Design, implementation and evaluation of transnational collaborative programmes in astronomy education and public outreach

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I

Introduction

This thesis presents a study of how science can most effectively be used to engage and educate the global public and specifically describes the role of astronomy in doing this.

Astronomy has a special place in the field of science education and public engagement with science. It has great appeal for large sections of the public for several reasons (National Research Council 2010). First, the sky and the stars are accessible to everyone. Secondly, astronomical images are spectacularly beautiful, as demonstrated most notably by the Hubble Space Telescope and the Very Large Telescope. Thirdly, astronomical and cosmological research deals with the origins and evolution of the Universe – a topic of broad philosophical interest. Fourthly, the idea of space travel exploits widespread excitement around exploration and adventure. Fifthly, the possibility of life in outer space is deeply embedded in social imagination (Graham, 2002). There are other aspects of astronomy that make it particularly suitable for large global initiatives in science engagement. During the last half century astronomy has become a “big science” with such expensive observational facilities that cross-national and even global collaborations are required to fund them. Astronomy brings together nations through international organisations and collaborations. Following the same trend, astronomy education and public outreach (EPO) is also a global endeavour, involving thousands of organisers and reaching millions of individuals.

Introduction

In this thesis, we shall use astronomy as a case study to consider the effect and impact of transnational collaborations with innovative approaches and centralised coordination in science education and public outreach. The thesis is based on eight years of designing, implementing and evaluating transnational collaborative programmes in astronomy education and public outreach, from the perspective of the practitioner. We shall also show that large global science EPO projects can result in sustainable outcomes that outlive the projects themselves and analyse the various aspects of global science communication project that are necessary for their success. The thesis will focus on two large projects in astronomy EPO, the International Year of Astronomy 2009 and an educational programme for young children, Universe Awareness. n this chapter, we shall set the scene by considering some relevant aspects of science communication and show how science communication has become an activity of two-way public engagement. We shall also discuss key aspects of the relationship between astronomy and society.

Science Communication and Public Engagement

"Science communication", "Public Engagement" and "Education and Public Outreach" are blanket terms covering communication aspects about scientific research to those members of the public who are neither professionals nor specialists in the relevant field. Public engagement with science is the topic that describes the myriad ways in which the scientific community can share its scientific enterprise and knowledge with the wider society in a more inclusive way. Lewenstein (2015) describes two main areas in public engagement under two main aspects: "engagement" as a learning activity and "engagement" as public participation in science. In Table 1 we present an overview of the main categories of public engagement initiatives. All have in common that scientists (in the case of astronomy, astronomy-related communities, such as educators and amateur astronomers) reach out to individuals and society-at-large to engage them with science. Engagement is, by definition, a two-way communication process, involving both listening and interacting, with the goal of generating mutual understanding. Public engagement has become an essential tool for building and strengthening public support for research, but has also instigated some criticism regarding the role of science in society.

Publication

This section is based on draft position paper by Bochove, C., Reid, G.,Russo, P. and Maes, K. (2015) *Science and society: why science both deserves and needs trust, and how universities and governments can build it*, LERU, in prep.

Table 1. Overview of the main categories of public engagement initiatives (based on Bell et al. 2009).

Category	**Characteristics**	**Examples of public engagement initiatives**
Developing interest in science	Experience excitement, interest, and motivation to learn about science.	• Exhibits • Media: TV news, generic newspapers/ magazines, etc.

Understanding some science	Understand concepts, explanations, arguments, models, and facts related to science. Manipulate, test, explore, predict, question, observe, and make sense of science.	• Public talks • Documentaries • Popular-science books and magazines • Workshops and hands-on exhibitions • Websites
Using scientific reasoning and reflecting on science	Reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on their own process of learning about phenomena.	• Dialogue initiatives, like Science Cafes
Participating in the science enterprise	Public participates in scientific activities and learning practices with others, using scientific language and tools Public identifies as someone who knows about, uses, and sometimes contributes to science.	• Citizen-science projects

In this thesis, we discuss different projects, issues of and best practices for public engagement with astronomy, which include all the categories presented in Table 1.

