Individual
Category / *Mention honorable, Catégorie projet indivi-
duel au niveau secondaire ou CÉGEP.*



“Upside down, smaller and real image in the same scene”, by Ibrahim Berkay Sahin and Mesut Yanikgonul, Nile Academy, Toronto, Ontario

1st Prize, High School/CÉGEP Class Project Category / 1^{er} prix, catégorie projets scolaires au niveau secondaire ou CÉGEP.



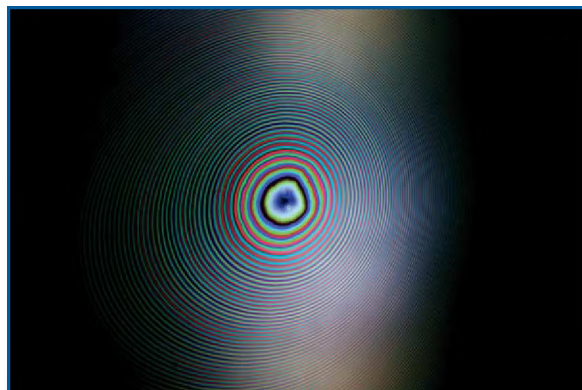
"Tout est dans le centre de la masse" by Amélie Drouin, Cité-des-Jeunes, Vaudreuil-Dorion, Québec

2nd Prize, High School/CÉGEP Class Project Category /
2^e prix, catégorie projets scolaires au niveau secondaire
ou CÉGEP.



"Aile de drosophile" by Richard Germain, Pointe-des-Cascades, Québec

1st Prize, Open Category / 1^{er} prix, Catégorie Ouvert à tous.



"Anneaux de Newton" by Richard Germain, Pointe-des-Cascades, Québec

Honourable mention, Open Category / Mention honorable,
Catégorie Ouvert à tous.



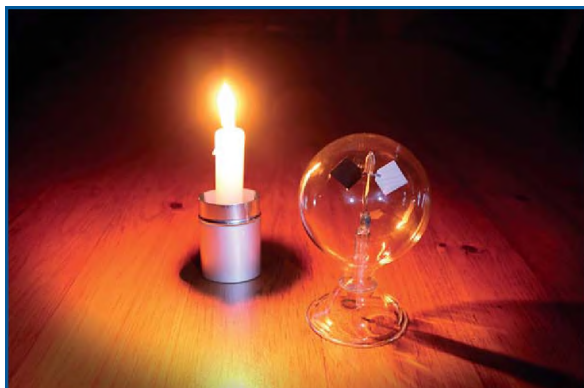
"Que la lumière s' Watt" by Richard Germain, Pointe-des-Cascades, Québec

1st Prize, IYL2015 Category / 1^{er} prix, catégorie IYL2015.



"Reflection in Glass" by Jonathan Lew, Burnaby, British Columbia

2nd Prize, IYL2015 Category / 2^e prix, catégorie IYL2015.



"Radiomètre de Crookes" by Richard Germain, Pointe-des-Cascades, Québec

Honourable mention, IYL2015 Category / Mention honorable, catégorie IYL2015.

Visit <http://www.cap.ca/aop/art.html> to read the accompanying description of each picture.
Visitez le <http://www.cap.ca/aop/art.html> pour lire la description qui accompagne chacune des photos.

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Books may be requested from the Book Review Editor, Richard Marchand, by using the online book request form at <http://www.cap.ca>.

CAP members are given the first opportunity to request books. For non-members, only those residing in Canada may request a book. Requests from non-members will only be considered one month after the distribution date of the issue of *Physics in Canada* in which the book was published as being available.

The Book Review Editor reserves the right to limit the number of books provided to reviewers each year. He also reserves the right to modify any submitted review for style and clarity. When rewording is required, the Book Review Editor will endeavour to preserve the intended meaning and, in so doing, may find it necessary to consult the reviewer. Reviewers submit a 300–500 word review for publication in PiC and posting on the website; however, they can choose to submit a longer review for the website together with the shorter one for PiC.

LA POLITIQUE POUR LA CRITIQUE DE LIVRES

Si vous voulez faire l'évaluation critique d'un ouvrage, veuillez entrer en contact avec le responsable de la critique de livres, Richard Marchand, en utilisant le formulaire de demande électronique à <http://www.cap.ca>.

