



VOLUME 4 ISSUE 3

The International Journal of

Science in Society

The International Journal of Science in Society



VOLUME 4 ISSUE 3 2012



THE INTERNATIONAL JOURNAL OF SCIENCE IN SOCIETY

www.science-society.com

First published in 2013 in Champaign, Illinois, USA
by Common Ground Publishing LLC
www.commongroundpublishing.com

ISSN: 1836-6236

© 2012-2013 (individual papers), the author(s)
© 2012-2013 (selection and editorial matter) Common Ground

All rights reserved. Apart from fair dealing for the purposes of study, research, criticism or review as permitted under the applicable copyright legislation, no part of this work may be reproduced by any process without written permission from the publisher. For permissions and other inquiries, please contact cg-support@commongroundpublishing.com.

The International Journal of Science in Society is peer-reviewed, supported by rigorous processes of criterion-referenced article ranking and qualitative commentary, ensuring that only intellectual work of the greatest substance and highest significance is published.

EDITOR

.....

Karim Gherab Martín, Spanish National Research Council, Consejo Superior de Investigaciones Científicas, Spain

EDITORIAL ADVISORY BOARD

.....

Carlos Elias, University Carlos III of Madrid, Madrid, Spain
Christopher Impey, University Distinguished Professor, Department of Astronomy, University of Arizona, Tucson, AZ
Michael Peters, University of Illinois, Urbana-Champaign, USA
Kayte Spector-Bagdady, Presidential Commission for Bioethics, Washington, D.C., USA

ASSOCIATE EDITORS

.....

Sulaiman Al-Balushi
Elizabeth Garcia Almanza
Peter Chamberlain
Nicole Clare Collie
Tanietta Delauney
Andrew Domondon
Julia Dordel
Seval Güven
Chris Impey
Tuula Keinonen
Narayan Khanal
Erika Landau
Fiona Lee
Alex Lobos
Joyce Lucas-Clark
Fhatuwani J. Mundalamo
Loreta Vivian Ramel-Galima
Natasha Sarkar
Michael Skoumios
Maneerat Suthanthangjai
Ryan Sweeder
Louis Trudel
Julie Wilson
Meili Yang

Scope and Concerns

MODERN SCIENCE, CONVENTIONALLY UNDERSTOOD



Conventional, modern science has had a number of characteristic features, which remain resilient today, but which are now also increasingly coming under challenge. Conventional science is about the physical-natural world, relatively autonomous of the social world. It is disinterested, striving to be independent of human agendas, values and interests. Its methods are consistent, stable and replicable, allowing the objective phenomena of the natural-physical world, external to human understanding, more or less to speak for themselves. It circulates its knowledge making practices amongst initiates to a self-enclosed discipline—an exclusive institutional, methodological and discursive space accessible only to participants who have been duly apprenticed as learners and passed tests of disciplinary entry. The connections between science and the everyday lifeworld are primarily through a unilinear, transmission model, from basic to applied science and from science to technology. Evaluations of social impacts are incidental rather than an integral to systemic feedback at the core of the scientific endeavor itself.

CHANGING SCIENCE: TOWARDS GREATER SOCIAL ENGAGEMENT



The Science in Society Conference, Journal, Book Imprint and News Weblog recognize the strengths, power and historic achievements of modern science in its conventional public and professional forms and self-understandings. However, they also explore the emergence in recent times of a more socially engaged science. This is a socially reflexive science, a science which reciprocates its understandings of the natural-physical world with the social world. It is a more open and dynamic science.

Here are some key propositions about the relations of science and society in a new, reciprocal science:

Society is deeply intertwined with science. Clear-cut and definitive separations cannot be made between the social-human and the natural-physical. This is both an epistemological proposition (our knowing the natural-physical world) and an ontological one (our being of and in the natural-physical world). Our methods may deceive when they purport to represent external phenomena in an unproblematized way.

Science is intrinsically interested. At its most cogent and most productive, science is engaged, responsible and accountable to the social world. It is integrally linked to agendas, interests, values and ethical stances. These need to be declared and exposed to examination, just as much as science's propositions about the character of the natural-physical world itself. A constant and searching investigation of human interests goes to the heart of the question of the social credibility and ongoing viability of science.

Science's methods are as humanist as they are objectivist. The methods of science must test the human-social context of knowing as much as they do knowable realities in the natural-physical world. Reciprocal science provides a full account of the conditions of knowing, not only in the microdynamics of observation, induction and calculation in relation to the natural-physical but also the broader social contexts of agenda-setting, risk assessment and application.

Interested, reciprocal science is increasingly interdisciplinary. The most pressing questions of our times—sustainability, climate, health, well-being, to name just a few of the great contemporary human interests—require holistic answers. Scientists need to cross disciplinary boundaries to answer them, not only the various disciplines amongst the sciences, but also the social sciences, humanities and professions. Scientists routinely cross disciplinary boundaries,

and they need to do so if they are to have a science which changes the world, albeit in small and incremental ways much of the time, and maybe also in potentially big ways.

A dynamic, socially engaged science must be an open science. It should not favor particular geographic, national or cultural centers. It should not be skewed by demographic closures which restrict access for some kinds of potential participant. It will cross many sites of knowledge making, some conventional and some new: companies, communities, schools, non-government organizations, the public sector, informally self-constituted groups. It must be decentralized in its locations and distributed in its modes of operation. It should be pluralistic, tolerant of paradigm clashes and open to new disciplinary and interdisciplinary practices. It should be collaborative in its spirit, bringing together cross-disciplinary teams marked by the complementarity of their differences. It should be as equitable and fair as it is rigorous in its modes of evaluation of intellectual quality and practical applicability.

Reciprocal science is subject-driven as well as object-oriented. Rather than establishing a primary investigator-instigated relation as has been conventionally the case in modern science, the new science should equally start with social questions. Such questions beg scientific investigation of natural-physical phenomena and their human context. This requires a change in the balance of agency between the lay public and the scientific expert, blurring the boundaries of where scientific questions are raised, how they are addressed and where they are answered.

Reciprocal science is more powerfully recursive. The knowledge system of reciprocal science is enabled in part by new technologies and social processes of scientific communication. Peer review is opened out, its criteria more explicitly stated rather than embedded in implicit professional and network-bound processes. The review process becomes more reflexive and responsive in its rating and moderation systems. Scientific writers and readers come from a wider variety of places, and evaluation of scientific worth is without prejudice to the geographical or institutional source of scientific knowledge-making. Science and scientists are exposed to a wider public, and for that become more accountable.

None of this is to say that that the newer, socially engaged science is unequivocally good. The more conventional modern science still has a role to play in many places, and is not without its peculiar merits. Although the Conference and its associated publication venues are future-oriented and agenda-setting, they do not assume a partisan position, supporting new kinds of science unequivocally against the heritage practices of science. Rather, these discussion spaces offer an open forum for debate. In moments of resolution of this debate, participants might be able to decide what of conventional disciplinary science that we want to preserve and what we might want to renovate.

Whichever model of science we chose to practice, one thing likely can be agreed. Science faces great challenges in these times. These are not only to be understood in terms of the depths and breadths of the questions it is expected to address. But science also faces a dialectic in which there seems simultaneously to be greater public trust in science today, yet also greater skepticism about its costs and benefits.

Table of Contents

Geoengineering: Reflections on Current Debates	1
<i>Paula Curvelo and Ângela Guimarães Pereira</i>	
Modern Western Science in Initial Chinese Archaeological Development	23
<i>Meili Yang</i>	
Using a Cross-disciplinary Investigation to Inform Questions about an Insecurely Provenanced Middle Eastern Manuscript: A Case Study of a Middle Eastern Manuscript	33
<i>Sophie Lewincamp, Nicole Tse, Petronella Nel, Marcelle Scott, and Robyn Sloggett</i>	
Students' Conceptions about the Nature of Sound: A Study of Their Evolution and Their Dependence on the State of Matter of the Medium	51
<i>Stefanos Iconomou and Michael Skoumios</i>	
The Effect of Participants' Race and Gender on Perceptions of STEM and Non-STEM Images of Women	63
<i>Shane T. Warren, Joon Soo Lim, John Nicholson, Emily D. Ryalls, Skye C. Cooley, Mark Goodman, Bonnie Oppenheimer, James Codling, Thomas Robinson, and Laci Kyles</i>	
Two Contrasting Paradigms of Science: Cartesian Mechanism and Undivided Wholeness	75
<i>Siddharth G. Chatterjee</i>	
The Persistence of Students' Conceptions about Buoyancy in Gases	95
<i>Anastasia Pantazopoulou and Michael Skoumios</i>	
Talk to Me—Biometrically Adaptive Consumer Packaging: The Effects of Emotion Relative to a Consumer's Purchasing Decisions	109
<i>Daniel E. Hutcherson, R. Andrew Hurley, Shaundra B. Daily, and Andrew D. Ozuts</i>	
Promoting Environmental Justice through University-Community Research Collaborations: The Case Study of Farm Worker Communities in Oxnard, California	133
<i>Haco Hoang, Grady Hanrahan, and Kaitlyn Noli</i>	

**The Societal Importance of Embracing Counterintuitive Thought in Science:
Assisted Exercise in Preterm Infants for Long-term Health Outcomes 145**

*Ellen Olshansky, Jessica Vaughan, Kelsi Sando, Julia Rich, Kimberley Lakes, and
Daniel Cooper*

**The Red Day Star, the Women’s Star and Venus: D(L/N)akota, Ojibwe and Other
Indigenous Star Knowledge 153**

Annette S. Lee, Jim Rock, William Wilson, and Carl Gawboy

What Students Know about Science 167

Chris Impey

Geoengineering: Reflections on Current Debates

Paula Curvelo, European Commission - Joint Research Centre, Italy
Ângela Guimarães Pereira, European Commission - Joint Research Centre, Italy

Abstract: In this paper we propose to investigate the current debates on geoengineering, here considered as an illustrative metaphor of particular technoscientific promises and 'techno-fix' narratives that are emerging in our society. After a brief introduction, where we provide the necessary background to understand the complex issues surrounding geoengineering, we discuss the relevance of this investigation. We then proceed to explore the controversies behind geoengineering, which start with its own definition. The analysis of the current debates around geoengineering experimentation, regulation and deployment reveal some of the dominant narratives of technoscientific progress and highlight important tensions and frictions in the relationship between science, policy and society. A reflection on these issues suggests the relevance of developing alternative approaches to furthering the 'democratisation and de-alienation' of geoengineering debates, thus responding to a perceived need for more careful consideration of the normative assumptions that lie behind the idea of deliberately manipulating Earth's climate to offset anthropogenic climate change.

Keywords: Climate Engineering, Geoengineering Debates, Climate Change, Narrative Inquiry, Master Narratives

Introduction

The idea of weather modification and climate manipulation is not new, nor is it associated with a particular discipline, branch of knowledge or area of expertise. For this reason, the (hi)story of geoengineering – i.e. 'the deliberate large-scale intervention in the Earth's climate system in order to moderate global warming' (The Royal Society 2009) – may have different beginnings, may explore (or omit) a variety of episodes and may be told from a particular point of view. These 'qualities' are visible in the fairly recent literature on the topic, where we find a variety of references introducing and contextualising the emergence of geoengineering technologies: the image of Ulysses assisted by, or being a victim of, deliberate weather modification schemes brought about by various gods and goddesses; the tempest conjured up by Prospero in William Shakespeare's play of the same name (Schneider 1996); the diabolical plan to tilt the Earth's axis and melt the polar ice in Jules Verne's novel *The Purchase of the North Pole* (Fleming 2006); the various attempts at artificial rainmaking (Fountain 2003, Fleming 2010, 2007), in what Robert DeCourcy Ward called the stage of 'production' (Ward 1930); the weather control fantasies of military planners and the way these visions shaped some of the weather modification programmes in the Cold War era (Bonnheim 2010, Fleming 2010, 2006, Keith 2000); the common links with the concept of 'terraforming' (Fleming 2010, Yanarella and Rice 2011) and the way its literature (both scientific and fictional) is trying to fill the gaps that still exist in geoengineering literature (Keith 2000).

These are but a few examples of the ubiquitous and eclectic ideas that, in some way, share a common theme with current geoengineering proposals: that which relates human expectations, fears and fantasies with the recurring appeal of the control of nature. Hence, even though some may appear unconnected with the history of geoengineering, such ideas are nonetheless useful in reminding us that recent proposals to geoengineer the climate are just one contemporary manifestation of man's long-standing desire to control nature – an early-twenty-first-century embodiment of the 'Baconian project' of human mastery over nature.

By looking at 'the long history of deceptive and delusional attempts to control nature', Fleming identifies three cycles 'of promise and hype' that capture the pathological features of weather and climate control schemes (Fleming 2006, 2007).

The first cycle, the 'Pluviculturalists', began in the 1840s with the work of the meteorologist James Pollard Espy, who propounded a theory of artificial rainmaking by lighting huge fires.

The second cycle, 'Cloud seeding in the Cold War and Vietnam War eras', began in 1946 with the pioneer experiments in cloud seeding by Irving Langmuir and his associates at the General Electric Research Laboratory, which rapidly evolved from lab science experiments to commercial rainmaking applications, and ultimately 'the attempted weaponization of the clouds' (Fleming 2006).

Three decades later, the term geoengineering was coined by the physicist Cesare Marchetti to describe a proposal for tackling the problem of CO₂ control in the atmosphere with a CO₂ management system, where 'CO₂ is collected at proper fuel transformation points and finally injected into the deep seas taking advantage of natural thermohaline circulations' (Marchetti 1977, vi). Almost at the same time, on the other side of the globe, the Russian climatologist Mikhail Budyko was probing the potential of different techniques to modify the aerosol layer of the stratosphere to prevent the warming of the climate (Schneider 1996, Bonnheim 2010, Budyko 1977).