Evolving phases of science communication
Science communication can be considered to have undergone three main phases in its development: the "science literacy" phase (SL), the "public understanding of science" phase (PUS), and recently, the public engagement with science and technology phase (PE).

Scientific literacy (SL) assumes that the public should have a certain knowledge level of science (Miller, 1983). This approach tries to fill the "knowledge gap" between scientists and the public by communicating facts about science in a one-way direction. It has become known as the "deficit model" and is based on the assumption that a non-knowledgeable public cannot participate in science or scientific decisions. The public understanding of science (PUS) approach focuses on the primary concept that "*it's fine to disagree with science, but by being better informed, your choice is built on more secure foundations*" (Royal Society, 1985; Bowater & Yeoman, 2013). However, this phase still implies that all scientific knowledge lies with the scientific elite of professional scientists.

A recent phase of science communication that emerged during the past few decades involves a two-way "public engagement" with research. Practitioners of the PE approach regard PUS and SL science communication as too arrogant and elitist. The public engagement approach was boosted by a UK's House of Lords Science & Society 2000 report (House of Lords 2000). This report was prompted in the UK by two science-related controversies during the nineties, namely the Bovine spongiform encephalopathy (BSE – commonly known as mad cow disease) (Blue 2010), genetically modified (GM) food (Shaw 2002) and the controversial links between the immunization vaccine against measles, mumps, and rubella and autism (Clarke 2010). These controversies resulted in a public mistrust towards science and scientists, with large implications to the way science was communicated to society and the important aspects of science such as scientific uncertainty (Retzbach, Otto & Maier 2015).

Until the public engagement phase, the communication between researchers and society implied a "top-down" approach of one-way communication from the research community to the public. As a result of public awareness of the controversies mentioned above, the pressure increased for researchers to engage in dialogue activities with the public. It was realised that such dialogue is important for democratic participation in research (Irwin, 2006) and that it can lead to an increased trust and confidence in research (Haste et al. 2005).

Despite this new approach to science communication, Wildson, Wynne and Stilgoe (2005) argue that, while some aspects have improved, the new approach has not yet been proven sufficient and the dialogue has been seen as a way to control and manage public opinion. This has been the case of communication aspects of climate change issues (Hart & Nisbet 2011; Carvalho & Peterson 2012). Science communication needs to be prepared to engage with society in all aspects, and its uncertainties, of the scientific enterprise and not exclusively with scientific results or discoveries. As Miller (2001) expresses: "*it is important that citizens get used to scientists arguing out controversial facts, theories, and issues. More of what currently goes on backstage in the scientific community has to become more visible if people are going to get a clearer idea of the potential and limitations of the new wonders science is proclaiming*."

There are, however, new trends of public participation in scientific enterprise emerging in science communication, notably as citizen-science projects with crowd-sourced data collection and analysis, and as crowdfunding for science projects, as described in Chapter IV.2.

Despite the limitations, Public Engagment with Science (PES) brings a variety of benefits to science, research staff and students, as well as to the wider public: Public engagement activities inform the public about the ongoing research and provide a platform for researchers to discuss their research projects and plans with the wider public. To achieve these benefits, research communities need to design public engagement activities to be practical, innovative, educational, and research-based. All of these aspects feed each other with resources, ideas, and opportunities for research studies, and even support each other financially (NCCPE, 2012). In this thesis we analyse and discuss several case studies that have components of the three phases of science communication, but with a focus on public engagement with an active participation of the stakeholders.

