Teaching and Learning Astronomy

John R. Percy

Department of Astronomy and Astrophysics, and Ontario Institute for Studies in Education, University of Toronto, Toronto ON, Canada M5S 3H4

Abstract. I review the teaching and learning of astronomy, in elementary and secondary school, colleges and universities, and for the public through astronomy outreach and communication. I describe International Year of Astronomy 2009, and some of the national and personal projects in which I am involved.

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INTRODUCTION

Astronomy education is often neglected, relative to astronomy research, especially in research-intensive universities and research institutes. But astronomy education is absolutely *essential* to the health of the astronomical profession. It helps to attract students to physical sciences and technology, and there is a declining interest in the physical sciences in many countries – in part, because of the way that they are taught. Astronomy education directly impacts the quality of the school and university education that future astronomers receive.

Equally important: it affects public awareness, understanding, appreciation, and support of astronomy – and of science in general. Scientists have an *obligation* to communicate and explain their work to the taxpayers who support their salary and their research. And astronomy education, outreach, and communication are enjoyable to do, and much appreciated by people of all ages.

Furthermore: even if professional astronomy did not exist, astronomy deserves a secure place in both school and public education, as a result of its scientific, technological, historical, philosophical, and cultural importance. It permeates the culture of almost every society. Its practical applications are so basic that they are often forgotten. It has contributed to the advancement of mathematics, computation, and technology. It is a forefront science. It reveals our cosmic roots, and our place in time and space, and shows us a universe that is vast, varied, beautiful, and inspiring. It has many positive applications to education, especially through its interdisciplinary connections. Because of its intrinsic interest, it attracts young people to science and technology. It is an enjoyable hobby for millions of people. For a comprehensive list of reasons why astronomy is “useful", and should be part of the educational curriculum, see [20].

Two recent conference proceedings give a comprehensive overview of astronomy education: [19, 16].

ASTRONOMY EDUCATION RESEARCH

Astronomy research is subject to a rigorous process called *the scientific method*. Scientific information and theories are only as good as the evidence that supports them. Astronomy education should be subject to equally rigorous standards. Methods of teaching are only as good as their *demonstrated* effectiveness.

Effectiveness can be judged through formal educational research. Unfortunately, educational research tends to be carried out by specialists who inhabit their own world, and it is published in specialized journals that very few astronomers read. We must therefore depend on information that is published in secondary sources such as books, conference proceedings, or review articles.

Each of us can also perform informal educational research through a simple process called *action research*, or simply through critical *reflection*. This should include some form of *assessment* of our teaching, which includes both evaluation and improvement. Action research is an informal but systematic way to carry out practical research of any kind. There are numerous websites that explain the nature, history, and use of action research; just do an Internet search on that term.

Education Basics

At the very least, astronomy educators should know the basic concepts of education as a discipline. There is a general strategy for approaching any education, outreach, or communication activity. It goes by various names, but I use a version from Hodson [8]. One starts by establishing *objectives and goals* for the activity. Is it to educate? To inspire? To entertain? One then chooses an appropriate *curriculum*, considering the audience's level and needs. Especially in formal education, the curriculum includes not just knowledge, but skills, applications, and attitudes. It would be unfortunate, for instance, to teach the factual aspects of a topic, without indicating why it is relevant and interesting. Having chosen the curriculum, one must then choose and use *effective methods of teaching*. Lecturing is not usually an effective method, except perhaps for a mature, interested audience. Finally, one must *assess* every stage of the process, and use the results not only to evaluate the students (in a formal education setting) but also to *improve* or modify the objectives, curriculum, teaching and assessment methods. *Formative assessment* is done during the education activity; *summative assessment* is done at the end. There are obvious advantages to formative assessment; its results can be used immediately to improve the effectiveness of the activity as it is being done.

The usual objective of an education activity is learning – though remember the importance of inspiring the audience as well. Learning occurs at various levels or depths; this is often expressed in terms of Bloom's Taxonomy ([1]). Slater and Adams [30] have given examples of how Bloom's Taxonomy might apply to the teaching of introductory astronomy to non-science majors in university. The levels of understanding, from lowest to highest, are: (i) knowledge; (ii) comprehension; (iii) application; (iv) analysis; (v) synthesis; (vi) evaluation. An alternative to Bloom's Taxonomy is the SOLO Taxonomy, which is based heavily on understanding the connections between different pieces of knowledge.

Generally, too much teaching is done and evaluated at the lower levels of understanding, especially as it is easier to design multiple choice questions to test these levels. But it is possible to devise questions, even multiple choice questions, to test the higher levels. And we should always be preparing our students to function at these levels i.e. to be critical thinkers.