However, it was only at the beginning of this century that geoengineering entered the mainstream debate on climate change. According to Fleming, the beginning of the third cycle, 'Weather modification in the 21st century' – in which 'discussion of weather and climate modification has returned to the science-policy agenda, framed as seemingly inevitable responses to killer storms and global warming' – coincides with the publication of the U.S. National Research Council report titled "Critical Issues in Weather Modification Research" (National Research Council 2003), and the report commissioned by the U.S. Pentagon, "An Abrupt Climate Change Scenario and its Implications for United States National Security" (Schwartz and Randall 2003). But perhaps the most important impetus came in 2006, with the publication of an editorial essay by Nobel laureate Paul Crutzen in the journal *Climatic Change* (Crutzen 2006) that brought discussions of geoengineering more squarely into the focus of scientific debates (Roger Pielke Jr. 2010).

Yet, to fully understand these events, we have to consider them in the context of increasing doubt and disbelief regarding the commitment of the international community to adequately respond to the problem of global warming. In fact, throughout the 21st century, the geoengineering discourse has been closely coupled with the climate change agenda, being affected by its major convulsions in the scientific and political arenas.

Lastly, the continued misunderstanding and disbelief in the science of climate change, the recognition that global warming is the net result of various institutional failures, and the recent tendency to favour transformational (rather than incremental) responses to this problem, appear to have combined with the major uncertainties of climate change to provide the conditions for geoengineering to emerge as a paradigmatic case 'where facts are uncertain, values in dispute, stakes high and decisions urgent' (Funtowicz and Ravetz 1993, 1994a).

Exploring Geoengineering Debates

Though the idea of weather and climate control is not new, the purpose and extent of climate modification proposals since the beginning of this century seem to have overtaken the original concepts and the scientific questions from which they arose, and have been appropriated by the competing interests that surround climate change science.

The environmental problems and scientific uncertainties that many of the climate engineering schemes evoke are being brought to the centre of the climate change debate, feeding environmental controversies and bringing to light value disputes at the same time as the discourse becomes more and more politicised (Sarewitz 2004).

Against this background, the analysis of geoengineering debates may contribute not only to uncovering the variety of knowledge, values and interests that compete in the climate change science, but also to mapping the dynamics of these debates in the context of the major narratives that are emerging in our society — thus seen as a valuable approach to understanding the mutual

co-production of science and society, in which ‘scientific knowledge both embeds and is embedded in social identities, institutions, representations and discourses’ (Jasanoff 2004).

In this context, approaching geoengineering in a holistic manner is another way of looking at the problem of climate change and the ‘scalar dislocations’ it introduces in modern systems of experience and understanding (Jasanoff 2010). In fact, the ethical, political, environmental and social considerations that surround the debates on geoengineering seem to offer a privileged perspective for rethinking the human place in nature.

Debates around the Definition of Geoengineering

We start the analysis of current debates on geoengineering by focusing on the major disputes around the definition of geoengineering – a term on which the scientific community seems far from reaching a consensus, as has been pointed out by several authors and was made clear in the 2011 IPCC expert meeting on geoengineering.

‘A substantial amount of time in the Expert Meeting was spent in discussing terminology in and around geoengineering. This underlines the ambiguities associated with the term geoengineering and the range of opinions on the subject’ (Boucher, Gruber, and Blackstock 2011, 2).

In fact, many of the controversies surrounding geoengineering start with the lack of consensus regarding the broadness and significance of the term. A look at the recent literature on the topic (scientific articles, books, policy reports and media articles) reveals two major sources of disagreement. The first of these is the different meanings attributed to the term. One example of this may be seen in the confrontation between those authors that suggest that we began geoengineering the Earth’s climate when we started causing significant disturbances to the planetary environment (resulting in a definition of geoengineering closely related to that of the ‘Anthropocene’¹ (Crutzen and Stoermer 2000)), and those espousing definitions that highlight the particular characteristics of the actions carried out with different climate engineering techniques.

‘In its broadest sense, geoengineering involves deliberately modifying the Earth system and its processes to suit societal needs and improve the planet’s habitability. During recent years, discussions of this controversial concept have been confined largely to global-scale engineering approaches intended to counteract the effects of anthropogenic climate change. Proponents of geoengineering point out that humans have been modifying the Earth system and its processes unintentionally for some time; therefore, why not do it in a deliberate manner with specific goals in mind?’ (Greene, Monger, and Huntley, 2010).

As the above quotation suggests, a broad definition of geoengineering tends to underestimate the arguments against the most controversial schemes to modify the energy balance of the atmosphere. By contrast, a narrow definition of the term highlights the intentionality of geoengineering actions, thus calling for a critical examination of the ethical, social, and political issues raised by these proposals.

But even if general agreement could be achieved on the particularities of geoengineering actions, the different types of proposals that the term encompasses seem to be a second source of

¹ Paul Crutzen and Eugene Stoermer coined the term *Anthropocene* to describe a new geological epoch, ‘in which humankind has emerged as a globally significant — and potentially intelligent — force capable of reshaping the face of the planet’ (Clark, Schellnhuber, and Crutzen 2004).

fuzziness more difficult to address. To illustrate this, we briefly present the two different families of methods into which geoengineering schemes are usually classified (The Royal Society 2009):

- i. Carbon Dioxide Removal (CDR) methods, which aim to reduce the concentration of CO₂ in the atmosphere and transfer it to long-lived reservoirs, and
- ii. Solar Radiation Management (SRM) methods, which aim to reduce the amount of solar energy absorbed by the Earth.

The first family of methods includes large-scale engineering approaches, which use either chemical or physical processes to directly remove CO₂ from the atmosphere or the oceans, (e.g. engineered air capture and enhanced weathering techniques), and biologically-based methods seeking to simulate or enhance natural carbon storage processes (e.g. afforestation and reforestation, biomass and biochar, ocean fertilisation methods, among others).

The second family of methods includes some of the most controversial geoengineering proposals. Four groups of techniques have been proposed to reduce the incidence and absorption of incoming solar radiation: i) *Space-based approaches* – reducing the amount of solar energy reaching the Earth by positioning sun-shields in space with the aim of reflecting or deflecting solar radiation; ii) *Changes in stratospheric aerosols* – injecting sulphates or other types of particles into the upper atmosphere, with the aim of increasing the scattering of sunlight back to space; iii) *Increases in cloud reflectivity* – increasing the concentration of cloud-condensation nuclei in the lower atmosphere, particularly over ocean areas, thereby whitening clouds with the aim of increasing the reflection of solar radiation; and iv) *Increases in surface albedo* – modifying land or ocean surfaces with the aim of reflecting more solar radiation out to space (The Royal Society, 2009; Williamson et al. 2012, p.26).

As this brief overview suggests, the different technological characteristics of these proposals, the different costs estimated for each method, the potential efficacy of their use, the levels of uncertainty associated with their deployment, and the distinctive risks they raise result in a multitude of solutions that seem difficult to bring together under the broad umbrella of the term geoengineering.

One of the first attempts to clarify the ambiguity of the term was made in 1996 by Thomas Schelling, who identified the features that geoengineering seems to imply: global, intentional and unnatural interventions (Schelling 1996). Four years later, David Keith took this proposal further by pointing to the three core attributes that serve as ‘markers of geoengineering’ actions: the scale (global or continental), the intent (the deliberate nature of the action rather than a side effect of it) and the degree to which the action is a countervailing measure (Keith 2000). The reasons for replacing ‘unnatural’ features by the ‘degree to which the action is a countervailing measure’ were not properly explained – even though this had implications for the type of proposals that the term encompasses².

² In order to exemplify these implications it seems appropriate to refer briefly to the use of weather modification techniques (such as cloud seeding and hurricane suppression) that are taking place in many countries around the world. As recently stated by the World Meteorological Organisation: ‘since the 1980’s there has been a decline in support for weather modification research, and a tendency to move directly into operational projects’ (WMO 2010). Given the similarities between weather modification (WM) techniques and some geoengineering methods, the concerns raised by the increasing number of WM operational programmes (fog dispersion, rain and snow enhancement and hail suppression) have gained momentum in the context of the contemporary debates on geoengineering — leading, almost inevitably, to a discussion on the criteria that differentiate these two domains. However, although widely mentioned, the scale marker seems to be insufficient to exclude WM techniques from the vast range of methods that the term geoengineering encompasses. This becomes clear from the way the ‘countervailing measure criterion’ has been evoked, namely by drawing attention to the differences between ‘weather’ and ‘climate’ modification techniques, and to the far-reaching consequences of the latter: ‘Weather modifications such as cloud seeding which affect the weather for no longer than a season, in our view, do not fall within the definition of geoengineering (...) We conclude that weather techniques such as cloud seeding should not be included within the definition of geoengineering used for the purposes of activities designed to effect a change in the global climate with the aim of minimising or reversing anthropogenic climate change’ (UK House of Commons. Science and Technology Committee 2010, 15). Nonetheless, it is telling that according to this same report: ‘Cloud seeding could affect climate when carried out over a long period’ (Idem).

Nevertheless, these three markers seem to translate the meaning of the term geoengineering as commonly used by the scientific community nowadays, furthering the conceptual distinction between geoengineering proposals and other responses to climate change.

However, in considering the ethical issues raised by these technologies, it becomes clear that these markers tend to hinder the various values, rationales and normative assumptions underlying the range of CDR and SRM techniques considered under the broad umbrella of the term geoengineering. As mentioned by Gardiner, the ethical discussion of geoengineering is made more difficult by the complexity of the terrain:

‘First, a number of interventions are already being proposed for combating climate change, and it is not clear that all of them should be classified together. For example, some suggest deflecting a small percentage of incoming radiation from the Sun by placing huge mirrors at the Lagrange point between it and the Earth, some advocate fertilizing the oceans with plant life to soak up more carbon dioxide, some suggest a massive program of reforestation, and some propose capturing vast quantities of emissions from power plants and burying them in sedimentary rock deep underground. But do these interventions raise the same issues? Should we count all of them as “geoengineering”?’ (Gardiner 2010, 285).

To overcome the obstacles raised by the broadness of the term, Bunzl appeals to the methodological distinction between small ‘g’ proposals and big ‘G’ proposals³. According to the author, this distinction is fundamental to deconstructing some of the common arguments for advancing further and faster in geoengineering research. In fact, because big ‘G’ proposals fall into a specific class of scientific endeavours (where the object of interest is not ‘modular’ or ‘encapsulated’), they generate a set of methodological challenges, allowing the moral argument as to ‘whether research should be done’ to give way to the methodological argument as to ‘whether it could be done’ — thus shifting the burden of proof to the proponents of geoengineering.

‘But what if the object of your interest is not modular or encapsulated? What do you do then? For that, after all, is the feature that big “G” geoengineering proposals have in common. They call for interventions on systems that lack just this characteristic. You cannot encapsulate part of the atmosphere and it is too complex to be able to build a realistic non-virtual model at scale. As such, it is reasonable to ask whether we could ever have a sound basis for moving to full deployment of any such proposed intervention. And if not, then why bother to even research such proposals in the first place?’ (Bunzl 2009, 2).

It seems most reasonable to question the feasibility of geoengineering research in light of its object of interest. Indeed, the pressure of practice under which science operates today (Carrier 2011) is giving rise to the emergence of new objects of research – ambivalent beings, hybrid products and theoretically constructed objects through which we gain a new understanding and control of nature – that call for a more careful consideration of the complex narratives and practices of science and technology (Funtowicz and Ravetz 1993, 1994b, Latour 1987, Law 2002, Haraway 1997, Michael 2006).

³ ‘Of course there is geoengineering and then there is GEOENGINEERING. Nobody gets very wound up about the idea of planting trees or painting roofs white as instances of geoengineering — which is not to say that they will necessarily do much good. The kind of geoengineering that elicits howls of disapproval is grander than this — it is things like space mirrors, sulphur injection into the upper atmosphere, and iron fertilisation of the oceans — it is the idea of intervention on a grand scale’ (Bunzl 2009).

Following this appeal, some authors have suggested that it is precisely at the level of these objects of research that we can find the meaningful distinction between science and technoscience, an ontological difference that ‘becomes more explicit when research results are presented in particular settings and when the objects of research are exhibited for the specific interest they hold’ (Bensaude-Vincent et al. 2011, 365). Accordingly, and by way of illustration, it could be said that when the result of a global climate model experiment is presented as scientific evidence for understanding the role of aerosols in climate forcing, this would conform to traditional conceptions of science. However, when sulphate aerosols are presented for their capacity to counteract the climate forcing of growing CO₂ emissions, this should be seen as a ‘hallmark of technoscience’.

As we will see next, many of the controversies surrounding geoengineering go beyond the ambiguities of the term. However, and as pointed by Bunzl, some important questions regarding the research, governance and deployment of these technologies can only be properly answered if we consider the significant differences between the multitude of proposals that the term encompasses.

Unveiling the Multiple Narratives behind Geoengineering Discourses

An overview of the subject of geoengineering may be extremely illustrative, but also bewildering, with regard to the controversies that the term encompasses. At first glance, one may be frightened by the revisited version of Edvard Munch’s ‘The Scream’ on the cover of the report of the ETC Group, entitled ‘Geopiracy – The Case Against Geoengineering’ (ETC Group 2010). Perhaps one may also find this reference in a suggested comparison between the way the Krakatoa eruption inspired Munch to create this work and the way the eruption of Pinatubo inspired geoengineers to cool the Earth (Hamilton 2010). One may come across the variety of histories that feed ‘chemtrails’ theories⁴, or one of the scientific studies that compare different geoengineering options (Keith and Dowlatabadi 1992, Keith 2000, National Research Council 1992, Vaughan and Lenton 2011). By chance, one may stumble over a few of the various attempts to rank these options: some evocative but difficult to assess (Adam 2009), others suggesting a scientific asset (Boyd 2008, Lenton and Vaughan 2009, The Royal Society 2009), and yet others being sarcastic about this last possibility (Singer-Vine 2010). Lastly, one will most likely end up with Meinrat Andreae’s decadent image of our society’s addiction to fossil fuels, ‘It’s like a junkie figuring out new ways of stealing from his children’ (Morton 2007), or with one of the many meaningful terms that populate the geoengineering world: ‘back-up plan’ (Inman 2010); ‘catastrophic climate change’ (Gardiner 2011, Hegerl and Solomon 2009); ‘climate anxiety’ (Bonnheim 2010); ‘covert geoengineering’ (Lawrence 2006); ‘emergency brake’ (Brovkin et al. 2009); ‘fallback strategy’ (Keith 2002, Keith and Dowlatabadi 1992); ‘geohack’ (Singer-Vine 2010); ‘global thermostat’ (Goodell 2010); ‘planet-hacking techniques’ (Kintisch 2010); ‘planetary medicine’ (Lovelock 2008, 2009); ‘predatory geoengineering’ (Gardiner 2011); ‘retooling the planet’ (Bronson, Mooney, and Wetter 2009); ‘stopgap’ (Barrett 2008, Bunzl 2009); ‘technological fix’ (Montenegro and Greenwood 2009)...