Les membres de l'ACP auront priorité pour les demandes de livres. Ceux qui ne sont pas membres et qui résident au Canada peuvent faire une demande de livres. Les demandes des non-membres ne seront examinées qu'un mois après la date de distribution du numéro de la Physique au Canada dans lequel le livre aura été déclaré disponible.

Le Directeur de la critique de livres se réserve le droit de limiter le nombre de livres confiés chaque année aux examinateurs. Il se réserve, en outre, le droit de modifier toute critique présentée afin d'en améliorer le style et la clarté. S'il lui faut reformuler une critique, il s'efforcera de conserver le sens voulu par l'auteur de la critique et, à cette fin, il pourra juger nécessaire de le consulter. Les critiques pour publication dans la PaC doivent être de 300 à 500 mots. Ces critiques seront aussi affichées sur le web ; s'ils le désirent les examinateurs peuvent soumettre une plus longue version pour le web.

BOOKS RECEIVED / LIVRES REÇUS

The following titles are a sampling of books that have recently been received for review. Readers are invited to write reviews, in English or French, of books of interest to them. Unless otherwise indicated, all prices are in Canadian dollars.

A list of all books available for review, books out for review and book reviews published since 2000 are available on-line at www.cap.ca (Publications).

In addition to books listed here, readers are invited to consider writing reviews of recent publications, or comparative reviews on books in topics of interest to the physics community. This could include for example, books used for teaching and learning physics, or technical references aimed at professional researchers.

Les titres suivants sont une sélection des livres reçus récemment aux fins de critique. Nous invitons nos lecteurs à nous soumettre une critique en anglais ou en français, sur les sujets de leur choix. Sauf indication contraire, tous les prix sont en dollars canadiens.

La liste de tous les livres disponibles pour critique, ceux en voie de révision, ainsi que des critiques publiées depuis 2000 sont disponible sur : www.cap.ca (Publications).

En plus des titres mentionnés ci-dessous, les lecteurs sont invités à soumettre des revues sur des ouvrages récents, ou des revues thématiques comparées sur des sujets particuliers. Celles-ci pourraient par exemple porter sur des ouvrages de nature pédagogique, ou des textes de références destinés à des professionnels.

GENERAL INTEREST

LECTURES ON PARTICLE PHYSICS, ASTROPHYSICS AND COSMOLOGY, Edited by Merino, Carlos, Springer, 2014; pp. 480; ISBN: 978-3319122373; Price: 192.93.

NUCLEAR RADIATION INTERACTIONS, Sidney Yip, World Scientific Publishing, 2015; pp. 350; ISBN: 9789814368070; Price: 69.82.

PARTICLE ACCELERATORS: FROM BIG BANG PHYSICS TO HADRON, Amaldi, Ugo, Springer, 2014; pp. 284; ISBN: 978-3319088693; Price: 39.94.

SCIENCE AND HUMAN EXPERIENCE VALUES, CULTURE, AND THE MIND, Leon N. Cooper, Cambridge University Press, 2014; pp. 256; ISBN: 9781107043176; Price: 16.07.

STOCHASTIC DYNAMICS AND IRREVERSIBILITY, Tomé, Tânia, Oliveira, Mário J., Springer, 2014; pp. 394; ISBN: 978-3319117690; Price: 91.32.

THE COSMIC MICROWAVE BACKGROUND, Evans, Rhodri, Springer, 2014; pp. 204; ISBN: 978-3319099279; Price: 39.94.

THE QUANTUM DISSIDENTS, Freire Junior, Olival, Springer, 2015; pp. 356; ISBN: 978-3662446614; Price: 113.02.

THE TWIN SISTER PLANETS VENUS AND EARTH: WHY ARE THEY SO DIFFERENT? Malcuit, Robert J., Springer, 2014; pp. 401; ISBN: 978-3319113876; Price: 147.27.

UNLOCKING THE SECRETS OF WHITE DWARF STARS, Hugh Van Horn, Springer, 2014; pp. 324; ISBN: 978-3319093680; Price: 34.24.