Theories of Science Education

For many years, the dominant theory of science education has been *constructivism*: people build new knowledge on concepts and information that they already have. Some of those concepts may be incorrect, and teachers must know that in order to teach effectively. For instance, most people believe that seasonal changes in temperature are due to the changing distance of the earth from the sun, and that astronauts feel “weightless" because there is no gravity in space. Constructivism builds on the work of Jean Piaget and, more recently, Jerome Bruner. Social factors are also important in education, as expressed through Lev Vygotsky’s Social Development Theory. And students have “multiple intelligences", a concept promoted by the work of Howard Gardner; they learn through many senses, not just by listening and reading.

Recent brain research has led to new insights in how students learn effectively; this is referred to as *neuroscience-based education*. Alanna Mitchell, in an excellent series of articles in the *Toronto Star* newspaper, 31 October to 7 November, 2009, listed the following factors that promote neural connections: learning by doing; physical movement; using more than one sense to learn; having fun learning; being emotionally calm and open to learning; building on information already present (constructivism); discerning patterns; taking some risk, but not too much; having a positive connection with the teacher; knowing why you are learning. The following factors block neural connections: hunger, stress, fear, boredom, or tiredness; facts that do not connect with anything else; being told that there is only one way to learn; believing that you are born with a fixed level of intelligence (and therefore having no motivation to try harder); believing that boys and girls are good at some things, but not others (likewise).

Astronomy Education Review

One way to facilitate better astronomy education is to make information readily available. There are many useful articles on the subject, but they are published in a wide range of journals, magazines, and websites, many of them not available to or used by astronomy educators.

The concept of a dedicated astronomy education journal was developed in the 1990’s and, in 2001, the American Astronomical Society and the Astronomical Society of the Pacific launched *Astronomy Education Review*, a free on-line journal ([34]). The editors, and driving forces behind the project were Andrew Fraknoi and Sidney Wolff. Wolff arranged for her institution (NOAO) to host the journal. The operation of the journal has recently been transferred to the American Astronomical Society, and to its publisher, the American Institute of Physics. The website is aer.aip.org. *AER* includes both refereed papers on astronomy education research, and more general articles and notes. Articles on astronomy education are still published elsewhere, but Fraknoi collects and publishes an annual list of such articles, in *AER*, at least those in the English language.

The Astronomy Education Research Charter

The Astronomy Education Research Charter is a document, still under development, to encourage astronomy educators and their institutions to develop (through research) and use “best practices" in education and outreach i.e. to heighten the prominence, effectiveness, and application of astronomy education research within the astronomical community. It was patterned after two other Charters: the Baltimore Charter, which addresses the need for gender equity in astronomy, and the Washington Charter, which deals with astronomers’ obligations to communicate their work to the public.

Development of the Charter was begun at a one-day meeting of astronomy educators at Tufts University in Boston ([27]), and continued on-line using a wiki process; the current version is given by [28]. The challenge, now, is to implement these recommendations.

ASTRONOMY EDUCATION IN SCHOOLS

Astronomy education in the schools is dictated by the curriculum, which may be determined nationally, provincially, or locally. Whether astronomy is included in the curriculum depends on whether the education authorities believe that it is useful or relevant. It is important for astronomers to communicate the relevance of astronomy to ministries of education. Elsewhere ([20]), I have published a long list of reasons why astronomy is “useful", and should be included in the curriculum. Even if astronomy is in the curriculum, teachers may not teach it, because they have little or no background in astronomy, or astronomy teaching. They deserve our support. And students may not learn the astronomy that is taught to them.

In my province of Ontario, the revised secondary school science curriculum has been revised for 2009 [14]. The curriculum emphasizes science skills and “habits of mind", science careers, and the STSE nature of science – science, technology, society, and environment. Each topic in the curriculum begins with its societal applications and relevance.

The curriculum is contained in a comprehensive document that outlines not only the content – knowledge, skills, and applications – but also essential topics such as safety, special-needs students, environmental education, careers, literacy and numeracy. I believe that my highest-impact contribution to astronomy in Ontario’s schools is through my input to the curriculum; the Ministry of Education consults me during the curriculum development process, and asks me to review a semi-final draft of the document. My other high-impact contribution is in reviewing textbooks, since these are used by hundreds of thousands of students. They are also an essential tool for teachers who have little background in the subject.