Table 2. Phases and their characteristics associated with the development of science communication

Phase	**Characteristics**	**Criticism**	**Relevant literature**
Scientific Literacy (SL)	• Deficit of knowledge • Communication from scientists to public • One-way communication • Public is informed	• Public are simple receivers of knowledge without a say in the process. • Scientific knowledge lies with the scientific elite of professional scientists	Miller, 1983
Public Understanding of Science (PUS)	• Similar to scientific literacy • Focus on the understanding of the scientific enterprise, including the processes and uncertainties • Still one-way communication		Royal Society, 1985
Public Engagement with Science (PES)	• Dialogue between the public and the scientists. • Public engaged in scientific reasoning • Public reflects on science enterprise • Public engages in practical aspects of science • Ultimately public might identify themselves with the science enterprise	• PES has been seen as a way to control and manage public opinion	House of Lords, 2000 NCCPE, 2012

Practical science communication and public engagement

Public engagement with Science (PES) is a practical endeavour that takes many shapes and forms, ranging from large-scale education programmes to citizen-science projects and science festivals. All of these vehicles help researchers disseminate the benefits of their work to society while allowing them to keep abreast of public concerns and expectations. There are several reasons why PES has become a prime form of science communication. PES helps to maximize the flow of knowledge between research communities and society, giving research communities the potential to create impact through learning and innovation in the wider society (NCCPE, 2010). Strategic investment in public engagement helps to maximize this potential by focusing attention and support on the multiple, often informal, ways in which research enriches the lives of the wider public. PES contributes to both social inclusion and social responsibility and can lead to a range of positive outcomes. By embedding public engagement into their activities, researchers are better able to understand and respond to local, national, and global social issues (UUK, 2010 & Robinson et al. 2012).

PES can help to build trust and mutual understanding between research communities and the public. Trust is critical to healthy higher education and research systems, but it is difficult to establish trust unless there are opportunities for the public to engage with research. More than three-quarters of a random sample of the public were found to agree with the statement that, "*we ought to hear about potential new areas of science and technology before they happen, not afterwards.*" (Ipsos MORI, 2015) By facilitating such a desire, PES enables the understanding of research to grow at a time when deference to authority and professional expertise is decreasing.

The Internet has facilitated the development of science projects in which millions of people can collaborate towards a common research project. These so-called citizen-science projects enable the public to get involved in data collection, analysis, or reporting. The massive collaborations that can occur through citizen-science allow research at global spatial and temporal scales, leading to discovery that single scientists could never achieve on their own (SciStarter, 2015).

Science Communication and Academia
In recent years, science communication has become an established subject at universities in several countries, with an increasing number of bachelor and masters degree programmes[01] being offered. Science communication is embedded in different universities in different ways due to its inter- and multidisciplinary nature. This diversity is a "*sign of the subject's vitality, but it is also a condition of its vulnerability*" (Trench, 2008).

In parallel with its role in education, science communication is becoming an established research discipline, with research in both theoretical and applied topics. In-depth research in science communication is essential to provide the theoretical basis for the other core areas of public engagement activity described above. Results of research in the impact of public engagement initiatives are described in chapters IV.1 and IV.2 of this thesis.

Innovation in Science Communication
Until the last few years engaging the public in science has been traditional in its methods and not very creative. However, public engagement activities often generate unforeseen outcomes that can stimulate creativity and innovation. One of the most profound rewards of public engagement is its

[01] Chapters II.2, III.1, III.2, IV.1 and IV.2 of this thesis were developed as part of the projects of several master students in science communication and related fields.

unpredictability: new perspectives, challenging questions, and lateral insights can all help to sharpen thinking, release creativity, and unlock new collaborations and resources. In this thesis, we shall describe and analyse several new innovations in science communication, including the development of a new platform for peer-reviewed astronomy education activities and the astronomy educational resource Universe in a Box, as described in Chapter III.2.

Astronomy and Society

Publication

This section is based on Rosenberg, M., Russo, P., Bladon, G., & Christensen, L. L. (2013). *Astronomy in Everyday Life*, Communicating Astronomy with the Public Journal, 14.

With the increasing cost of curiosity-driven sciences such as astronomy and the diverse demands on national budgets, there is great pressure on scientists to justify the societal benefits of their research in an evidence-based approach. The difficulties in describing the importance of astronomy, and fundamental research in general, are summarised by Nobel Prize winner Ahmed Zewali: "*Preserving knowledge is easy. Transferring knowledge is also easy. But making new knowledge is neither easy nor profitable in the short term. Fundamental research proves profitable in the long run, and, as importantly, it is a force that enriches the culture of any society with reason and basic truth."*

More recently, C. Renée James (2012) outlines the recent technological advances that we owe to astronomy, such as global positioning systems (GPS), medical imaging, and wireless Internet. In defence of astronomy, Dave Finley (2013) states, "*In sum, astronomy has been a cornerstone of technological progress throughout history, has much to contribute in the future, and offers all humans a fundamental sense of our place in an unimaginably vast and exciting Universe*."