Despite the confusion a first glance may suggest, a more detailed analysis of the literature in the field may be extremely valuable in understanding the particular kinds of knowledge, values and interests that are competing in the climate change debate and in uncovering some of the dominant narratives that operate at different levels of society.

One reasonable and logical way of digging through the debates on geoengineering is ‘to collect, structure, and relate the very different arguments that have been advanced for and against climate engineering’ (Rickels et al. 2011): the ‘moral hazard argument’ (The Royal Society

⁴ The term ‘chemtrail’ is derived from ‘chemical trail’ and specifically refers to chemical or biological agent trails left by aircraft for a purpose undisclosed to the general public, allegedly causing respiratory illnesses and other health problems.

2009); the ‘the slippery slope’ argument; the ‘technical fix’ argument; the ‘unpredictability’ argument (Keith 2000); the ‘lesser evil’ argument; the ‘arm the future’ argument, the ‘cost-effectiveness’ argument; the ‘research first’ argument; the ‘stalking horse’ argument (Gardiner 2010, Gardiner 2011); the ‘common sense’ argument (Jamieson 1996); the ‘desperation argument’ (Gardiner 2012), etc. These different arguments tend to be linked around the main theses that have been identified in the debate on the pros and cons of geoengineering research and deployment (Betz and Cacean 2012, Rickels et al. 2011) and illustrate the diversity of attempts in this area. Many of these arguments emerge in the debates in and around the ‘grey zones’, or interfaces, between science, policy and society (Siune et al. 2009), and can be grouped, for systematisation purposes, into three interconnected domains: i) geoengineering research and experimentation; ii) geoengineering regulation and governance, and iii) geoengineering implementation and misuse (Figure 1) .

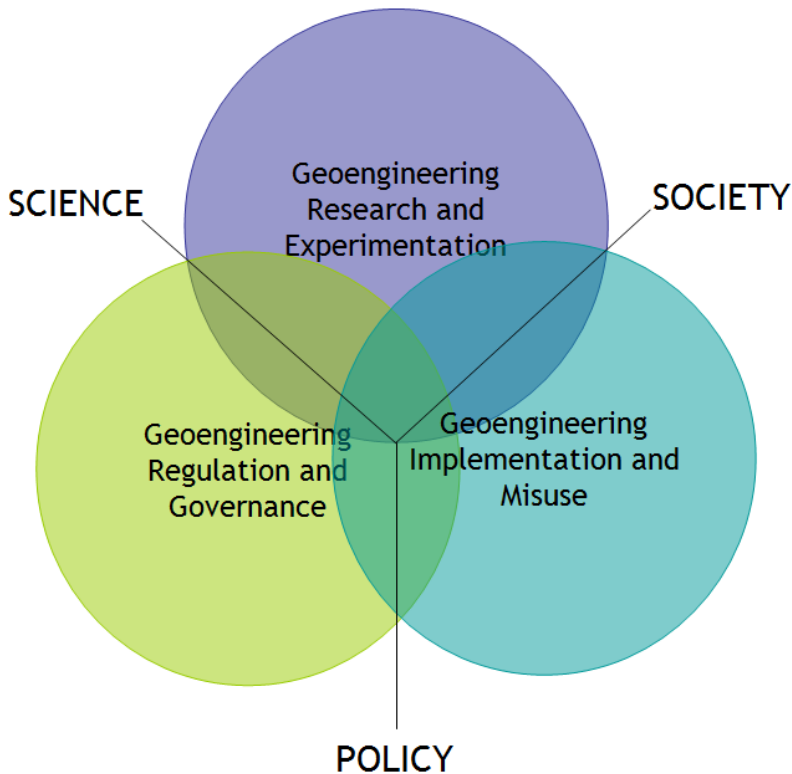


Figure 1– Domains within which Current Debates on Geoengineering Can Be Grouped

Geoengineering Research and Experimentation

In this first domain, we have identified some of the most active disputes over geoengineering, which is not surprising given that research is the stage where much of the geoengineering proposals currently are at and experimentation is the expected next step. The construction of the arguments varies, but in general they fall into three major groups:

- i) The first group holds that geoengineering, along with mitigation and adaptation, is a valid and unavoidable response to climate change, so we must invest in geoengineering research in order to be prepared for a likely climate emergency:

‘The rate of increase of climate change, along with the continuing increase in emissions of greenhouse gases, has created a very serious predicament for the world. Drastically reducing the world’s use of fossil fuels will take time and may raise near-term costs for energy, even after the effort gets seriously started and production costs for new energy technologies drop. As a result, global warming is likely to press up against or even exceed the level that the Commission of European Communities, for example, has concluded is likely to lead to dangerous and unacceptable consequences. For this reason, it seems prudent for the nations of the world to initiate an effort in geoengineering (...)’ (MacCracken 2009, 33).

This argument finds its support in two inter-related narratives of technoscientific progress that tend to shape and frame key dimensions of science and governance: the risk of dismissing a ‘promising technology’ and the ‘speed imperative’ that impels us to act immediately ‘before it is too late’ (Felt et al. 2007). Furthermore, this argument often appears coupled with another, that of the ‘incredible economics of geoengineering’ (Barrett 2008).

ii) The second group, and perhaps the most significant, regards geoengineering with reserve but considers it would be a mistake to ban geoengineering research without first reducing the uncertainties surrounding the associated benefits and risks, claiming that it is premature to discard these options without carrying out adequate, though ‘moderate’, research into the topic (Blackstock and Long 2010, Blackstock et al. 2009, Robock 2008, 2011).

‘The reasons why geoengineering may be a bad idea are manifold, though a moderate investment in theoretical geoengineering research might help scientists to determine whether or not it is a bad idea’ (Robock 2008).

This strong argument is sustained by the new credo of ‘evidence-based’ decision making, where facts must precede any exercise of values.

iii) The third group comprises arguments against geoengineering research – particularly research into SRM methods. The arguments are of two kinds:

- those opposing geoengineering solutions on principle, on the basis of the common sense belief that ‘two wrongs do not make a right’, and
- those challenging the soundness of the arguments in favour of geoengineering research, in this way trying to deconstruct some of the narratives on which they are based.

Since the first kind of argument concerns the validity of geoengineering solutions, it does not directly address the specific case of geoengineering research (which is assumed to be as doubtful as the concept itself). Here, we can find many of the arguments that try to demolish the ‘techno-fix’ ideas behind geoengineering solutions: SRM methods do not address the root cause of anthropogenic climate change; geoengineering is ‘unnatural’ and SRM technologies are objectionable (Jamieson 1996, NERC 2010a, b); we have to find a place consistent with the limits of nature (Bunzl 2009) and technology cannot replace the process of ‘social engineering’ (Weinberg 1991) that this goal implies.

The second kind of argument against geoengineering research tends to emerge in the ethical discussion of the subject (Keith 2000, Gardiner 2011, Bunzl 2009, Victor et al. 2009, Jamieson 1996, Hamilton 2013). Morrow, Kopp and Oppenheimer present a clear synthesis of these arguments:

‘There are four ethical reasons to worry about performing climatic SWCE⁵ research at all, over and above its effects on humans, animals, and ecosystems. First, pursuing

⁵ In this paper the authors refer to SRM as “short-wave climate engineering” (SWCE).

SWCE solutions to climate change may create a moral hazard, exacerbating the challenge of mitigating emissions. Second, SWCE research may lead to development of technologies that could be used for nefarious purposes. Third, beginning SWCE research in earnest may create interest groups within scientific or business communities that would have strong incentives to push for SWCE (or at least SWCE research) even if it turns out to be unwise. Finally, money spent on SWCE research is unavailable for other kinds of research, such as on the mitigation of or adaptation to climate change' (Morrow, Kopp, and Oppenheimer 2009).

Discussions about governance mechanisms and basic principles to guide future geoenvironmental research tend to highlight the profound reorientation of technoscientific practices in contemporary societies – of what has been seen as a major shift from the 'laboratory ideal' to the 'field ideal' of experimentation (Schwarz and Krohn 2011). Indeed, the recognition that 'several geoenvironmental technologies are demonstrably non-encapsulated' (Bracmort and Lattanzio 2013, 5) tends to further polarise the debate. On the one hand, those who call for 'a moratorium on all geoenvironmental activities outside the laboratory' (ETC Group 2010, 40). On the other hand, those who consider that the 'least risky option would involve starting with small-scale field experiments and gradually ramping up the scale' (Eccleston and March 2011, 358).

'Another key question is how to address further research. Proponents of further research argue that it is needed in order to obtain reliable information about the feasibility and risks. However, this would at some stage require real-world field experiments that would have to be gradually scaled up in order to know the impacts of a particular technique and whether it is effective. Apart from the difficulty of drawing the line between research and deployment, most existing rules of international law do not make this distinction' (Bodle 2013, 468).

And once again, Morrow, Kopp and Oppenheimer provide an interesting point of view on this subject, introducing the 'narrative of ethics' to the debate, and suggesting that climatic SWCE research⁶ is very similar to nuclear weapons testing. They thus propose careful ethical consideration guided by three principles derived from the ethics literature on research with human and animal subjects:

'The Principle of Respect requires that the scientific community secure the global public's consent, which would need to be voiced through their representatives and given for any studies within specified parameters, rather than on a case-by-case basis. The Principle of Beneficence and Justice requires that researchers strive for a favorable risk-benefit ratio and a fair distribution of risks and anticipated benefits, all while protecting the basic rights of the individuals affected. Finally, the Principle of Minimization requires that no study last longer, cover a greater geographical extent, or exert a greater influence on the climate than is necessary to test the specific hypotheses in question' (Morrow, Kopp, and Oppenheimer 2009, 1).

A similar position was articulated in the "Oxford Principles", a set of five overarching principles for governance of geoenvironmental research: (i) geoenvironmental to be regulated as a public good; (ii) public participation in geoenvironmental decision-making; (iii) disclosure of geoenvironmental research and open publication of results; (iv) independent assessment of impacts; and (v)

⁶ According to the authors, other kinds of climate engineering research (such as modelling studies and engineering studies) do not raise the same concerns as climatic studies – which aim '*to determine the climatic response to climate engineering and therefore could have widespread impacts on both human populations and the biosphere*'.

governance before deployment (Rayner et al. 2013, Rayner et al. 2009). This leads us to the second domain of the geoengineering debate: that of geoengineering regulation and governance.

Geoengineering Regulation and Governance

In this second domain, the debate revolves around two main concerns: the need i) to regulate specific geoengineering activities (large-scale research projects, small-scale field tests, field experiments, trial deployment and implementation) and ii) to balance carefully the technical, legal, ethical, economic and social concerns in a policy and governance framework, which is 'international in scope and remains flexible in light of fresh evidence' (The Royal Society 2009). If the first domain suggests that we are in the sphere of geoengineering science, here we feel we are crossing into the sphere of geoengineering politics:

'As geoengineering is considered more seriously, the question of norms to govern deployment will arise. Norms might be needed not only to determine when such systems might be used but also the kinds of evaluations that geoengineers might be required to make before deployment, compensation for parties harmed, cost sharing, and commitments to maintain geoengineering systems once deployed' (Victor 2008, 330).

In fact, in this second domain the debate tends to move from the functioning of science to its interactions with policy and society, particularly by exploring three major narratives:

i) The narrative of ethics, which introduces the questions of public value into the geoengineering field to overcome the difficulties of ensuring 'citizen representation' and the concerns of legitimacy associated with this (thus providing the basis for discussing the permissibility of the most controversial schemes and becoming an important legitimising factor for geoengineering activities). In the debate on geoengineering regulation and governance, this narrative focuses primarily on the concepts of fairness and justice, drawing upon formulations of environmental ethics and ethical and legal guidelines for human and animal subjects research (Miller 2010a, Morrow, Kopp, and Oppenheimer 2009, Keith 2002):

'Yet, for me, phrases like "legitimate international process" and "all stakeholders" sound too much like climate scientists and government diplomats getting together to decide the fate of the planet. That hasn't worked so well so far, and not only because vulnerable developing countries have not been adequately consulted. So what kind of governance process do we need? To my mind, a potentially potent analogy is that of informed consent in human subjects research. Just like geoengineering research, human subjects research brings potentially significant public and private benefits by alleviating disease, injury, and even death. Yet, because such research is also very dangerous, societies have adopted strict regulations for the conditions under which that research can be done' (Miller 2010a).

ii) The narrative of failure, which spotlights the side effects and unintended consequences of geoengineering proposals, and therefore calls for the adoption of precautionary approaches and global, transparent and effective control and regulatory mechanisms. This narrative informs the politics of geoengineering, being particularly evident in the discussion of the risks surrounding field experiments with such technologies, concerns about unilateral attempts to conduct large-scale geoengineering actions, and the way they may weaken conventional mitigation and adaptation efforts, in what is referred to as the 'moral hazard' argument:

'In the context of geoengineering, the risk is that major efforts in geoengineering may lead to a reduction of effort in mitigation and/or adaptation because of a premature

conviction that geoengineering has provided ‘insurance’ against climate change’ (The Royal Society 2009, 37).

iii) Lastly, the ‘valid science’ narrative, suggesting possible ways to promote further ‘strategic research’ in the geoengineering field, the establishment of appropriate institutions for geoengineering governance, and greater citizen involvement, and calling for climate change science to become more critically reflective about its own role and impact. The ‘valid science’ narrative, appears under different forms on discourses of geoengineering regulation and governance, being particularly prominent in the debate on the involvement of relevant international scientific organisations, the establishment of international bodies and the first attempts to devise possible configurations to govern the research and deployment of geoengineering technologies (Olson 2011, Bodansky 2011, 2012, Bracmort and Lattanzio 2013).