Elementary School

In Ontario, some basic concepts of astronomy, such as cycles in nature, are taught in grade one (age 6), but the main “dose" of astronomy occurs in grade six (age 11), where one-fifth of the science curriculum is devoted to astronomy and space – at least in theory. But most teachers of grade six are generalists; they teach most or all subjects in the curriculum. Very few have a strong background in science, or science teaching. Both students and teachers may have deep-seated misconceptions about astronomy and physics, and may have the same pseudoscientific beliefs as the general public has – astrology, space aliens, creationism etc. These have been discussed by Narlikar [15] and Percy and Pasachoff [17]. Actually: if teachers are aware that they have such misconceptions, they may be able to teach more effectively! In astronomy, there is also an (apparent) shortage of hands-on activities (“the stars come out at night, the students don’t"), though organizations such as the Astronomical Society of the Pacific have large numbers of well-tested activities on their websites. There are also “minds-on" activities; and students also can observe and analyze astronomical *images*, as astronomy researchers do.

Another challenge in countries such as mine is reaching populations which are traditionally under-represented in science – inner-city youth, Aboriginal youth, and girls, who tend not to be attracted to the mathematical and physical sciences.

Secondary School

Many of the challenges in teaching astronomy at this level are the same as for elementary school: astronomy may not be part of the curriculum; if it is, the content may be inappropriate or boring; teachers have little or no background in astronomy, or astronomy teaching; they may teach little or none of the material in the astronomy section of the curriculum – especially as the curriculum, and teachers’ other duties, are increasingly over-loaded. In Ontario, most teachers of grade nine are not Physical Science specialists. The topics that they find most challenging, and for which they request most support, are: astronomy, optics, and climate change.

Practical activities continue to be a challenge, though there is an increasing number of on-line activities, data, images, and remote telescopes. But this kind of technology is effective only when it is curriculum-connected, and supported by teacher professional development ([13]). Otherwise, it may be perceived as nothing more than an elaborate video game.

Student interest in astronomical topics is very high, but the topics of greatest interest – black holes, extra-terrestrial life, space exploration, and cosmology ([9]) – may not be in the curriculum.

Education of Teachers

Given that few teachers have any background in astronomy, or astronomy teaching, pre-service and in-service training is essential ([7, 5]). But astronomy must compete with all the other topics that teachers must learn about. Each year, I give a two-hour workshop to pre-service science teachers at the Faculty of Education at the University of Toronto. Links between astronomers and faculties of education, however, are very rare in North America.

I also give numerous workshops and presentations to in-service teachers, especially through the Science Teachers Association of Ontario (www.stao.org), a strong and effective organization that is one of my favourite partners, but these workshops are attended only by teachers who are interested. Even workshops that are offered through school boards on professional development days may not reach the teachers who really need them.

ASTRONOMY EDUCATION IN COLLEGES AND UNIVERSITIES

In North America, post-secondary institutions are divided into colleges and universities. Colleges generally specialize in undergraduate education (“liberal arts colleges"), or vocational education (“community colleges"). Universities are generally more research-active, though many liberal arts colleges excel at undergraduate research. I will refer to post-secondary institutions generically as “universities" here, but will keep the differences between colleges and universities in mind.

Especially in research-intensive universities, a major challenge is achieving a balance between teaching and research. Research generally receives more financial and infrastructure support, and is given higher weight in the hiring and promotion of faculty.

The Boyer Report (*Reinventing Undergraduate Education*, [3]) made a strong case for strengthening undergraduate teaching, especially by linking teaching and research, and it is beginning to have an impact. Now, the most important concept in undergraduate education is *engagement*. Systematic surveys of student engagement are being carried out, especially the National Survey of Student Engagement (nsse.iub.edu). Most research-intensive universities, including my own, are achieving low but improving scores on this survey. Mass media, such as *Maclean’s* magazine, and *The Globe and Mail* newspaper in Canada, also “rate" universities, but their methodology is not rigorous.

Engagement, in one sense, refers to students’ degree of satisfaction with their academic and non-academic experience in university. In a pedagogical sense, it refers to the state of students’ minds as they participate in lectures, labs, tutorials, and assignments. In lectures, especially large ones, are their minds actively focussed on the topic at hand, or are they just making notes for later memorization and regurgitation? Do assignments test higher levels of Bloom’s Taxonomy? Are the students simply copying their assignments from other students, or buying their essays from a local “editing service", or on-line?