VIEWING AND IMAGING THE SOLAR SYSTEM, Clark, Jane, Springer, 2015; pp. 256; ISBN: 978-1-4614-5178-5; Price: 34.99.

UNDERGRADUATE TEXTS

AN INTRODUCTION TO PRACTICAL LABORATORY OPTICS, J.F. James, Cambridge University Press, 2014; pp. 196; ISBN: 9781107687936; Price: 36.95.

LASERS WITH NUCLEAR PUMPING, Melnikov, S.P.; Sinyanskii, A.A.; Sizov, A.N.; Miley, George H., Springer, 2014; pp. 455; ISBN: 978-3319088815; Price: 204.35.

PHYSICS OF THE PLASMA UNIVERSE [v], Peratt, Anthony L., Springer, 2015; pp. 406; ISBN: 978-1-4614-7819-5; Price: 139.00.

QUANTUM FIELD THEORY FOR THE GIFTED AMATEUR, Tom Lancaster and Stephen J. Blundell, Oxford University press, 2014; pp. 512; ISBN: 9780199699322; Price: 195.00.

QUANTUM THEORY: A MATHEMATICAL APPROACH, Bongaarts, Peter, Springer, 2014; pp. 445; ISBN: 978-3319095608; Price: 102.73.

QU'EST-CE QUE LE BOSON DE HIGGS MANGE EN HIVER, Pauline Gagnon, Éditions Multimondes Inc., 2015; pp. 200; ISBN: 978-2895444909; Price: 26.96.

SYMMETRY AND PHYSICAL PROPERTIES OF CRYSTALS, Malgrange, Cécile; Ricolleau, Christian; Schlenker, Michel, Springer, 2014; pp. 522; ISBN: 978-9401789929; Price: 136.98.

GRADUATE TEXTS AND PROCEEDINGS

ACTIVE CONTROL OF MAGNETO-HYDRODYNAMIC INSTABILITIES IN HOT PLASMAS, Edited by Iguchine, Valentin, Springer, 2015; pp. 342; ISBN: 978-3-662-44222-7; Price: 139.00.

AMORPHOUS SEMICONDUCTORS, Sándor Kugler, Koichi Shimakawa, Cambridge University Press, 2015; pp. 160; ISBN: 978-1107019348; Price: 109.95.

ASTEROSEISMOLOGY OF STELLAR POPULATIONS IN THE MILKY WAY, Edited by Miglio, Andrea; Eggenberger, Patrick; Girardi, Léo; Montalbán, Josefina, Springer, 2015; pp. 185; ISBN: 978-3319109923; Price: 227.18.

ELECTRICITY AND MAGNETISM FOR MATHEMATICIANS: A GUIDED PATH FROM MAXWELL'S EQUATIONS TO YANG-MILLS (2ND COPY), Thomas A. Garrity, Cambridge University Press, 2015; pp. 304; ISBN: 9781107435162; Price: 35.96.

FAST SPECTRAL VARIABILITY IN THE X-RAY EMISSION OF ACCRETING BLACK HOLES [v], Skipper, Chris, Springer, 2015; pp. 150; ISBN: 978-3-319-09587-5; Price: 99.00.

MAKING STARSHIPS AND STARGATES, Woodward, James F., Springer, 2012; pp. 279; ISBN: 978-1-4614-5623-0; Price: 51.31.

MANY-BODY APPROACH TO ELECTRONIC EXCITATIONS, Bechstedt, Friedhelm, Springer, 2014; pp. 584; ISBN: 978-3662445921; Price: 261.43.

MERCURY'S INTERIOR, SURFACE, AND SURROUNDING ENVIRONMENT: LATEST DISCOVERIES, Pamela Elizabeth Clark, Springer, 2015; pp. 99; ISBN: 978-1493922437; Price: 49.53.

NON-PERTURBATIVE DESCRIPTION OF QUANTUM SYSTEMS, Feranchuk, Ilya; Ivanov, Alexey; Le, Van-Hoang; Ulyanenko, Alexander, Springer, 2014; pp. 362; ISBN: 978-3319130057; Price: 102.73.

ORGANIC-INORGANIC HYBRID NANOMATERIALS, Edited by Kalia, Susheel; Haldorai, Yuvaraj, Springer, 2014; pp. 385; ISBN: 978-3319135922; Price: 295.67.