‘Meaningful research may also require actual trial deployment of geoengineering systems so that norms are informed by relevant experience and command respect through use. Standard methods for international assessment organized by the Intergovernmental Panel on Climate Change (IPCC) are unlikely to yield useful evaluations of geoengineering options because the most important areas for assessment lie in the improbable, harmful, and unexpected side effects of geoengineering, not the ‘consensus science’ that IPCC does well’ (Victor 2008, 321).

Together, these intertwined narratives tend to invoke the concept of ‘good governance’, which refers to the ‘principles of openness, participation, accountability, effectiveness and coherence’, and the need for science to function properly, i.e. ‘assuring the productive functioning of its endeavours, and the maintenance of scientific integrity’ (Siune et al. 2009).

Geoengineering Implementation and Misuse

The third domain includes the discussions surrounding the benefits and risks of using geoengineering to counteract global warming. While on the one hand we are still in the domain of empirical science, surrounded by simulation models that seek to address the climatic consequences of geoengineering schemes (Matthews and Caldeira 2007, Lenton and Vaughan 2009) and attempts to assess and rank different geoengineering methods – in terms of efficiency, affordability, safety, controllability, timeliness, reversibility, among others (The Royal Society 2009, Vaughan and Lenton 2011, Boyd 2008, Bellamy et al. 2012) – on the other hand we are also in the domain of ‘geoengineering plausibility’, where expectations, fears, fantasies, beliefs, and, of course, scientific expertise conspire to produce visions of *geoengineered worlds*.

The discourses about geoengineering implementation range from expert reviews that examine the potential advantages, drawbacks and risks of the different schemes to recent participatory processes that seek to elicit public and/or stakeholder views and perceptions of geoengineering (Bellamy et al. 2012). In these discourses we find many of the narratives previously identified, now being used to fill the empty spaces left by the inherent uncertainties associated with geoengineering technologies and climate change science. The positions vary and are not consistent with the traditional divisions usually found in the climate change debate — a ‘quality’ of the geoengineering debate that was already stressed by Dale Jamieson in 1996:

‘The recent debate makes for strange bedfellows. Many of those who believe most strongly that climate change is occurring are reluctant to embrace geoengineering approaches to reversing it. This is because they believe that the ‘hand of man’ is implicated in most of our environmental problems and they see geoengineering as more of the same. Others, who are interested in exploring or developing geoengineering possibilities, are disinclined to believe that climate is changing. On their view planetary

systems are relatively insensitive to human behaviour and for that reason we shouldn't worry too much about the risks of geoengineering. So to simplify: some people believe that there is a problem but that geoengineering is no solution; others believe that geoengineering is a solution but that there is no problem' (Jamieson 1996, 323).

This quotation is one of the many that emphasise the ambiguity and lack of correspondence between the various grey shades of geoengineering positions and the common black/white division between climate 'alarmists' and climate 'sceptics', which reinforces the importance of looking at geoengineering holistically.

Such a look is particularly relevant in examining the discourses about the potential misuses of geoengineering technologies, which should be considered in the broader context of the history of weather and climate modification, where many of the attempts to advance these technologies did not have peaceful intentions (Keith 2000, Fleming 2006, 2007, 2010, Bonnheim 2010)⁷. In fact, the narratives about the risk of hostile uses of geoengineering technologies should be seen not only in the context of climate modification history, but also in the context of other potential harmful technologies:

'It may be possible to reduce the risk of intentional misuse through governance arrangements such as those that have been used to control nuclear, biological and chemical weapons. Similarly, it may be possible to prevent risks from unintentional misuse through sound regulation. However, in some cases the only effective measures for reducing risk may also forestall beneficial uses of geoengineering, for example by having a general chilling effect on scientific progress in this area' (Powell et al. 2010, 2).

Concluding Remarks: Furthering the 'Democratisation and De-alienation' of the Geoengineering Debate

Using the internet as a primary source of information, we started our investigation by collecting different kinds of materials, including scientific articles, books, policy reports, films, interviews, media news and blog comments. We then analysed them to identify the main debates around geoengineering technologies.

Through this analysis we have identified three interconnected areas of current debate on geoengineering: geoengineering research and experimentation; geoengineering regulations and governance; and geoengineering implementation and misuse (Figure 1). Within these areas we have also identified the main arguments called into question in the geoengineering debates and the underlying 'master narratives' in which they are embedded (Figure 2).

The significance of geoengineering proposals can only be grasped in the context of the wider 'imaginary' of science and technology in which geoengineering narratives are rooted. Hence, we suggest examining those debates further, taking into consideration the dominant narratives of science, technology and society.

⁷ Leading to the ratification of the UN Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD) in 1978.

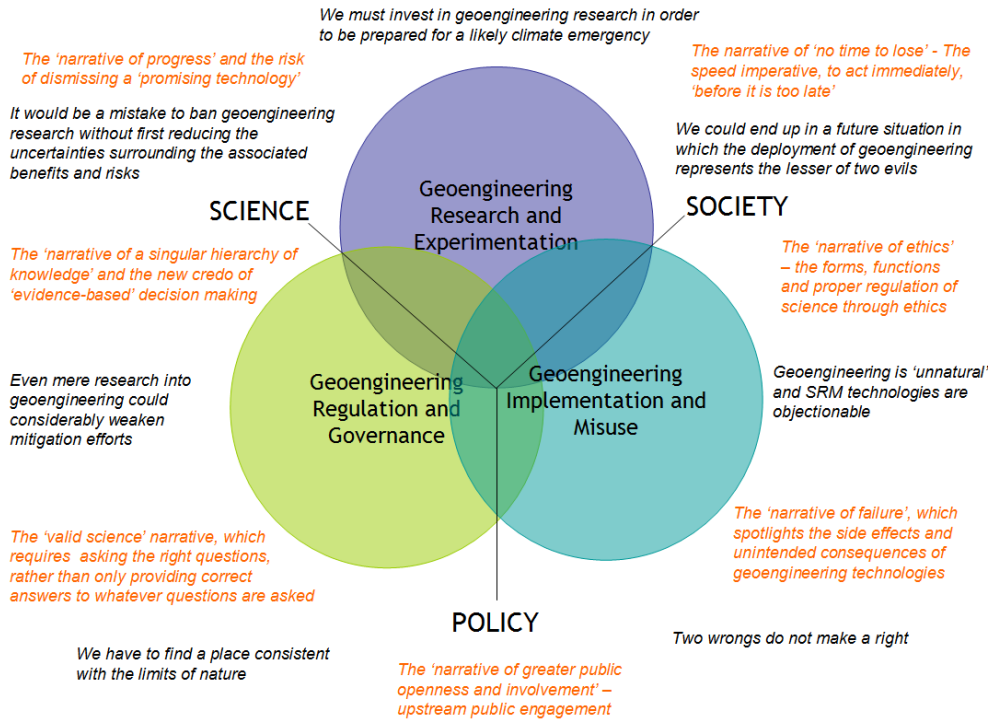


Figure 2 – The three interconnected domains in which geoengineering debates are taking place: main arguments and underlying master narratives.

Different conceptions, understandings and value assumptions concerning the changing relationships between science and society, science and technology, and science and nature tend to shape the geoengineering debate and inform the analytical framework within which the geoengineering domain has been problematised (Scholte, Vasileiadou, and Petersen 2013, Sikka 2012, Huttunen and Hildén 2013, Luokkanen, Huttunen, and Hildén 2013, Nerlich and Jaspal 2012). This reinforces the need to unbind geoengineering discourses from the deeply embedded narratives of science, technology and society that present technoscientific innovation as the solution to our most critical problems and as a substitute for social change. Similarly, the construction of narratives that give meaning to human action within nature, and provide guidance for humans' domination of nature, deserves a more critical and open reflection than has been the case to date. As a result, many authors have been highlighting how important it is to consider public perceptions of geoengineering and therefore to help reveal the perceived moral orders underlying geoengineering proposals (Boyd 2008, Bracmort and Lattanzio 2013, Cicerone 2006, Miller 2010b, The Royal Society 2009).

The need for democratic decision-making and public engagement in the area of geoengineering has been clear for some time now (Jamieson 1996). However, only recently have the practical implications and challenges of such demands begun to be properly considered (Morton 2007, Miller 2010a, b, Powell et al. 2010, Bracmort and Lattanzio 2013, ETC Group 2010, NERC 2010a, Orr et al. 2011, CSPO 2010, Debatepedia 2009, Parkhill and Pidgeon 2011, Macnaghten and Owen 2011, Corner, Pidgeon, and Parkhill 2012, Poumadère, Bertoldo, and Samadi 2011).

In the context of current 'policy vacuums', characterised by 'a growing sense of urgency coupled with a lack of knowledge of what to do and a lack of institutions where the issues could

be addressed' (Rommetveit, Funtowicz, and Strand 2010), these initiatives assume critical importance. And though the scope, scale and complexity of the climate change issues tend to 'render the fulfilment of the deliberative ideal a practical impossibility' (*Idem*), the recurrent claims that argue for a closer connection between science and society, with the purpose of exposing to public scrutiny the hidden assumptions, values and visions that are deeply embedded in geoengineering proposals, seem more than justified.

Therefore, in supporting the need to subject the scientific debate on geoengineering to more open and critical reflection, we highlight the importance of rebuilding the 'geoengineering scientific worldview' on social processes of trust and credibility (Irwin and Wynne 1996), in this way impelling climate change science to better reveal the competing interests, values and assumptions of climate engineering proposals. We also see this as an opportunity to promote critical thinking about social problems that tend to be 'circumvented' and reduced to technological fixes (Weinberg 1991), thus 'alienating' and 'diverting' our attention from an essential question, that of our place in nature.

In fact, the debates on climate engineering seem to offer an excellent framework within which to examine how modern science's 'alienation from the earth' is leading to the 'alienation from the world' (Arendt 1958), a condition clearly depicted by Funtowicz and Strand:

'Barring and bracketing the environmentalist talk – which also has been an important part of our own talk – of planetary dangers, we would like to propose that the planet is indeed not the object at risk. The object at risk is we ourselves as a collective (present and future) subjectivity and agency: the human right behind the human rights: that of personhood and hope. With personhood and hope in focus, the challenge is not the usual of what to do but, more importantly, how to do it as certain avenues of action are now deemed unacceptable' (Funtowicz and Strand 2011, 8).

REFERENCES

- Adam, David. 2009. Five extreme ways to beat climate change. *The Guardian*, <http://www.guardian.co.uk/environment/2009/nov/04/extreme-climate-change-solutions/print>.
- Arendt, Hannah. 1958. *The Human Condition*. 2nd ed. Chicago: The University of Chicago Press.
- Barrett, Scott. 2008. "The Incredible Economics of Geoengineering." *Environmental and Resource Economics* no. 39 (1):45-54.
- Bellamy, Rob, Jason Chilvers, Naomi E. Vaughan, and Timothy M. Lenton. 2012. "A review of climate geoengineering appraisals." *Wiley Interdisciplinary Reviews: Climate Change* no. 3 (6):597-615. doi: 10.1002/wcc.197.
- Bensaude-Vincent, Bernadette, Sacha Loeve, Alfred Nordmann, and Astrid Schwarz. 2011. "Matters of Interest: The Objects of Research in Science and Technoscience." *Journal for General Philosophy of Science* no. 42 (2):365-383. doi: 10.1007/s10838-011-9172-y.
- Betz, Gregor, and Sebastian Cacean. 2012. *Ethical Aspects of Climate Engineering*. Karlsruhe: KIT Scientific Publishing.
- Blackstock, Jason J., David S. Battisti, Ken Caldeira, Douglas M. Eardley, Jonathan I. Katz, David W. Keith, Aristides A. N. Patrinos, Daniel P. Schrag, Robert H. Socolow, and Steven E. Koonin. 2009. *Climate Engineering Responses to Climate Emergencies*. Novim Study Group, 2009 [cited 20.09.2010. Available from <http://arxiv.org/ftp/arxiv/papers/0907/0907.5140.pdf>.
- Blackstock, Jason J., and Jane C. S. Long. 2010. "The Politics of Geoengineering." *Science* no. 327 (5965):527-. doi: 10.1126/science.1183877.
- Bodansky, Daniel. 2011. "Governing Climate Engineering: Scenarios for Analysis". *Discussion Paper 2011-47*, Harvard Project on Climate Agreements, Belfer Center for Science and International Affairs.
- Bodansky, Daniel. 2013. *The Who, What, and Wherefore of Geoengineering Governance*. SSRN 2012 [cited May 11 2013]. Available from <http://ssrn.com/abstract=2168850>
- Bodle, Ralph. 2013. "Climate Law and Geoengineering." In *Climate Change and the Law*, edited by Erkki Johannes Hollo, Kati Kulovesi and Michael Mehling, 447-471. Dordrecht: Springer.
- Bonnheim, Noah Byron. 2010. "History of climate engineering." *Wiley Interdisciplinary Reviews: Climate Change* no. 1 (6):891-897.
- Boucher, O., N. Gruber, and J. Blackstock. 2011. "Summary of the Synthesis Session" In: *IPCC Expert Meeting Report on Geoengineering*. [O. Edenhofer, C. Field, R. Pichs-Madruga, Y. Sokona, T. Stocker, V. Barros, Q. Dahe, J. Minx, K. Mach, G.-K. Plattner, S. Schlömer, G. Hansen, M. Mastrandrea (eds.)] IPCC Working Group III Technical Support Unit, Potsdam Institute for Climate Impact Research, Potsdam, Germany.
- Boyd, Philip W. 2008. "Ranking geo-engineering schemes." *Nature Geoscience* no. 1:722-724. doi: 10.1038/ngeo348.
- Bracmort, Kelsi, and Richard K. Lattanzio. 2013. "Geoengineering: Governance and Technology Policy" (Congressional Research Service Report No. R41471). Available from <http://www.fas.org/sgp/crs/misc/R41371.pdf>.
- Bronson, Diana, Pat Mooney, and Kathy Jo Wetter. 2009. *Retooling the Planet? Climate Chaos in the Geoengineering Age*. A report prepared by ETC Group for the Swedish Society for Nature Conservation. Stockholm: Swedish Society for Nature Conservation. Available from <http://www.etcgroup.org/content/retooling-planet-new-etc-group-report-geoengineering>