And who is to blame for the low level of engagement, especially in research-intensive universities? It’s true that many students enter university with weak academic skills and attitudes. Especially in the last decade, universities in North America have witnessed “the millennium generation" – a generation of students who have been looked after by family, school, and community, and have not developed the motivation and independence to succeed in university. Large class sizes are a problem, especially in first year. Students are accustomed to a school setting, where they are in classes of approximately 30, and where they have regular interaction with their teachers. But a major cause is the fact that *university instructors and teaching assistants receive little or no training in teaching or other aspects of pedagogy*. This is to be compared with their many *years* of training in research. So the situation is the reverse of that in the schools, where teachers are well trained in pedagogy, but not necessarily in content knowledge.

Astronomy Education for Non-Science Students

In North America, about 250,000 non-science students take introductory astronomy courses each year; they are the “bread and butter" for astronomy departments across the continent. As a result, there is a rich assortment of good resources to support instructors: a variety of textbooks with good ancillaries; and websites, workshops, and conferences organized by societies such as the American Astronomical Society, and the Astronomical Society of the Pacific. Slater and Adams’ book [30] is a brief but excellent guide to teaching the so-called “Astronomy 101" course.

Nevertheless, the teaching of Astronomy 101 is not usually done well. In many smaller universities and colleges, this may be because it is taught by non-astronomers, but the main problem is the usual one: instructors and teaching assistants have received little or no training in pedagogy. Slater and Adams’ book [30] is an excellent starting point, and a recent article on “Teaching and learning astronomy in the 21st century" ([26]) should be read by every Astronomy 101 instructor and teaching assistant. This national study shows that “interactive learning strategies can significantly improve student understanding of core concepts in astrophysics", but they also caution that “the quality of implementation is crucial; professional development must be provided, and encouraged".

Non-science students may also have deeply-rooted misconceptions about astronomical and physical topics but, as Tobias [32] has argued, “they’re not dumb, they’re different". Their content knowledge may be less accurate, but they may also have different – but equally legitimate – needs. They are interested in the relevance of science to technology, society, and the environment, not just in isolated facts and theories. It is often difficult for astronomers, when teaching Astronomy 101 students, to realize and accept that the students are quite different than they are.

A technology that can improve student interaction and engagement is the “clicker" or personal response device ([4]). This provides useful and immediate feedback to both student and instructor. Clickers can be integrated with the general concepts of peer instruction ([6]), even in large classes. In my university, Astronomy 101 classes are as large as a thousand students. Clickers can also track individual students’ learning, (and keep attendance). But like any technology, they must be used with careful thought and reflection. And we must remember that, especially with non-science students, we must leave them with a positive impression of the value of science and the wonder of the universe, not just with a correct understanding of concepts.

Astronomy Education for Science Students

All of the general challenges apply: science students may have deficient academic skills and attitudes, especially in first year. My colleagues in physics and chemistry report that students arrive in those courses, in first year, lacking especially math skills. Misconceptions about fundamental topics such as light and gravity may be less prevalent than among non-science students, but science students may still believe in pseuduscientific topics such as astrology, space aliens, and creationism.

Strangely enough: at the university level, there is no equivalent to the comprehensive secondary-school curriculum document, with advice on how to develop generic skills such as communication. But universities are placing increasing emphasis on developing these high-level academic skills. This is especially true of liberal arts colleges, and other less-specialized institutions. At my own university, the astronomy and physics curricula are over-loaded and over-specialized, apparently intended to prepare students for graduate work. But there is a benefit to preparing science students for a wider variety of real world careers ([33]), one being teaching. For these careers, a less-specialized program of courses is desirable. This can be achieved through double-major programs, and by a greater emphasis on breadth in the degree requirements.

Real or virtual visits to observatories give students a sense of how astronomy is done, and astronomy clubs or other gatherings give students an opportunity to talk with astronomers in a more informal setting than the classroom.

See Percy [21] for other comments about undergraduate astronomy education, in both the developing and the developed world.

Linking Teaching and Research

One way to develop high-level generic research skills is through undergraduate research projects, as long as they are well-designed and supervised. In a recent review ([24]), I explained how students could “learn astronomy by doing astronomy", so I shall not repeat the whole discussion. One way is by doing authentic research projects; I shall discuss this further, below.

But research experiences can be built into regular laboratory courses by providing real astronomical instruments (including remote telescopes), data, and software, and by giving meaningful projects – not just “cookbook" projects which are designed to produce a known answer. In fact, *all* assignments, including homework, should be as creative and meaningful as possible.

In lectures, students enjoy hearing about the instructor’s research, and about other research done by faculty and students at the university. One of the benefits of lectures is that the instructor can share his/her enthusiasm for their subject.