PATH INTEGRALS AND HAMILTONIANS PRINCIPLES AND METHODS, Belal E. Baaquie, Cambridge University Press, 2014; pp. 433; ISBN: 9781107009790; Price: 125.95.

PHASE TRANSITIONS IN MATERIALS, Brent Fultz, Cambridge University Press, 2014; pp. 583; ISBN: 9781107067240; Price: 94.95.

PHYSICS OF SEMICONDUCTOR DEVICES, Massimo Rudan, Springer, 2014; pp. 649; ISBN: 978-1493911509; Price: 113.02.

PRACTICAL SEISMIC DATA ANALYSIS, Hua-Wei Zhou, Cambridge University Press, 2014; pp. 496; ISBN: 9780521199100; Price: 78.95.

PRINCIPLES OF DISCRETE TIME MECHANICS, George Jaroszkiewicz, Cambridge University Press, 2014; pp. 360; ISBN: 9781107034297; Price: 136.55.

PROGRESS IN NONLINEAR NANO-OPTICS, Edited by Sakabe, Shuji; Lienau, Christoph; Grunwald, Rüdiger, Springer, 2015; pp. 273; ISBN: 978-3319122168; Price: 147.27.

PROTEIN FOLDING, Dwevedi, Alka, Springer, 2015; pp. 110; ISBN: 978-3319008813; Price: 79.85.

RAY TRACING AND BEYOND: PHASE SPACE METHODS IN PLASMA WAVE THEORY, E.R. Tracy, A.J. Brizard, A.S. Richardson, A.N. Kaufman., Cambridge University Press, 2014; pp. 541; ISBN: 9780521768061; Price: 120.95.

SEA-LEVEL SCIENCE UNDERSTANDING TIDES, SURGES, TSUNAMIS AND MEAN SEA-LEVEL CHANGES, David Pugh, Philip Woodworth, Cambridge University Press, 2014; pp. 407; ISBN: 9781107028197; Price: 103.95.

SEISMIC AMPLITUDE: AN INTERPRETER'S HANDBOOK, Rob Simm, Mike Bacon, Cambridge University Press, 2014; pp. 279; ISBN: 9781107011502; Price: 83.95.

SEISMIC REFLECTIONS OF ROCK PROPERTIES, Jack Dvorkin, Mario A. Gutierrez, Dario Grana, Cambridge University Press, 2014; pp. 338; ISBN: 9780521899192; Price: 78.95.

SOURCE MECHANISMS OF EARTHQUAKES THEORY AND PRACTICE, Agustín Udías, Raúl Madariaga, Elisa Buforn, Cambridge University Press, 2014; pp. 311; ISBN: 9781107040274; Price: 78.95.

THE BETHE WAVEFUNCTION, Michel Gaudin. Translator: Jean-Sébastien Caux, Cambridge University Press, 2014; pp. 360; ISBN: 9781107045859; Price: 115.95.

THE PHYSICS OF ACCRETION ONTO BLACK HOLES, Maurizio Falanga and Tomaso Belloni, Springer, 2014; pp. 492; ISBN: 978-1493922260; Price: 204.35.

THE QUANTUM THEORY OF NONLINEAR OPTICS, Peter D. Drummond, Cambridge University Press, 2014; pp. 380; ISBN: 978-1-107-00421-4; Price: 83.95.

THE TIDAL DISRUPTION OF STARS BY SUPERMASSIVE BLACK HOLES, Stone, Nicholas Chamberlain, Springer, 2014; pp. 154; ISBN: 978-3319126753; Price: 147.27.

THEORY OF INELASTIC SCATTERING AND ABSORPTION OF X-RAYS, Michel van Veenendaal, Cambridge University Press, 2015; pp. 237; ISBN: 9781107033559; Price: 99.95.

XUV PUMP-PROBE EXPERIMENTS ON DIATOMIC MOLECULES, Schnorr, Kirsten, Springer, 2015; pp. 191; ISBN: 978-3319121383; Price: 147.27.