- Brovkin, Victor, Vladimir Petoukhov, Martin Claussen, Eva Bauer, David Archer, and Carlo Jaeger. 2009. "Geoengineering climate by stratospheric sulfur injections: Earth system vulnerability to technological failure." *Climatic Change* no. 92 (3):243-259.
- Budyko, Mikhail Ivanovich. 1977. *Climatic Changes*. Gidrometeoizdat, Leningrad (R) (1977) English translation by American Geophysical Union, Washington D.C. 261 pp.
- Bunzl, Martin. 2009. "Researching geoengineering: should not or could not?" *Environmental Research Letters* no. 4 (4):1-3. doi: 10.1088/1748-9326/4/4/045104.
- Carrier, Martin. 2011. "Knowledge, Politics, and Commerce: Science Under the Pressure of Practice." In *Science in the Context of Application*, edited by Martin Carrier and Alfred Nordmann, 11-30. Dordrecht: Springer.
- Cicerone, Ralph J. 2006. "Geoengineering: Encouraging Research and Overseeing Implementation" *Climatic Change* no. 77:221-226. doi: 10.1007/s10584-006-9102-x.
- Clark, William C., Hans J. Schellnhuber, and Paul J. Crutzen. 2004. "Science for Global Sustainability: Toward a New Paradigm." In *Earth System Analysis for Sustainability*, edited by Hans J. Schellnhuber, Paul J. Crutzen, William C. Clark, Martin Claussen and Hermann Held, 1-28. Cambridge, MA: MIT Press.
- Corner, A., N. Pidgeon, and K. Parkhill. 2012. "Perceptions of geoengineering: Public attitudes, stakeholder perspectives, and the challenge of 'upstream' engagement." *Wiley Interdisciplinary Reviews: Climate Change* no. 3 (5):451-466. doi: 10.1002/wcc.176.
- Crutzen, Paul J. 2006. "Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma?" *Climatic Change* no. 77:211-219.
- Crutzen, Paul J., and Eugene F. Stoermer. 2000. "The "Anthropocene".*" Global Change Newsletter* no. 41:12-13
- CSPO. *Citizens' Engagement Program with High School Students. Tinkering with the Temperature of Planet Earth: A citizens' deliberation on climate geoengineering*. Arizona State University, Consortium for Science, Policy & Outcomes 2010 [cited 02.02.2011. Available from <http://www.cspo.org/projects/highschooldeliberation/geo.htm>.
- Debatepedia. *Debate: Geoengineering. Is geoengineering a good idea?* 2009 [cited 12.02.2011. Available from http://debatepedia.idebate.org/en/index.php/Debate:_Geoengineering.
- Eccleston, Charles H., and Frederic March 2011, *Global Environmental Policy: Concepts, Principles and Practice*. Boca Raton, FL: CRC Press.
- ETC Group. 2010. *Geopiracy - The Case Against Geoengineering*. Ottawa, Canada: ETC Group. Available from <http://www.cbd.int/doc/emerging-issues/etcgroup-geopiracy-2011-013-en.pdf>
- Felt, U., B. Wynne, M. Callon, M. E. Gonçalves, S. Jasanoff, M. Jepsen, Pierre-Benoît Joly, Z. Konopasek, S. May, C. Neubauer, A. Rip, K. Siune, A. Stirling, and M. Tallacchini. 2007. *Taking European Knowledge Society Seriously*, Report of the Expert Group on Science and Governance to the Science, Economy and Society Directorate, Directorate-General for Research, European Commission, Luxembourg.
- Fleming, James R. 2006. "The pathological history of weather and climate modification: Three cycles of promise and hype." *Historical Studies in the Physical and Biological Sciences* no. 37 (1):3-25.
- Fleming, James R. 2007. "The Climate Engineers. Playing God to Save the Planet." *Wilson Quarterly*, Spring 2007, no. 31:46-60.
- Fleming, James R. 2010. *Fixing the Sky - The checkered history of weather and climate control, Columbia studies in international and global history*. New York: Columbia University Press.
- Fountain, Henry. 2003. "The Science of Rain-making is still patchy." *New York Times* (October 19, 2003).

- Funtowicz, Silvio O., and Jerome R. Ravetz. 1993. "Science for the post-normal age." *Futures* no. 25 (7):739-755. doi: 10.1016/0016-3287(93)90022-L.
- Funtowicz, Silvio O., and Jerome R. Ravetz. 1994a. "Emergent complex systems." *Futures* no. 26 (6):568-582. doi: 10.1016/0016-3287(94)90029-9.
- Funtowicz, Silvio O., and Jerome R. Ravetz. 1994b. "Uncertainty, Complexity and Post-Normal Science." *Environmental Toxicology and Chemistry* no. 13 (12):1881-1885.
- Funtowicz, Silvio O., and Roger Strand. 2011. "Change and Commitment: Beyond Risk and Responsibility." *Journal of Risk Research* no. 14 (8):995-1003. doi: DOI: 10.1080/13669877.2011.571784.
- Gardiner, Stephen. 2011. *A Perfect Moral Storm: The Ethical Tragedy of Climate Change*: Oxford: Oxford University Press.
- Gardiner, Stephen. 2012. The Desperation Argument for Geoengineering. *PS: Political Science and Politics*, Available from <http://ssrn.com/abstract=2183457>.
- Gardiner, Stephen M. 2010. "Is 'arming the future' with geoengineering really the lesser evil? Some doubts about the ethics of intentionally manipulating the climate system." In *Climate Ethics, Essential Readings*, edited by S. M. Gardiner, S. Caney, D. Jamieson and H. Shue, 284-312. Oxford: Oxford University Press.
- Goodell, Jeff. 2010. *How to Cool the Planet. Geoengineering and the Audacious Quest to fix Earth's Climate*. Boston: Houghton Mifflin Harcourt.
- Greene, C. Monger, B. Huntley, M. 2010. "Geoengineering: The Inescapable Truth of Getting to 350". *Solutions*. Vol 1, No. 5. pp. 57-66 - <http://www.thesolutionsjournal.com/node/771>
- Hamilton, Clive. 2010. "The powerful coalition that wants to engineer the world's climate". *The Guardian* (series: Guardian Environment Network) Available from, <http://www.guardian.co.uk/environment/2010/sep/13/geoengineering-coalition-world-climate>.
- Hamilton, Clive. 2013. "No, we should not just 'at least do the research'" *Nature* no. 496:139.
- Haraway, Donna. 1997. *Modest_Witness@Second_Millennium.FemaleMan@_Meets_Oncomouse™, Feminist and Technoscience*. New York: Routledge.
- Hegerl, Gabriele C., and Susan Solomon. 2009. "Risks of Climate Engineering". *Science* 325: 955-956, Available from <http://www.sciencemag.org/cgi/content/full/325/5943/955>.
- Huttunen, Suvi, and Mikael Hildén. 2013. "Framing the Controversial: Geoengineering in Academic Literature." *Science Communication*. doi: 10.1177/1075547013492435.
- Inman, Mason. 2010. "Planning for plan B". *Nature* 4 (Nature Reports - Climate Change): 7-9, Available from <http://www.nature.com/climate/2010/1001/full/climate.2010.135.html>.
- Irwin, Alan, and Brian Wynne. 1996. "Introduction." In *Misunderstanding science? The public reconstruction of science and technology*, edited by Alan Irwin and Brian Wynne. Cambridge: Cambridge University Press.
- Jamieson, Dale. 1996. "Ethics and Intentional Climate Change." *Climatic Change* no. 33:323-36.
- Jasanoff, Sheila. 2004. *States of Knowledge: The Co-Production of Science and Social Order*. London: Routledge.
- Jasanoff, Sheila. 2010. "A New Climate for Society." *Theory, Culture & Society* no. 27 (2-3):233-253. doi: 10.1177/0263276409361497.
- Keith, David W. 2000. "Geoengineering the climate: history and prospect." *Annual Review of Energy and the Environment* no. 25:245-284.
- Keith, David W. 2002. "Geoengineering." In *Encyclopedia of Global Change*, edited by A. S. Goudie, 495-502. New York, NY: Oxford University Press.
- Keith, David W., and Hadi Dowlatabadi. 1992. "A Serious Look at Geoengineering." *EOS, Transactions American Geophysical Union* no. 73 (27):289-293.
- Kintisch, Eli. 2010. The Latest on Geoengineering. *Science* 327 (5969): 1070-1071, doi: 10.1126/science.327.5969.1070-b.

- Latour, Bruno. 1987. *Science in Action: How to Follow Scientists and Engineers Through Society*. Cambridge, Massachusetts: Harvard University Press.
- Law, John. 2002. *Aircraft Stories: Decentering the Object in Technoscience*. Durham, North Carolina: Duke University Press.
- Lawrence, Mark G. 2006. "The Geoengineering Dilemma: To Speak or not to Speak" *Climatic Change* 77: 245-248.
- Lenton, T. M., and N. E. Vaughan. 2009. The radiative forcing potential of different climate geoengineering options. *Atmospheric Chemistry and Physics (ACP)* 9: 2559-2608, <http://www.atmos-chem-phys-discuss.net/9/2559/2009/acpd-9-2559-2009.pdf>.
- Lovelock, James. 2008. "A geophysicist's thoughts on geoengineering." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* no. 366 (1882):3883-3890. doi: 10.1098/rsta.2008.0135.
- Lovelock, James. 2009. *The vanishing face of Gaia. A final warning*. London: Penguin Books.
- Luukkanen, Matti, Suvi Huttunen, and Mikael Hildén. 2013. "Geoengineering, news media and metaphors: Framing the controversial." *Public Understanding of Science*. doi: 10.1177/0963662513475966.
- MacCracken, Michaels C. 2009. *Beyond Mitigation: Potential Options for Counter-Balancing the Climatic and Environmental Consequences of the Rising Concentrations of Greenhouse Gases*. Washington, D.C.: The World Bank. Available from <https://openknowledge.worldbank.org/handle/10986/9051>.
- Macnaghten, Phil, and Richard Owen. 2011. "Environmental science: Good governance for geoengineering." *Nature* no. 479 (7373):293-293. doi:10.1038/479293a
- Marchetti, Cesare. 1977. "On geoengineering and the CO2 problem". *Climatic Change* 1 (1): 59-68. doi: 10.1007/BF00162777.
- Matthews, H. Damon, and Ken Caldeira. 2007. "Transient climate-carbon simulations of planetary geoengineering". *Proceedings of the National Academy of Sciences (PNAS)* 104 (24): 9949-9954, doi: 10.1073/pnas.0700419104.
- Michael, Mike. 2006. *Technoscience and Everyday Life: The Complex Simplicities of the Mundane*. Maidenhead: Open University Press.
- Miller, Clark A. 2010a. *The Human Subjects of Geoengineering*. Arizona State University, Consortium for Science, Policy & Outcomes, [cited 08.09.2010]. Available from <http://www.cspo.org/soapbox/view/100311P9IA/the-human-subjects-of-geoengineering/>.
- Miller, Clark A. 2010b. *International Review of Geoengineering*. Arizona State University, Consortium for Science, Policy & Outcomes, [cited 08.09.2010]. Available from <http://www.cspo.org/soapbox/view/100319P4WK/international-review-of-geoengineering/>.
- Montenegro, Maywa, and Veronique Greenwood. 2009. *Will the Future Be Geoengineered?* Available from http://seedmagazine.com/content/article/will_the_future_be_geo-engineered1/.
- Morrow, David R, Robert E Kopp, and Michael Oppenheimer. 2009. "Toward ethical norms and institutions for climate engineering research." *Environmental Research Letters* no. 4. doi:10.1088/1748-9326/4/4/045106.
- Morton, Oliver. 2007. "Climate change: Is this what it takes to save the world?" *Nature* 447: 132-136, doi:10.1038/447132a.
- National Research Council (Panel on Policy Implications of Greenhouse Warming). 1992. *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base*. Washington, DC: National Academy Press.
- National Research Council. 2003. *Critical issues in weather modification research*. Committee on the status and future directions in U.S. weather modification research and operations. Washington, DC: National Academy Press.

- NERC. 2010a. *Experiment Earth? Report on a Public Dialogue on Geoengineering*. The Natural Environment Research Council, The Sciencewise Expert Resource Centre, The Royal Society, and the multi-agency Living With Environmental Change (LWEC) programme.
- NERC. 2010b. *Experiment Earth - Public Dialogue on Geoengineering* (Geoengineering online survey from 5 th March to 12th April 2010 - Summary report). Available from http://www.ipsos-mori.com/Assets/Docs/Publications/geoengineering_online-survey_final-report_june2010.pdf
- Nerlich, B., and R. Jaspal. 2012. "Metaphors We Die By? Geoengineering, Metaphors, and the Argument From Catastrophe." *Metaphor and Symbol* no. 27 (2):131-147.
- Olson, Robert L. 2011. *Geoengineering for Decision Makers*. Washington, DC: Woodrow Wilson International Center for Scholars. Available from <http://www.wilsoncenter.org/event/report-release-geoengineering-for-decision-makers>.
- Orr, P.R., C.L. Twigger-Ross, E. Kashefi, K. Rathouse, and J.D. Haigh. 2011. *Experiment Earth? Report on a Public Dialogue on Geoengineering*. A report to the Natural Environment Research Council (NERC). Available from <http://www.nerc.ac.uk/about/consult/geoengineering-evaluation-report.pdf>.
- Parkhill, Karen, and Nick Pidgeon. 2011. *Public engagement on geoengineering research: preliminary report on the SPICE deliberative workshops* (Understanding Risk Group Working Paper, 11-01, Cardiff University).
- Poumadère, M., R. Bertoldo, and J. Samadi. 2011. "Public perceptions and governance of controversial technologies to tackle climate change: Nuclear power, carbon capture and storage, wind, and geoengineering." *Wiley Interdisciplinary Reviews: Climate Change* no. 2 (5):712-727. 10.1002/wcc.134.
- Powell, Russell, Steve Clarke, Mark Sheehan, Tom Douglas, Bennett Foddy, and Julian Savulescu. 2010. *The Ethics of Geoengineering* [Working Draft]. Available from http://www.practicaethics.ox.ac.uk/_data/assets/pdf_file/0013/21325/Ethics_of_Geoengineering_Working_Draft.pdf.
- Rayner, Steve, Clare Heyward, Tim Kruger, Nick Pidgeon, Catherine Redgwell, and Julian Savulescu. 2013. "The Oxford Principles." *Climatic Change*. doi: 10.1007/s10584-012-0675-2.
- Rayner, Steve, Catherine Redgwell, Julian Savulescu, Nick Pidgeon, and Tim Kruger. 2009. *Memorandum on draft principles for the conduct of geoengineering research*. House of Commons Science and Technology Committee enquiry into The Regulation of Geoengineering.
- Rickels, W., G. Klepper, J. Dovern, G. Betz, N. Brachatzek, S. Cacean, K. Güssow, Heintzenberg J., S. Hiller, C. Hoose, T. Leisner, A. Oschlies, U. Platt, A. Proelß, O. Renn, S. Schäfer, and Zürn M. 2011. *Large-Scale Intentional Interventions into the Climate System? Assessing the Climate Engineering Debate*. Scoping report conducted on behalf of the German Federal Ministry of Education and Research (BMBF). Kiel: Kiel Earth Institute.
- Robock, Alan. 2008. "20 reasons why geoengineering may be a bad idea." *Bulletin of the Atomic Scientists* no. 64 (2):14-18.
- Robock, Alan. 2011. Bubble, bubble, toil and trouble. An editorial comment. *Climatic Change*, doi:10.1007/s10584-010-0017-1.
- Roger Pielke Jr. 2010. *The Climate Fix. What scientists and politicians won't tell you about global warming*. New York: Basic Books.
- Rommetveit, Kjetil, Silvio Funtowicz, and Roger Strand. 2010. "Knowledge, democracy and action in response to climate change". In: Bhaskar, R., Frank, C., Hoyer, K.G., Naess, P. and Parker, J. (Eds.) *Interdisciplinarity and Climate Change: Transforming knowledge and practice for our global future*, Abingdon: Routledge, pp. 149-163.