Students should be encouraged and trained to use the Internet critically and effectively. They can access and read current and historical research papers. They should be expected and trained to write high-quality laboratory and project reports. A few may even want to learn how to write good non-technical articles on astronomy, and publish them on-line or in a student newspaper.

My own experiences with student research projects in astronomy have recently been described ([23]). They include the Research Opportunity Program, in which second-year students receive a full course credit for working on a research project; the Ontario Work-Study Program, which provides up to 200 hours of career-related employment to eligible students; the senior thesis, a fourth-year research project; various summer employment opportunities; and the University of Toronto Mentorship Program, which enables outstanding senior high school students to work on research projects at the university. My projects deal with variable stars and stellar evolution [22]. Projects are small, self-contained, and original. They result in a conference presentation and/or research publication, with the students as co-authors. Many make use of data from the American Association of Variable Star Observers (www.aavso.org). The data are obtained by skilled amateur (volunteer) astronomers. My students develop and integrate their science, math, and computing skills by analysing and interpreting the data, motivated by the fact that they are doing real science, with real data. The results are usually presented at AAVSO conferences, and/or published in the AAVSO *Journal*, thereby providing feedback to the AAVSO observers about how their work benefits both science and education. On the AAVSO website, there is a wealth of useful tools and information that enable students to work with real astronomical data.

GRADUATE ASTRONOMY EDUCATION

In a recent review ([21]), I discussed graduate astronomy education for the developing world. But most of the same considerations apply to the developed world e.g. professors receive little or no training in (graduate) teaching, supervision, or mentoring. Graduate astronomy departments constantly debate the optimal balance between coursework and research, with some departments offering mostly coursework, and some offering mostly research. In my experience, graduate students' success depends not only on their academic background – grades on courses – but also on non-academic traits and abilities, such as motivation, enthusiasm, autonomy, flexibility, initiative, creativity, and time management and communication skills. In a recent survey ([31]), PhD graduates report that they wish they had received more training in communication, teaching, mentoring, management, teamwork, and working in a multidisciplinary setting.

Graduate students' training in teaching is especially important. It prepares them for their work as graduate teaching assistants; in North America, much instruction in research universities is done by teaching assistants. It also prepares them for their future careers as professors. And if the training is poor or non-existent, that suggests to them that teaching is not a high priority.

In my university, teaching assistants are required, by their union contract, to receive a few hours of training. For those who are interested, there is a comprehensive Teaching Assistant Training Program; about 100 students graduate from this program each year, and about 600 attend one or more workshops. [There are over 13,000 graduate students at my university.] There is a non-credit graduate course on Teaching in Higher Education; about 120 students take this course each year. And there is a variety of lectures and workshops in the university for teaching assistants who are interested, but most teaching assistants do not choose to take advantage of these opportunities. In my department, there are frequently long, informal discussions, at coffee time, about educational matters, involving both faculty members and graduate students.

PUBLIC OUTREACH AND COMMUNICATION IN ASTRONOMY

Astronomers have an obligation to share their work with the taxpayers who support them, and this obligation is increasingly recognized by the professional astronomical community. One indication was the development of *The Washington Charter* [2], an appeal to astronomers and their institutions to take this obligation seriously. Shortly after, the International Astronomical Union established a commission (or interest group) on Communicating Astronomy to the Public. This has led to a series of conferences (e.g. [12, 29]) and a new journal *CAPJournal: Communicating Astronomy to the Public*.

The general principles of effective outreach and communication are the same as for any educational activity: establish objectives and goals, whether to educate, inspire, or entertain; choose appropriate content, considering the audience's level and needs; use effective communication strategies and methods; assess the effectiveness of the activity at each stage; and use this assessment to improve the activity, or to do better next time.

There are general rules for effective communication. Know the needs, motivations, interests, level, and prior knowledge of your audience or readers. Decide on your objectives – to inform, inspire, or entertain. Organize your material into introduction, short sections, and summary. Use simple language, free of undefined jargon or acronyms. Make sure diagrams or slides are simple, readable, and suitably captioned. Keep your delivery or writing simple, clear, and interesting. Follow instructions; keep to the right length or time! In an oral presentation, make sure you are audible. After the presentation, wait patiently for questions and discussion; repeat or rephrase questions so that all can hear and understand them. Rehearse, rehearse, rehearse!

Most communication of astronomy, of course, is done by journalists, so astronomers must learn to interact and partner with the print and electronic media. There are ways of doing this, which we can learn from our institutions and professional societies.