Thus, although "blue skies" research such as astronomy rarely contributes directly to tangible outcomes on a short timescale, the long-term societal benefit has been demonstrated. Although difficult to quantify economically, there are a large number of examples that show how astronomy has contributed to technology development and society by constantly pushing for instruments, processes, and software that are beyond our current capabilities. The pursuit of this research requires cutting-edge technology and methods that can, on a longer timescale and through their broader application, make a substantial difference to peoples lives. The fruits of scientific and technological development in astronomy include applications such as personal computers, communication satellites, mobile phones, GPS, solar panels, and magnetic resonance imaging (MRI) scanners (National Research Council 1991).

Carl Sagan described astronomy's simplest and most inspirational contribution to society in his book The Pale Blue Dot (Sagan & Druyan 2011): "*It has been said that astronomy is a humbling and character-building experience. There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known.*"

Although public support for investment in astronomy and space exploration over the last thirty years has been strong (ESA 1998; NSB, 2002; Mori, 2004; Eurobarometer, 2005; Safwat et al., 2006; Entradas 2011), doubts have also been expressed about the wisdom and effectiveness of such expenditure when measured against the large number of problems facing society (Ottavianelli, 2002; Mori, 2004, Safwat et al., 2006; Jones, 2007). The Nobel Prize winner in Literature José Saramago (1998) expresses his scepticism in his acceptance Nobel acceptance speech "*This same schizophrenic humanity that has the capacity to send instruments to a planet to study the composition of its rocks can with indifference note the deaths of millions of people from starvation. To go to Mars seems more easy than going to the neighbour.*"

Astronomy encompasses a broad range of disciplines including biology, geology, chemistry, physics, engineering, philosophy and history. Astronomy and its related fields are at the forefront of science and technology, answering fundamental questions and driving innovation. These considerations prompted the International Astronomical Union's strategic plan "Astronomy for Development 2010–2020" (Miley, 2009). This has three main areas of focus: technology and skills; science and research; and culture and society.

Astronomy education and public outreach provides an important link between the scientific astronomical community and society, giving visibility to scientific success stories and supporting both formal and informal science education. While the principal task of an astronomer is to further our knowledge about the Universe, disseminating this new information to a wider audience beyond the scientific community is becoming increasingly important.

This Thesis

In this thesis, we explore the features, characteristics, constraints, and challenges in designing, implementing, and evaluating transnational collaborative programmes in science education and public outreach. Our astronomy case studies will illustrate several innovations and the importance of centralised coordination in ensuring that large global science EPO projects result in sustainable outcomes. Table 3 gives an overview of the issues and innovations we shall address.

In Part II, we shall study in detail the design, implementation and evaluation of two large astronomy EPO initiatives, the International Year of Astronomy 2009 (Chapter II.1) and the educational Universe Awareness programme (Chapter II.2). The International Year of Astronomy 2009 (IYA2009) was a platform for sharing the latest discoveries in astronomy with society and for emphasizing the essential role of astronomy in science education. We treat IYA2009 as an example of a successful massive science communication project and draw lessons relevant to the design and implementation of future large global science communication projects.

Universe Awareness (UNAWE) is a global science education programme that uses the beauty and grandeur of the Universe to encourage young children, particularly those from underprivileged backgrounds, to have an interest in science and technology, and to foster their sense of global citizenship. We shall discuss several innovations in science education developed during the course of implementing this programme, such as Space Scoop – an astronomy service news for children – and duo internships – teacher training provided jointly by an astronomy student and a student teacher.