- Sarewitz, Daniel. 2004. "How science makes environmental controversies worse." *Environmental Science and Policy* no. 7 (2004):385-403.
- Schelling, Thomas. 1996. "The economic diplomacy of geoengineering." *Climatic Change* no. 33 (3):303-307. doi: 10.1007/BF00142578
- Schneider, Stephen H. 1996. "Geoengineering: Could— or should— we do it?" *Climatic Change* no. 33 (3):291-302.
- Scholte, Samantha, Eleftheria Vasileiadou, and Arthur C. Petersen. 2013. "Opening up the societal debate on climate engineering: how newspaper frames are changing." *Journal of Integrative Environmental Sciences*:1-16. doi: 10.1080/1943815x.2012.759593.
- Schwartz, Peter, and Doug Randall. 2003. *An Abrupt Climate Change Scenario and Its Implications for United States National Security* (report prepared by the Global Business Network (GBN) for the Department of Defence).
- Schwarz, Astrid, and Wolfgang Krohn. 2011. "Experimenting with the Concept of Experiment: Probing the Epochal Break." In *Science Transformed? Debating Claims of an Epochal Break*, edited by Alfred Nordmann, Hans Radder and Gregor Schiemann, 119-134. Pittsburgh: University of Pittsburgh Press.
- Sikka, T. 2012. "A critical discourse analysis of geoengineering advocacy." *Critical Discourse Studies* no. 9 (2):163-175.
- Singer-Vine, Jeremy. *Choose Your Own Geohack. Explore geoengineering's most interesting strategies with Slate's interactive guide.* The Slate Group [September 24, 2010]. Available from <http://www.slate.com/id/2268479/>.
- Siune, K., E. Markus, M. Calloni, U. Felt, A. Gorski, A. Grunwald, A. Rip, V. Semir, and S. Wyatt. 2009. *Challenging Futures of Science in Society - Emerging trend and cutting-edge issues. Report of the MASIS Expert Group setup by the European Commission.* Brussels: European Commission, Directorate-General for Research Science in Society.
- The Royal Society. 2009. *Geoengineering the climate: science, governance and uncertainty.* London: The Royal Society.
- UK House of Commons. Science and Technology Committee. 2010. *The Regulation of Geoengineering, Fifth Report of Session 2009–10.* Available from <http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/221.pdf>.
- Vaughan, Naomi, and Timothy Lenton. 2011. "A review of climate geoengineering proposals." *Climatic Change* no. 109:745-790. doi: 10.1007/s10584-011-0027-7.
- Victor, David G. 2008. "On the regulation of geoengineering". *Oxford Review of Economic Policy* 24 (2): 322-336.
- Victor, David G., M. Granger Morgan, Jay Apt, John Steinbruner, and Katharine Ricke. 2009. "The Geoengineering Option—A Last Resort Against Global Warming?" *Foreign Affairs* no. 88 (2): 64–76.
- Ward, Robert DeCourcy. 1930. "How far can man control his climate?" *The Scientific Monthly* no. 30:5-18.
- Weinberg, Alvin M. 1991. "Can Technology Replace Social Engineering?" In *Controlling Technology: Contemporary Issues*, edited by W. B. Thompson. Buffalo, NY: Prometheus Books, pp. 41-48.
- Williamson, P., Watson, R.T., Mace, G., Artaxo, P., Bodle, R., Galaz, V., Parker, A., Santillo, D., Vivian, C., Cooper, D., Webbe, J., Cung, A. and E. Woods. (2012). "Impacts of Climate-Related Geoengineering on Biological Diversity". Part I of: *Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matters.* Secretariat of the Convention on Biological Diversity. Montreal, Technical Series No. 66, 152 pages.
- WMO. 2010. *Executive Summary of the WMO Statement on Weather Modification* (Expert Team on Weather Modification Research, Abu Dhabi, 22-24 March 2010) Available from

https://www.wmo.int/pages/prog/arep/wwrp/new/documents/WMR_documents.final_27_April_1.FINAL.pdf

Yanarella, Ernest J., and Christopher Rice. 2011. "Global Warming and the Specter of Geoengineering: Ecological Apocalypse, Modernist Hubris, and Scientific-Technological Salvation in Kim Stanley Robinson's Global Warming Trilogy." In *Engineering Earth. The Impacts of Megaengineering Projects*, edited by Stanley D. Brunn, 2233-2252. Dordrecht: Springer.

ABOUT THE AUTHORS

Paula Curvelo: Paula Curvelo is a PhD student at the University of Lisbon. Since September 2010, she has been developing her research activities in the field of Science and Technology Studies (STS) at the European Commission – Joint Research Centre.*

Dr. Ângela Guimarães Pereira: Ângela Guimarães Pereira is a scientific officer at the European Commission – Joint Research Centre*. She has a PhD in Environmental Impact Assessment with the New University of Lisbon. Since the early 1990's she has been collaborating in several European projects which are framed in ideas of democratisation of science; throughout those projects she has worked on anticipating societal issues in relation to environmental governance and emerging technologies. In all those projects she was studying and looking at methodological issues for communicating about science and technology in contexts of public engagement. At the JRC she is currently leading the action "Security Ethics in New I&C Technologies" (SETICS).

* The views expressed in this paper are those of the authors and do not necessarily represent the official views of the European Commission.

Modern Western Science in Initial Chinese Archaeological Development

Meili Yang, National Tsing Hua University, Taiwan

Abstract: For China, during wartime—specifically the early twentieth century—the most immediate demand or expectation of Western science was to acquire advanced scientific techniques. Modern archaeology was introduced in China along with the introduction of natural science activities conducted by Western scientists working in China, particularly in geological and paleontological fields. In the present article, the author examines three archaeological cases—the Zhoukoudian excavation, Yangshao sites excavation and Anyang excavation projects—performed immediately following the May 4th Movement in China in 1919 to explore the sources of modern Chinese archaeology development in its initial stage, and ascertain how modern Western science was working in the field.

Keywords: Science, Archaeology, China, Early Twentieth Century

Introduction

Beginning in the late nineteenth century, after experiencing tremendous political, economic, social, and intellectual hardship, the Chinese strongly believed that only with advanced Western science and technology was their country likely to survive. The May 4th Movement in 1919 was supported by most Chinese intellectuals because it boosted the infusion of Western science.¹ It marked the decision and desire of the Chinese government and intellectuals to accept and study Western science. ‘Science’ was enthusiastically discussed and intentionally regarded as a crucial condition for most contemporary actions.²

The influence of modern Western science on human lives has had multiple dimensions in the last century. Edward Shils stated the initial definition of ‘natural science’ or just ‘science,’ is that “the very existence of science which aims to discover what was previously unknown [and therefore] denies the validity of knowledge drawn from the past in whatever sphere science is conducted.”³ However, the purpose to develop science and technology evolved to keep up with scientific progress and application in various fields⁴. For China, during wartime—the early twentieth century—the most immediate demand or expectation of Western science should have been to acquire advanced and efficient scientific techniques rather than to discover unknown knowledge⁵.

Modern archaeology was introduced in China with natural science activities conducted by Western scientists working in China, particularly in geological and paleontological fields. In the present article, the author examines three archaeological cases performed immediately following the May 4th Movement to explore the sources of modern Chinese archaeology development in its initial stage, and ascertain how modern Western science was working in the field.

The Present Problem

To study Western science in the early twentieth century, many avenues were available. As in Japan, in addition to encouraging young Chinese students to study in Europe or the United States, Western natural scientists were hired to teach in universities or consult in Chinese government offices.⁶ For instance, American Amadeus W. Grabau was employed to teach Geology at Peking University, Swedish geologist J. G. Andersson consulted for the Chinese government, and Canadian anatomist Davidson Black worked at the Peiping Union Medical College (P.U.M.C).

However, eventually, these Western scientists worked in Chinese archaeology and contributed or influenced initial Chinese archaeology development. This came about partly

because archaeology usually occupies the boundary between natural sciences and the humanities.⁷ Moreover, until the end of the nineteenth century, archaeology was still not separated from certain natural sciences, especially geology, geography, biology and paleontology. Field techniques basically relied on well-established geological method, and theoretical interpretation followed the dominant biological evolutionism.⁸

In addition, because of the considerable abundant prehistoric and historic remains in China's territory, Western scientists became interested in Chinese archaeology. Therefore, although modern Western archaeology was not intentionally introduced into China during wartime, it had been brought in, accompanied by these natural scientists' interest and activities in the early twentieth century.

As stated, three archaeological excavation projects were conducted by Western scientists and first-generation Chinese scientist immediately following the May 4th Movement. The first was the Zhoukoudian excavation, an evolutionary archaeological project conducted by Davidson Black in 1926-27. The second was the Yangshao cultural sites excavation, a prehistoric archaeological project conducted by J. G. Andersson in 1921 and 1923-24. The third was the Anyang excavation in 1928-1937, a historical archaeological project, first conducted by Li Chi.

These excavations were not only considered to be important events in Chinese archaeological development in its initial stage, but also became the cornerstone of scientific archaeology in China.⁹ However, they were also good examples for exploring the present problem—how modern Western science was transplanted into China and regarded as a crucial condition in promoting Chinese scientific archaeological development in its initial stage.

The Evolutionary Archaeological Case

Modern archaeology basically includes three essential tasks: field work, laboratory work and the integrated interpretation of archaeological materials. In general, the first two employ natural science techniques and obtain objective data, whereas the last has more options depending on the researcher's theory and intentionality.

The Zhoukoudian (周口店) Excavation

Keen interest followed J. G. Andersson's announcement that a hominid tooth was found at Zhoukoudian in 1926. The Geological Survey of China and the Department of Anatomy at the P.U.M.C. organized an evolutionary archaeological program to mount a two-year intensive investigation of the Zhoukoudian cave deposit, a two hundred thousand year-old site. It was supported by the Rockefeller Foundation in the United States.¹⁰

In fact, the primary goal of the Zhoukoudian excavation was similar to the American Museum of Natural History's "missing link" project to look for fossil Hominidae, an evolutionary archaeological project¹¹. Davidson Black (1884-1934) and Swedish paleontologist Anders Birger Bohlin (1898-1990) were the two primary investigators, whereas the Chinese participants were nearly all young students studying scientific techniques, including Li Jie (李捷, 1894-1977), Yang Zhongjian (楊鍾健, 1897-1979) and Pei Wenzhong (裴文中, 1904-1982), all with limited natural science training in geology.

Field Work and Laboratory Examination

Black conducted the project and devised the full-scale excavation plan. Then he put the fieldwork under the direction of Bohlin. Black's primary work was actually to perform the laboratory examination of the vast amount of fossils brought from the field. For example, when Bohlin found a left lower molar at the site, Black identified it as a human tooth, christening it *Sinanthropus pekinensis*.¹²

As a byproduct of the two-year excavation program, Black also helped establish the Cenozoic Research Laboratory (CRL) to process and analyze the archaeological and geological materials brought from the field. The CRL was organized as a subdivision of the Geological Survey of China. It not only carried out work on the Zhoukoudian excavation project and investigated general Cenozoic geology and paleontology throughout China, but also played a very important role in the exchange of knowledge between Western and Chinese scientists at that time.¹³

'Science' Working in the Project

Evolutionary archaeology relied considerably on natural scientific techniques, including geological field techniques and physical laboratory examination. Moreover, this project was actually a Western scientists' program performed in China. To Chinese participants or the public, the knowledge was new and beyond the extent of traditional cognition. The obtained information was difficult for most contemporary Chinese to understand. Therefore, the archaeological result actually did not gain much attention in China at that time, and even later, in 1929, when the Peking Man skull was unearthed by Pei Wenzhong.

However, the stereotype about 'science' was still related to white coats and laboratories at that time.¹⁴ In terms of this project, the laboratory, CRL was constructed, and a set of evolutionary archaeological methods was introduced into China—meticulous field work and accurate laboratory examination that seemed to provide an ideal paradigm for infusing modern Western science. In the following years, a reciprocal policy was promoted by the Chinese government to grant some science-advanced countries permission to establish laboratories in China.