Observatories, Planetariums, and Science Centres

Thanks to organizations such as the International Planetarium Society, the Association of Science-Technology Centres, and the Astronomical Society of the Pacific, there are many workshops, conferences and proceedings with a wealth of useful information; see also [10] for a short summary. In my city, Toronto, there are three such facilities that have contributed strongly to astronomy education and outreach in the last 75 years. Their stories are illuminating.

The David Dunlap Observatory of the University of Toronto opened in 1935; its 1.88m telescope was then the second-largest in the world. Through to the 1980s, it was a centre of research, education, and outreach. Many of the university's astronomers and graduate students did their research there. After the 1980s, research usage declined, mostly because of changing research interests of the astronomers, and the availability of telescopes at much better sites. In 2007, the observatory was sold to a land developer. By then, very few astronomers, and no graduate students used the telescope regularly. The public education program continued, but was eclipsed by those at the planetarium, and later at the science centre. As of 2009, the observatory's public education program was being continued by the Toronto branch of the Royal Astronomical Society of Canada, but its future is uncertain.

The McLaughlin Planetarium of the Royal Ontario Museum in Toronto opened in 1968 and, for three decades, was one of the world's major planetariums. In 1995, however, the museum was faced with possible budget cuts, and it closed the planetarium because it thought that the site could be used for some purpose that would generate a higher revenue. This turned out not to be the case. In fact, the planetarium was close to breaking even, financially. And shortly after its closing, astronomy became a compulsory part of the elementary and the secondary school curriculum, and there was an even greater need and demand for school programs. The planetarium site was briefly a children's museum, and is now used as a storage area. The Museum does, however, have small, portable, inflatable planetariums, and serves about 30,000 schoolchildren annually.

The Ontario Science Centre opened in Toronto in 1967, and is presently Canada's most-visited cultural institution. Despite administrative challenges (which I know about, because I served as Vice-Chair of the Board of Trustees for six years), it is well-managed, innovative, and successful. It has several staff members with astronomical backgrounds, and is now a major centre for astronomy exhibits, and programs for students, teachers, and the public. It has a strong partnership with the Toronto branch of the Royal Astronomical Society of Canada, who meet there, and present “star parties" for the public.

Why did the Ontario Science Centre succeed in astronomy education? One reason is because science education is its core mission; the Royal Ontario Museum's strength is in art and archaeology, though it also has significant collections in paleontology and mineralogy. The Science Centre also has a large staff which is highly skilled in all aspects of science education, including programs and exhibits, as well as education, assessment, and marketing.

For the success of such institutions, there is also a strong need for attention and support from the academic and professional astronomy community. Partnership is always a benefit.

INTERNATIONAL YEAR OF ASTRONOMY

International Year of Astronomy 2009 (IYA) celebrated the 400th anniversary of Galileo's development and first use of the astronomical telescope. His results changed our understanding of the universe, and our place in it. IYA was led by the International Astronomical Union, with the support of UNESCO, and the endorsement of the UN General Assembly. It was celebrated in 148 countries. The IYA international website is www.astronomy2009.org

The IYA vision was to help the citizens of the world rediscover their place in the universe through the day and night-time sky, to appreciate the impact of astronomy and basic sciences on their daily lives, and to understand better how scientific knowledge can contribute to a more equitable and peaceful society. The aim of IYA was to stimulate worldwide interest, especially among young people, in astronomy and science under the central theme “The Universe: Yours to Discover"! (This slogan was contributed by my province of Ontario; the slogan on our automobile license plates is “Ontario: Yours to Discover"). The objectives of IYA reflect a more holistic view of astronomy than simply forefront research – its cultural influence, past and present; its inspirational nature; our responsibility for the future of our planet; our role as peaceful, international collaborators; and astronomy’s potential to encourage scientific and critical thinking. Such objectives are definitely relevant to the school and university science curriculum, but are not always stated explicitly.

Canadian IYA Activities and Projects

In Canada, IYA was led by an Executive Committee, and Advisory Board, representing all parts of the astronomical community, including both professional and amateur astronomers. We believe that the greatest contribution to the success of IYA in Canada was this effective partnership, especially between professionals and amateurs.

Our vision was “to offer an engaging astronomy experience (a “Galileo Moment") to every person in Canada, and to cultivate partnerships that sustain public interest in astronomy". We set a goal of one million Galileo Moments, and defined them conservatively. They generally involved face-to-face interactions between astronomers and their audience. We did not include, for instance, a very successful project that placed engaging astronomy posters on every public transit vehicle in Toronto and Montreal, which reached millions of riders. By October 2009, we had exceeded a million Galileo Moments.