In Part III, we shall investigate the design and implementation of two additional innovations in astronomy educational resources International Astronomical Union's astroEDU (Chapter III.1) and UNAWE's Universe in a Box (Chapter III.2). Hundreds of thousands of astronomy education resources exist, but their discoverability and quality is highly variable. As a web platform for astronomy education activities, astroEDU tackles this issue. Using the familiar peer-review workflow of scientific publications, astroEDU is improving standards of quality, visibility, and accessibility. astroEDU targets activity guides, tutorials, and other educational activities prepared by teachers, educators, and other education specialists. The innovative aspect of astroEDU is that each of the astroEDU educational activities is peer-reviewed double-blindly by an educator and an astronomer to ensure a high standard in terms of scientific content and educational value. Physical educational resources, then, provide a useful supplement for educators to demonstrate abstract or complex concepts. There has been considerable research on the benefits of resources based on inquiry-based learning for scientific and technical subjects.

UNAWE's Universe in a Box is an astronomy kit developed to explain difficult and abstract astronomical concepts to young children by providing practical activities, as well as the materials and models required to do them. The innovative approach to a collaborative development across the UNAWE network has made Universe in a Box the first international astronomy education resource produced as well as used globally. We investigate the advantages and disadvantages of different models for the production and distribution of global science education kits. We also present and discuss the preliminary social and educational impact and potential of such an educational kit.

In Part IV, we study the impact of astronomy EPO initiatives on astronomical research and provide evidence that appropriate public engagement initiatives can lead to long-term public support for scientific research. However there is not yet a complete understanding of the impact of public engagement initiatives within the context of long-term science policy. We show that public engagement initiatives like IYA2009 or large grassroots movements led by citizen scientists and space *aficionados* can have profound long-term effects on research funding and research productivity. To demonstrate this, we explore changes of research capacity in developing countries (Chapter IV.1) and the role and relevance of public grassroots movements in the policy of space astronomy initiatives, such NASA/ESA's Hubble and James Webb (Chapter IV.2). We present recent cases that illustrate policy decisions involving broader interest groups and consider new avenues of public engagement, including crowdfunding and crowdsourcing.

Table 3. Issues and innovations addressed in this thesis.

Chapter	Issues investigated	Innovations described	Contributions of the author
II.1. The International Year of Astronomy as a Massive Science Communication Project	The need for centralised coordination to enable the participation of large numbers of geographically dispersed people in astronomy EPO initiatives.	Exploitation of non-professional astronomers for public engagement initiatives.	Coordination and implementation of IYA2009 globally, including the planning, execution, and evaluation of the global IYA2009 activities, projects, and events.
II.2. Universe Awareness as a Transnational, Collaborative Programme in Education	Design, implementation, and assessment of a large transnational collaborative programmes in astronomy education	Innovations in science education: Space Scoop (astronomy news service for children) and duo internships "Duo" teacher training provided jointly by astronomy and teaching students.	Coordination, design, implementation, and assessment of Universe Awareness.
III.1. Peer-review Platform for Astronomy Educational Activities	The implementation of a peer-review process to improve the educational and scientific quality of educational activities.	Each astroEDU educational activity is peer-reviewed double-blindly by an educator and an astronomer to ensure a high standard of scientific content and educational value.	Development, concept and the editorial processes of IAU astroEDU.
III.2. Design, Development, and Impact of Physical Resources for Science Education	Design and development of a global physical educational resource.	Collaborative development across the UNAWE network has made Universe in a Box the first international astronomy education resource produced and used globally.	Identification of the need for such global resources and supervision of the development, distribution, and assessment of Universe Awareness.

IV.1. A Survey of Astronomical Research: A Baseline For Astronomical Development	The impact of astronomy EPO initiatives in the development of astronomy as a research field in developing countries.	This is the most complete study of the evolution of astronomy research publications in the developing world.	Research co-design and analysis.
IV. 2. The Influence of Social Movements on Space Astronomy Policy	Public engagement initiatives as catalyser for long-term public support for science.	For the first time, we investigate the role of social/ grassroots movements in astronomy policy.	Research co-design and analysis.

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