The Institute of Natural Science in Shanghai was constructed with Japanese aid in 1931, focusing on introducing and training young Chinese students in fundamental natural sciences, such as physics, chemistry, biology and geology.¹⁵ In addition, Father Emile Licent (1876-1952) was alleged to have established a laboratory in Tianjin (天津), to collect paleontological samples and prehistoric archaeological materials in China's territory for the Museum of Natural History in Paris and Marcellin Boule's laboratory in France.¹⁶

Black died in 1934. According to Li Chi's statement, younger contemporary Chinese researchers owed their scientific training to Black's contribution: "The scientific work carried out at Chou-k'ou-tien and in the Cenozoic Research Laboratory in Peking provided a tremendous stimulus to the younger generation of Chinese scientific researchers."¹⁷ It confirms that a set of organized Western scientific knowledge and method were introduced and contributed to the initial Chinese evolutionary archaeology.

The Prehistoric Archaeological Case

The Yangshao (仰韶) Sites Excavation

The second case concerns the excavation of Yangshao cultural sites in Henan, Gansu and Qinghai. In 1921, J. G. Andersson (1874-1960) received a Chinese government grant to excavate the Yangshaocun site in Henan. He found a similarity in the design between many painted shards unearthed from the site and those of Anau in southern Turkmenistan and Tripolje in the Ukraine. It led him to form a hypothesis about the 'Western origin of Chinese culture.' Andersson stated: "This was the working hypothesis upon which was based my journey to Kansu [Gansu] in the spring of 1923."¹⁸ In 1923-24, he surveyed and excavated in Gansu and Qinghai to test his hypothesis.

Basically, Andersson undertook this archaeological excavation project to prove the validity of his hypothesis, and discover the evidence of prehistoric migrations of the people who brought

painted ceramics from Eastern Europe to China. In the 1921 excavation, he was accompanied by Yuan F. L. (袁復禮, 1893-1987), a young Chinese geologist who carried out most of the topographical survey. However, Yuan was not interested in the archaeological remains unearthed from the site at that time.¹⁹

Extending the 1921 work, the 1923-24 excavation was actually conducted and performed by Andersson himself, accompanied by his Chinese servants and Western assistants. This was a complete deviation from the original intention of the Chinese government to hire him to explore ore deposits, such as iron ore, and train young Chinese scientists or students in geology.²⁰ Therefore, his archaeological activities in China were at times explained as another exemplary model of international museum collecting and archaeology by some Western scholars due to the leverage of his position as a Chinese official.²¹

Field Work and Laboratory Examination

As a geologist, Andersson applied field techniques to the prehistoric archaeological excavation, especially the stratigraphic data that had never been doubted at that time. However, the stratigraphic approach seemed to be unworkable because almost all Gansu areas sites, such as the Zhujiazhai (朱家寨) burials, were disturbed to some extent and a few even violently. In looking for a reasonable explanation, he traveled through eastern Gansu and observed the alteration of the whole landscape due to the tremendous earthquake that took place in the 1920s.²² He finally concluded that the disturbance of the Zhujiazhai site was caused by frequent earthquakes in the Gansu area.

A chronology for Gansu painted ceramics was established by Andersson based on the typological approach of arranging artifacts in chronological or developmental sequence, rather than on the meticulous geological stratigraphic data. The typological approach was commonly used in Europe at that time. However, subsequently, the chronology was proved faulty with regard to the order of sequential cultures in the Gansu area.²³

At that time, Andersson also made many comparisons between the findings of northern China and Manchuria, Central Asia, and even Eastern Europe, making reference to other artifacts of jade or bone and ancient Chinese texts. To solidify his 'Western origin of Chinese culture' hypothesis, Andersson sent a comparative table with figures to R. L. Hobson at the British Museum and Hubert Schmidt at the Museum für Volkerkunde. The former gave him a positive response: "... red pottery with black ornaments, clearly the same family of design as on the Neolithic pottery found on many sites in the Near East."²⁴ In contrast, the latter gave an uncertain reply: "Comparison can hardly be made at the same time with Anau I and with Tripolje, as was done by me, because these two cultures are not of the same age."²⁵

The Interpretation of the Archaeological Materials

To provide a reasonable or persuadable route of the cultural diffusion from Central Asia to China in prehistoric times, using painted ceramics to advance and prove his hypothesis, 'Western origin of Chinese culture,' Andersson explained:

"The distance from Honan to Anau is very great (fig. 8), but the two regions are connected by a highway of migrations which extends between the Tibetan highlands in the south and the Siberian taiga in the north. These vast expanses of steppe and desert which form a nearly continuous belt from the Pacific to the Black Sea have, according to the researches of Pumpelly and Huntington, during certain periods enjoyed a climate much more genial than the present."²⁶

In fact, before he proposed the 'Western origin of Chinese culture' hypothesis, similar thinking had been circulating among contemporaneous Western scholars. Andersson stated: "The

old question of western influences in the early Chinese civilization is again actualized by the discovery of the Yang Shao Polychrome pottery."²⁷ For example, T. J. Arne (1879-1965) had written:

“The unpainted earthenware chiefly suggests a comparison with the finds of earthenware vessels made by Mr. and Mrs. Torii in Eastern Mongolia. The painted pottery, on the other hand, shows associations with such distant regions as the west of Asia and the east and south of Europe.”²⁸

It seemed not be a novel thought to most westerners to separate whole ancient civilization in the world into two circles based on unpainted and painted ceramics produced. However, it was difficult at that time for Chinese intellectuals to agree that ancient Chinese civilization originated in western Central Asia.

‘Science’ Working in the Project

Regardless of the natural or social scientific methods applied by Andersson in this prehistoric archaeological project, his interpretation of those archaeological materials caused considerable controversy between Andersson and Chinese intellectuals. Compared with the first case, although both were Western scientists’ programs performed in China, the prehistoric archaeological activity was of more concern to Chinese intellectuals and even the public than the evolutionary archaeological excavation.

Andersson’s interpretation of those archaeological materials and derived thought, ‘Western origin of Chinese culture,’ immediately impacted Chinese traditional historical ideology and knowledge. As Fu Sinian (傅斯年, 1896-1950), a considerable influential Chinese historian, criticized: “The foreign archaeologists in China do not pay any attention to the material which represents indigenous Chinese culture, but are only interested in the remains which indicate cultural connections between China and the West.”²⁹

Although Fu’s critique couldn’t represent all Chinese intellectuals, a rethinking of the feasibility and applicability of Western science and scientific methods in contemporary China had become the most pressing problem and was debated among Chinese intellectuals. For instance, in the 1920s and 1930s, such problems as whether or not it is necessary to completely accept Western scientific knowledge and method, or what is appropriate or efficient to contemporary China, were enthusiastically discussed³⁰.

However, because of the prehistoric archaeological project, indigenous archaeological workers had to seriously confront the Chinese prehistoric cultures problem. Although Andersson’s chronology of Gansu prehistoric culture was proved faulty in the decades that followed, he introduced the scientific chronological method based on so-called ‘chronometer,’ ceramic types were studied and applied widely by Chinese indigenous archaeological workers³¹.

For instance, the Neolithic site at Chengziyai (城子崖), Shandong that was investigated and excavated in 1928 by Wu Jinding and others established a systematic chronology of the local prehistoric cultures³². In addition, later, Liang Siyong’s excavation of the Anyang late Shang capital site of Yin (殷), followed the scientific methods, the stratigraphy and ceramics typology. He recorded the accurate relationship between Shang and before Shang culture³³. This confirms that these scientific methods benefited Chinese prehistoric archaeology development in its initial stage.

The Historic Archaeological Case

The Historic Archaeological Case

The Anyang (安陽) Excavation

The quest for the origins of the so-called oracle bones eventually led to the archaeological site at Anyang and to its scientific excavation in 1928.³⁴ The initial survey and experimental excavation of the inscribed oracle bones was conducted by Dong Zuobin (董作賓; 1895-1963) in the fall of 1928. The formal scientific excavation began in October, 1928 and continued in the spring and fall of 1929, conducted by Li Chi (or Li Ji李濟; 1896-1979). The second stage of the excavation began in 1931, conducted by Liang Siyong (梁思永; 1904-1954).

The project received government support in 1933 and large-scale survey and excavation efforts were extended and continued until 1937 when the war between Japan and China began. The core participants in the project included Li Chi, Liang Siyong, Dong Zuobin, Wu Jinding, Guo Bochung, Liu Yao, Shi Zhangru and Gao Quxun.³⁵ The two primary conductors, Li Chi and Liang Siyong trained in anthropology or archaeology in the United States, while other participants were educated in Chinese literature or history in China. Apparently, the work would have a humanistic rather than a natural or social science orientation.

The Anyang excavation project had a complicated significance, especially as it was performed during the war, when archaeology was usually used as a reinforcing nationalism tool³⁶. The Anyang archaeological excavation, more or less, was accorded such a purpose. Moreover, Li refused to allow the Freer Gallery of Art in Washington D.C., to join this historical archaeological project³⁷. This created considerable pressure on Li and Liang to test their Western scientific training and to prove that indigenous archaeologists could conduct a scientific archaeological project independently.

Field and Laboratory Work and Interpretation

The primary investigator, Li Chi, intentionally worked scientifically. He contributed stratigraphic data and systematic records of every artifact uncovered in the excavation.³⁸ However, historical archaeology and prehistoric archaeology were two separate disciplines before the 1980s in the West, particularly in the interpretation of archaeological materials.³⁹ As Falkenhausen thought, Li Chi should have adjusted his original discipline in physical anthropology for this historical archaeological project.⁴⁰

After almost one year of field work, the excavation was halted due to the local peoples' protestations. In many writings, Li seemed to imply that the scientific archaeological work was difficult to perform at that time in China, partly because China's current political and social conditions were very harsh, and partly because neither the politicians nor the general public knew anything about 'science.'⁴¹

However, Li and Liang always made an effort to conduct the whole archaeological project scientifically. Unfortunately, the country's civil war did not cease after World War II. After the beginning of the Second Sino-Japanese War, these archaeological remains were moved, eventually to Taiwan in 1948, where Li Chi and his co-workers continued the laboratory work and interpretation of those archaeological materials⁴²

The whole process of Anyang excavation received much attention and appeared to be viewed as scientific archaeology by most archaeologists, art historians and others worldwide. It was also certainly expected and thought to be scientific by Chinese intellectuals.⁴³ However, subsequently, Western archaeologists criticized the excavation and written materials for relying excessively on historical texts and following traditional Chinese archaeological concerns, leading to a non-scientific archaeology orientation.⁴⁴

'Science' Working in the Project

The critique apparently dealt a heavy blow to indigenous archaeologists' efforts to work in scientific archaeology. The recognition of historical archaeology distinctly created a large gap between Chinese and Western archaeologists that was probably unperceived or unanticipated by

first-generation Chinese archaeological investigators. Nevertheless, some additional consideration should be accorded to the function of modern Western science in the first Chinese historical archaeological project.

It is also a common phenomenon that these Western scientifically trained and educated accepted first-generation archaeologists not only had to face an almost unknown science population (the public), but also had to internally balance the rooted tradition and intentionally-infused extrinsic element⁴⁵. At times, they were forced to make alterations to their processes and were also confused between science and non-science, and even deviated from their original intention.

Historical archaeology is a more sensitive field than prehistoric archaeology or evolutionary archaeology, because it touches on rooted historical ideology in local society, especially in interpreting archaeological materials. Particularly, China possesses a deep historical tradition. Therefore, although the Western scientific techniques for field and laboratory tasks were sophisticatedly employed in the Anyang project, how to scientifically integrate archaeological materials and historical texts became the challenge for indigenous archaeologist.

Conclusion

In China, since the late nineteenth century, the Doubters of Antiquity (*yigupai*) had displayed a skeptical attitude toward ancient texts and the traditional cognition system, and the continuing May 4th Movement signaled support and infusion of advanced Western science. However, with the passage of only a couple of decades—from the late nineteenth to the early twentieth century—it was too soon for Chinese intellectuals or even the public to realize the nature of ‘modern science,’ adjust their mentality, and put modern Western science into practice.

China possesses the longest continuous civilization and the longest recorded history in the world. The traditional archaeology initiated in the Song Dynasty (960-1238) had established a set of historiographical and antiquarian-based methods to recognize China’s past.⁴⁶ These factors characterized ancient Chinese civilization. However, they also became one of the heaviest burdens for transitioning Chinese intellectuals in the early twentieth century.

Western science was being intentionally regarded as a crucial condition necessary for gaining recognition and functioning within the context of contemporary archaeological actions. Compared with the evolutionary archaeologists and prehistoric archaeologists, historical archaeologists would confront a larger challenge in integrating archaeological materials and historical texts. Moreover, for indigenous Chinese first-generation historical archaeologists, the challenge was not only in the integration, but also in balancing between tradition and extrinsic Western science.

For several decades since the introduction of Western scientific archaeology, actually, even in the 1970s or 1980s, as Kwang-chih Chang stated: “There is little evidence of the sophisticated used of classificatory or quantitative methods...”⁴⁷. In fact, there is a long and arduous road ahead as real scientific archaeology development in China strives to perfect the application of certain feasible or appropriate methodologies of modern archaeology to systematically organize the tremendous Chinese archaeological data into significant resource materials for exploring Chinese ancient civilization.