Our national projects included:

- Postage stamps, issued in April 2009, which were among the most popular Canadian stamps ever. They showed two of Canada’s major observatories, superimposed on stunning images obtained with these.
- A $30 sterling silver commemorative coin, issued by the Royal Canadian Mint. It portrays one of Canada’s major observatories, together with an array of celestial objects.
- Astronomical “trading cards" (patterned after hockey trading cards, which are very popular in Canada), with images of astronomical objects, information in English and French, and instructions on how to get one’s name launched into space – an IYA project of the Canadian Space Agency.
- Easily-assembled planispheres – star charts for any date and time – based on a design by Canada’s National Research Council.
- A book *Mary Lou’s New Telescope*, highlighting astronomy’s appeal to young people, the problem of light pollution, and how students and the public can act to reduce environmental problems of this kind.
- Projects in partnership with Canada’s Aboriginal communities, designed to collect and celebrate indigenous sky knowledge, to preserve dark skies, and to encourage

Aboriginal youth to develop an interest in science and technology.

- A gallery of stunning Canadian astronomical images, which were displayed in science centres, airports, shopping malls, art galleries, and were available on-line.

My Personal IYA Activities and Projects

The IYA Canada Committee encouraged every professional and amateur astronomer in Canada to develop or join an IYA project that was especially suited to their interests and expertise. These are some of my projects:

- Because of my interest in school education, and because the Ontario secondary school science curriculum had been revised for 2009, I undertook several projects in partnership with the Science Teachers Association of Ontario. These included new resources to provide teachers with “pathways" through the grade six and nine curriculum, a three-day Summer Institute for school teachers, held at the University of Toronto in August 2009, and a project to use the *GalileoScope*, a replica of Galileo’s telescope, optimized for education, to help teach optics and astronomy in the revised curriculum [see www.galileoscope.org].
- As a long-time follower of Toronto’s Tafelmusik Baroque Orchestra, “one of the world’s best Baroque orchestras" according to *Gramophone Magazine*, I encouraged the orchestra to develop a multimedia program that explored the connections between astronomy and music over the ages. The program was superb ([25]). It has been performed in Canada and Mexico, and will be performed in the USA, China, and Malaysia in 2010.
- I am a member of Heritage Toronto, and a participant in their program of heritage walks in the city, so I developed a walking tour of buildings in and around the University of Toronto that had astronomical connections, ranging from 1839 to the present. This walk was first held on the summer solstice 2009 which, coincidentally, was National Aboriginal Day; Aboriginal people were Canada’s first astronomers (e.g. [11]).
- I organized two dozen presentations on astronomy in branches of the Toronto Public Library, the busiest public library system in the world. About a dozen presentations were for children, and were given jointly with an undergraduate summer student. These included a short illustrated presentation, a question period, demonstrations, hands-on activities, solar viewing (weather permitting), and handouts to take home. Other library presentations were for adult or senior audiences, and also included a long question period. People appreciate the opportunity to “ask an astronomer" – to talk with an astronomer face to face!

The success of these personal projects was determined not just by my own enthusiasm and effort, but even more so by my decision to work with excellent partners, including the Science Teachers Association of Ontario, the Tafelmusik Baroque Orchestra, Heritage Toronto, and the Toronto Public Library.

FINAL THOUGHTS

The effectiveness and therefore the quality of astronomy education, outreach, and communication varies from outstanding to very poor. To bring astronomy education to the same high level as we expect of astronomy research requires several actions:

- We must raise the profile and importance of astronomy education and outreach at all levels, in organizations, and in the minds of individual astronomers.
- We can do this most effectively through strategies that have high impact and wide reach.
- We must use methods of teaching, outreach, and communication that have been shown to be effective through formal or action research, experience, or reflection.
- We must establish effective partnerships within all parts of the astronomy education community, so we can build on the successful expertise of others.
- We must constantly practice assessment and improvement in every stage of the educational process.