BOOK REVIEW / CRITIQUE DE LIVRE

Book reviews for the following books have been received and posted to the Physics in Canada section of the CAP's website: <http://www.cap.ca>. When available, the url to longer versions are listed with the book details.

Des revues critiques ont été reçues pour les livres suivants et ont été affichées dans la section "La Physique au Canada" de la page web de l'ACP: <http://www.cap.ca>. Quand disponible, un lien url à une critique plus longue est indiqué avec les détails du livre.

ELECTRICITY AND MAGNETISM, 3RD ED., by Edward M. Purcell and David J. Morin, Cambridge University Press (2013), pp: 839, ISBN 9781107014022, Price 93.95.

Ce livre est utilisé dans plusieurs universités depuis environ 50 ans afin d'introduire l'électricité et le magnétisme auprès des étudiants au baccalauréat. L'auteur du livre d'origine, Edward M. Purcell, était un physicien renommé qui a entre autres reçu le prix Nobel de physique en 1952 pour sa découverte de la résonance magnétique nucléaire dans les solides et les liquides. La troisième édition a été habilement mise à jour par David Morin, un instructeur au département de physique de Harvard University. En plus de l'ajout d'exemples, la modification la plus intéressante est sans doute l'utilisation des unités du système international (SI). Avant d'entamer la lecture de ce livre, je crois qu'il est nécessaire que les étudiants aient des bases mathématiques solides, notamment en calcul différentiel et intégral et en analyse vectorielle. Au fil de la lecture, certaines sections très succinctes résument tout de même certains concepts essentiels comme le gradient, la divergence et le rotationnel.

Le livre se divise en 12 chapitres couvrant les sujets suivants typiques de tout cours d'introduction à l'électricité et au magnétisme de niveau universitaire: électrostatique, potentiel électrique, champ électrique autour des conducteurs, courant électrique, champs créés par des charges en mouvement, champ magnétique, induction électromagnétique, circuits à courant alternatif, équations de Maxwell et ondes électromagnétiques, champ électrique dans la matière, champ magnétique dans la matière et, enfin, un chapitre complet avec les solutions des problèmes. Chaque chapitre débute avec un paragraphe d'introduction qui donne une vue d'ensemble du chapitre. Plusieurs sections portent ensuite sur les différentes notions du chapitre et des images bien choisies aident à la compréhension. Les éléments importants sont également encadrés de façon à attirer l'attention. Quelques exemples de problèmes résolus dans ces sections permettent de comprendre comment utiliser les formules, mais ils sont tout de même peu nombreux. Ceci est cependant largement compensé par les nombreux problèmes à la fin des chapitres dont les solutions sont données au douzième chapitre. Enfin, chaque chapitre se termine par des

exemples intéressants d'applications provenant de la vie de tous les jours, un résumé du chapitre et des exercices supplémentaires.

Le livre est complété par 11 annexes donnant des informations complémentaires concernant entre autres la conversion d'unités, les coordonnées, la relativité restreinte, le rayonnement d'une charge accélérée, la supraconductivité, la résonance magnétique et certaines formules utiles. On retrouve également deux pages de références qui permettent d'approfondir certains sujets. Enfin, un index permet de se retrouver facilement dans le livre.

En résumé, il s'agit d'une très bonne ressource pour un cours d'électricité et du magnétisme de niveau universitaire. Ce livre était déjà utilisé dans plusieurs universités et cette troisième édition saura plaire entre autres avec davantage de problèmes et l'utilisation du système international d'unités.

Léo Barriault
Professeur de physique, niveau CÉGEP

The Editorial Board welcomes articles from readers suitable for, and understandable to, any practising or student physicist. Review papers and contributions of general interest of up to four journal pages in length are particularly welcome. Suggestions for theme topics and guest editors are also welcome and should be sent to bjoos@uottawa.ca.

Le comité de rédaction invite les lecteurs à soumettre des articles qui intéresseraient et seraient compris par tout physicien, ou physicienne, et étudiant ou étudiante en physique. Les articles de synthèse d'une longueur d'au plus quatre pages de revue sont en particulier bienvenus. Des suggestions de sujets pour des revues à thème sont aussi bienvenues et pourront être envoyées à bjoos@uottawa.ca.



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No.2 Applied Magnetism /
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