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REFERENCES

1. B.S. Bloom, *Taxonomy of Educational Objectives*, Allyn and Bacon, Boston, 1984.
2. C. Blue, in *Teaching and Learning Astronomy*, J.M. Pasachoff and J.R. Percy, editors, Cambridge University Press, Cambridge UK, 2005, 235-7.
3. Boyer Commission, *Reinventing Undergraduate Education*, naples.cc.sunysb.edu/Pres/boyer.nsp/, 1998.
4. D. Duncan, *Astronomy Education Review*, **5**, #1, 70-88, 2006.
5. M. Gerbaldi, in *Teaching and Learning Astronomy*, J.M. Pasachoff and J.R. Percy, editors, Cambridge University Press, UK, 146-52.
6. P.J. Green, *Peer Instruction in Astronomy*, Pearson Education Inc., Upper Saddle River NJ, 2003.
7. M.K. Hemenway, in *Teaching and Learning Astronomy*, J.M. Pasachoff and J.R. Percy, editors, Cambridge University Press, UK, 139-45.
8. D. Hodson, *OISE Papers in STSE Education*, University of Toronto, **2**, 7-20, 2001.
9. M. Krstovic, L. Brown, M. Chacko, and B. Trinh, *Astronomy Education Review*, **7**, #2, 18-24, 2008.
10. N. Lomb, in *Teaching and Learning Astronomy*, J.M. Pasachoff and J.R.. Percy, editors, Cambridge University Press, Cambridge UK, 221-226.
11. J. MacDonald, *The Arctic Sky*, Royal Ontario Museum, Toronto, 1998.
12. T.J. Mahoney, editor, *Communicating Astronomy*, Instituto de Astrofi sica de Canarias, La Laguna, 2005.

13. D.H. McKinnon, in *Teaching and Learning Astronomy*, edited by J.M. Pasachoff and J.R. Percy, Cambridge University Press, Cambridge UK, 2005, 104-116.
14. Ministry of Education and Training Ontario, *The Ontario Curriculum Grade 9 and 10 Science*, Queen's Printer for Ontario, Toronto, 2008.
15. J.V. Narlikar, in *Teaching and Learning Astronomy*, J.M. Pasachoff and J.R. Percy, editors, Cambridge University Press UK, 164-71.
16. J.M. Pasachoff, and J.R. Percy, editors, *Teaching and Learning Astronomy*, Cambridge University Press, Cambridge UK, 2005.
17. J.R. Percy and J.M. Pasachoff, in *Teaching and Learning Astronomy*, J.M. Pasachoff and J.R. Percy, editors, Cambridhe University Press, Cambridge UK, 172-6.
18. J.M. Pasachoff, in *Teaching and Learning Astronomy*, J.M.. Pasachoff and J.R. Percy, editors, Cambridge University Press, Cambridge UK, 97-103.
19. J.M. Pasachoff, R.M. Ros, and N. Pasachoff, editors, *Innovation in Astronomy Education*, Cambridge University Press, Cambridge UK, 2008.
20. Percy, J.R., in *Teaching and Learning Astronomy*, edited by J.M. Pasachoff & J.R. Percy, Cambridge University Press, Cambridge UK, 2005, 10-13.
21. J.R. Percy, in *Astronomy for Developing Countries*, J.B. Hearnshaw and P. Martinez, editors, Cambridge University Press, Cambridge UK, 229-36.
22. J.R. Percy, *Understanding Variable Stars*, Cambridge University Press, Cambridge UK.
23. J.R. Percy, in *Preparing for the 2009 International Year of Astronomy*, M.G. Gibbs et al., editors, ASP Conference Series, vol. 400, 363-367, 2008.
24. J.R. Percy, in *Innovation in Astronomy Education*, J.M. Pasachoff et al., editors, Cambridge University Press, Cambridge UK, 2008, 13-22.
25. J.R. Percy, *CAPJournal (Communicating Astronomy with the Public)*, #7, 24-5, 2009.
26. E.E. Prather, A.L. Rudolph, and G. Brissenden, *Physics Today*, **62**, #10, 41-47, 2009.
27. A. Price, *Astronomy Education Review*, **6**, 130-132.
28. A. Price, *Astronomy Education Review*, **8**, #1, pp. 3.
29. I. Robson and L. Lindberg Christensen, editors, *Communicating Astronomy with the Public*, European Southern Observatory, Munich, 2005.
30. T.F. Slater and J.P. Adams, *Learner-Centered Astronomy Teaching: Strategies for Astro 101*, Prentice-Hall, Englewood Cliffs, NJ, 2002.
31. S.J. Smith, L. Pederson-Gallegos, and C. Riegle-Crumb, *American Journal of Physics*, **70**, #11, 1081-92.
32. S. Tobias, *They're Not Dumb, They're Different*, The Research Corporation, Tucson AZ, 1990.
33. S. Tobias, K. Aylesworth, and D.F. Chubin, *Rethinking Science as a Career*, The Research Corporation, Tucson AZ, 1995.
34. S.C. Wolff and A. Fraknoi, in *Teaching and Learning Astronomy*, edited by J.M. Pasachoff and J.R. Percy, Cambridge University Press, Cambridge UK, 2005, 80-86.