NOTES

1. J. W. Olsen, "The Practice of Archaeology in China Today," *Antiquity* 61 (1987): 283.
2. Benjamin I. Schwartz, "The Debate on Science and Human Life," in *The Cambridge History of China, Volume 12, Republican China 1912-1949, Part 1*, ed. John K. Fairbank (Cambridge: Cambridge University Press, 1983), 439-444.
3. Edward Shils, *Tradition* (Chicago: The University of Chicago Press, 1981), 100-101.
4. Katharine Park and Lorraine Daston, "Introduction: The Age of the New," in *The Cambridge History of Science, Volume 3*, eds. Katharine Park and Lorraine Daston (Cambridge: Cambridge University Press, 2006), 4.
5. F. Bilich, *Science and Technology Planning and Policy* (Amsterdam: Elsevier Science Publishers, 1989), 3-6.
6. Charlotte Furth, *Ting Wen-chiang: Science and China's New Culture* (Cambridge, Massachusetts: Harvard University Press, 1970), 204.
7. E-tu Zen Sun, "The Growth of the Academic Community 1912-1949," in *The Cambridge History of China, Volume 13, Republican China 1912-1949, Part 2*, eds. John K. Fairbank and Albert Feuerwerker (Cambridge: Cambridge University Press, 1986), 367.
8. B. G. Trigger, *A History of Archaeological Thought* (second edition) (Cambridge: Cambridge University, 2006), 261.
9. Mark A. Pollard and Peter Bray, "A Bicycle Made for Two?: The Integration of Scientific Techniques into Archaeological Interpretation," *Annu. Rev. Anthropol* 36 (2007): 245-59.
10. B. G. Trigger, "Archaeology's Relations with the Physical and Biological Sciences: A Historical Review," *Proceedings of the 26th International Archaeometry Symposium* (1998), 1-9.
11. Colin Renfrew and Paul Bahn, *Archaeology: Theories Methods and Practice* (third edition) (New York: Thames & Hudson, 2000), 19.
12. John Monaghan and Peter Just, *Social and Cultural Anthropology: A Very Short Introduction* (Oxford: Oxford University, 2000), 1.
13. William Watson, "The Progress of Archaeology in China," in *Antiquity and Man*, eds. John D. Evans, Barry Cunliffe and Colin Renfrew (New York: Thames and Hudson, 1981), 65-70.
14. Xingcan Chen, *Zhong Guo Shi Qian Kao Gu Xue Shi Yan Jiu 1895-1949 (The History of Chinese Prehistoric Archaeological Research 1895-1949)* (Beijing: Sheng Huo, Du Shu and Xin Zhi San Lian Shu Dian, 1997), 21.
15. Trigger, *History of Archaeological Thought*, 265.
16. Davidson Black, P. Teilhard de Chardin, C. C. Young and W. C. Pei, "Fossil Man in China: The Choukoutien Cave Deposits with a Synopsis of Our Present Knowledge of the Late Cenozoic in China," *Geological Memoirs, Series A*, no. 11 (Peiping: The Geological Survey of China, 1933), 7.
17. Michon Scott, "Rocky Road: Roy Chapman Andrews," updated July 29, 2010 by Michon Scott, accessed May 28, 2012. <http://www.strangescience.net/andrews.htm>
18. Noel T. Boaz and Russell L. Ciochon, *Dragon Bone Hill: An Ice-Age Saga of Homo erectus* (Oxford: Oxford University Press, 2004), 20.
19. Jerome S. Cybulski and Paul Gallina, "The Works of Davidson Black," in *Homo erectus Papers in Honor of Davidson Black*, eds. Becky A. Sigmon and Jerome S. Cybulski (Toronto: University of Toronto Press, 1981), 14.
20. Black et al., Foreword to "Fossil Man in China."
21. Dora Hood, *Davidson Black: A Biography* (Toronto: University of Toronto, 1964).
22. Roger M. Keesing and Andrew J. Strathern, *Cultural Anthropology: A Contemporary Perspective* (third edition) (Fort Worth: Harcourt Brace College Publishers, 1998), 6.
23. Yukio Yamane (山根幸夫), "A Study on the Shanghai Science Institute," *Tokyo Woman's Christian University Essays and Studies* 30(1) (1979): 1-38.
24. Amir D. Aczel, *The Jesuit and the Skull: Teilhard de Chardin, Evolution, and the Search for Peking Man* (New York: Riverhead Books, Penguin Group Inc., 2007), 83-103.
25. Chi Li, *Anyang* (Seattle: The University of Washington, 1977), 45.
26. J. Gunnar Andersson, *Children of the Yellow Earth: Studies in Prehistoric China* (New York: The Macmillan Company, 1934), 225.
27. J. Gunnar Andersson, "An Early Chinese Culture," *Bulletin of the Geological Survey of China* 5 (1923), 19.
28. Magnus Fiskesjö and Xingcan Chen, *China Before China: Johan Gunnar Andersson, Ding Wenjiang, and the Discovery of China's Prehistory* (Stockholm: Museum of Far Eastern Antiquities, 2004), 16.
29. Pery Johansson, "Rescuing History from the Nation: the Untold Origins of the Stockholm Museum of Far Eastern Antiquities," *Journal of the History of Collections*, Advance Access published online on November 29, 2008, doi: 10.1093/jhc/fhn030.
30. J. Gunnar Andersson, "The Site of Chu Chia Chai," *Bulletin of Museum of Far Eastern Antiquities* 17 (1945), 1-63.
31. Siyong Liang, "Xiao tun Longshan yu Yangshao," in *Liang Siyong Kao Gu Lun Wen Ji*, ed. Zhongguo Ke Xue Yuan Kaogu Yan Jiu Suo Bian (Beijing: Ke Xue Chu Ban She, 1959), 91-98. Fiskesjö and Chen, *China Before China*, 114-118.
32. Andersson, "An Early Chinese Culture," 38.
33. Andersson, "An Early Chinese Culture," 39.
34. Andersson, "An Early Chinese Culture," 35-36.
35. Andersson, "An Early Chinese Culture," 42.
36. T. J. Arne, "Painted Stone Age Pottery from the Province of Honan, China," *Paleontologia Sinica, Series D, Vol. 1* (1925): 1-34.

29. Li Liu, *Chinese Neolithic: Trajectories to Early States* (Cambridge: Cambridge University Press, 2004), 5.
30. Schwartz, "The Debate on Science and Human Life," 406-450.
- Sun, "The Growth of the Academic Community 1912-1949," 361-420.
31. Erwin H. Ackerknecht, *Rudolf Virchow: Doctor Statesman Anthropologist* (Madison: The University of Wisconsin Press, 1953), 226.
32. Jinding Wu, "Stratigraphy and the Formation of Ch'êng-Tzū-Yai," and "Shards," in *Ch'êng-Tzū-Yai: A Report of Excavations of the Proto-history site at Ch'êng-Tzū-Yai, Li-ch'êng Hsien, Shantung*, eds. Chi Li, Ssü-yung Liang and Tso-ping Tung (Nanking: The Institute of History and Philology Academia Sinica, 1934), 11-25, 36-54.
33. Liang, *Liang Siyong Kao Gu Lun Wen Ji*, 91-98, 100-102.
34. Kwang-chih Chang, *Shang Civilization* (New Haven: Yale University Press, 1980), 42-47.
35. Siyong Liang, "The Note of Hougang Excavation," *Preliminary Reports of Excavations at Anyang*, part IV (Peiping: The National Research Institute of History and Philology Academia Sinica, 1933), 609-625.
- Chang, *Shang Civilization*, 46.
36. Trigger, *History of Archaeological Thought*, 236.
37. Li, *Anyang*, 56.
38. Li, *Anyang*, 60.
39. Kent G. Lightfoot, "Culture contact studies: redefining the relationship between prehistoric and historical archaeology," *American Antiquity*, 60(2) (1995): 202.
40. Lothar Von Falkenhausen, "On the Historiographical Orientation of Chinese Archaeology," *Antiquity* 67(1993): 842.
- Li, *Anyang*, 56.
41. Li, *Anyang*, 63.
42. Chi Li, Preface to *Studies of the Bronze Chia-Vessel*, New Series, no. 3, eds. Chi Li, Chang-ju Shih and Chu-hsun Kao (Nankang, Taiwan: The Institute of History and Philology Academia Sinica, 1968).
43. Sueji Umehara (梅原末治), *Kanan Anyō ihō* (The remained treasure of Anyang, Honan) (Kyoto: Kobayashi Shashin Seisakusho Shuppanbu, 1940), 1-78.
- Kwang-chih Chang, *The Archaeology of Ancient China* (Fourth Edition Revised and Enlarged) (New Haven: Yale University Press, 1986), 317.
- Trigger, *History of Archaeological Thought*, 265-66.
- Sinian Fu, "The Process of Anyang Yin Xu excavation (Ben Suo Fa Jue Anyang Yin Xu Zhi Jing Guo)," *Preliminary Reports of Excavations at Anyang, Part II* (Peiping: The National Research Institute of History and Philology, 1929), 394.
- Chi Li, "Sian Dai Kao Gu Syue yu Yin Syu Fa Jyue (Modern Archaeology and the Excavation of Yin Syu)," *Preliminary Reports of Excavations at Anyang, Part II* (Peiping: The National Research Institute of History and Philology, 1929): 405.
44. Trigger, *History of Archaeological Thought*, 265-66.
45. Sun, "The Growth of the Academic Community 1912-1949," 361-420.
46. Chang, *Archaeology of Ancient China*, 4-5.
- Falkenhausen, "Historiographical Orientation of Chinese Archaeology," 843.
47. Kwang-chih Chang, "Archaeology," in *Science in Contemporary China*, ed. Leo A. Orleans (Stanford, California: Stanford University Press, 1980), 501.

ABOUT THE AUTHOR

Prof. Meili Yang: Prof. Yang served as a senior curator in the Department of Antiquities at the National Palace Museum in Taipei from 1983-2007. She is currently teaching 'Chinese Art History' and 'Science and Art' in Taiwan. She received her MA in Chinese Art History from the National Taiwan University in Taiwan in 1983. In 2007, she began studying Conservation Science and Archaeology in the Department of Materials Science and Engineering, and School of Anthropology at the University of Arizona in Tucson, USA. She received a MS in Materials Science in 2010. She is always interested in using scientific methods to advance aiding Chinese Art History, Archaeology and Ancient Culture Studies, as well as Museum Conservation.

Using a Cross-disciplinary Investigation to Inform Questions about an Insecurely Provenanced Middle Eastern Manuscript: A Case Study of a Middle Eastern Manuscript

Sophie Lewincamp, University of Melbourne, Australia

Nicole Tse, University of Melbourne, Australia

Petronella Nel, University of Melbourne, Australia

Marcelle Scott, University of Melbourne, Australia

Robyn Sloggett, University of Melbourne, Australia

Abstract: Cultural materials conservation harnesses, builds and conveys knowledge with the aim that cultures will be preserved, sustained and strengthened. Materials science investigations have a very particular place in cultural materials conservation; and, together with historical, cultural and social studies, help to develop ethical and policy frameworks for cultural preservation. This interdisciplinary framework presents many challenges; materials science develops fundamental knowledge, and cultural materials conservation provides preservation solutions based on societal-driven questions. The transfer of fundamental knowledge into evidence-based practice and the method by which findings support the development of expertise in each field is also of interest. From a materials conservation perspective, this paper examines these issues in relation to a collection of Middle Eastern manuscripts belonging to the University of Melbourne. The manuscripts were acquired between 1959 – 1973 through booksellers and visits to the Middle East, and although some records of these transactions remain, the provenance of the majority of the material is unclear. Thus, the object itself provides the starting point for reconstructing, evaluating and integrating evidence.

Keywords: Cultural Materials Conservation, Material Science, Interdisciplinary, Social Impacts of Science, Evidence-based Research

Introduction

Acquired mainly between 1959 and 1973, the Middle Eastern Manuscript (MEM) Collection at the University of Melbourne contains approximately 190 manuscripts. Professor John Bowman built the collection from contact with booksellers in the United Kingdom and during visits to the Middle East. He sought to provide students with access to primary texts for cultural and language studies (Pryde 2008). With Bowman's retirement in 1973 the collection was no longer used for teaching and was deposited in the University of Melbourne Library. As a result there has not been active scholarship of the kind that would further inform and enhance knowledge and understanding of the materials (Lewincamp 2011). The Collection consists of secular and religious texts including books of poetry, astrology, mathematics, logic, grammar, Christian prayer books, and biographies, as well as commentaries on the Qu'ran and a number of Qu'rans. It includes material from across the Muslim world, with texts in Turkish, Persian, Arabic, Syriac, Sanskrit, and Urdu, as well as some Christian texts (Sloggett 2007, 89). Today these manuscripts are embedded in an English-language education system, making access to the content of the texts impossible for most students. As a result this collection is relatively unknown and under-researched, and much work remains to be done to verify information pertaining to the collection and to individual texts contained within it. In such circumstances, how to build a framework in which information about the texts can be uncovered, accumulated and made available, is a major research question. Using cultural materials conservation as the

investigatory methodology this paper brings together a range of disciplinary enquiries including historic, scientific, and codicological to further our understanding of this collection.

This study focuses on one text as a case study, MUL 17, a seventeenth century Arabic language manuscript titled *Ṣad kalamih Shāḥ Vilāyat - Manzūmih dar Ḥajj*. It was selected for study because its geographic and cultural provenance is uncertain, and its material components present useful avenues for analysis. The materials of the manuscript focused the investigative framework, involving continuous cross verification of information to frame hypotheses, develop methodologies, and to verify assertions.

What Conservation Does

The interdisciplinary field of cultural materials conservation combines a materials science methodology with an understanding of, and respect for, the historical and social context of objects (AICCM 2000). By necessity conservation spans disciplinary boundaries (Munoz Vinas 2005, 11; Avrami 2000, 10). In recent years, the contribution of conservation to broader contemporary issues has gained prominence in the literature (see for example Richmond and Bracker 2009). Cross-cultural studies of art and artifacts enables a greater understanding of how cultural diversity shapes social interaction, and by implication our own society. It also addresses the broader issue of how historical objects can have relevance in contemporary communities and ongoing public benefits (Sloggett 2009, 170). Interdisciplinary study ensures we have a broad intellectual tool-kit with which to address such complex enquiries.

Cross-cultural and interdisciplinary research must also address the persistent concern regarding the nature of knowledge, where some forms of knowledge are undermined by the stigma of ‘perceived illegitimacy’ through which they are viewed by others (Heberlein 1988, 7). This can occur between disciplines where one approach is considered to be ‘correct’ for the question at hand. In cross-cultural studies, of the kind examined in this paper, singular approach such can be limiting. In this respect, and where an object may have lost ‘proximity to those who understand and maintain its cultural meaning’, materiality remains an important key with which to engage in culture-related investigations (Sloggett 2008, 89). Framed by historical investigation, materials science, which includes basic visual examination through to highly sophisticated instrumental analysis can assist with material identification, and locating the object in a cultural context. For this case study, a materials-based examination focussed on the type and source of papers and pigments used in the production of the text.

Libraries, museums, and galleries contain countless items detached from the culture and society in which they were produced. The interdisciplinary research model provided by conservation considers knowledge in the sciences and the humanities as equal contributors to the rebuilding of knowledge and reacquainting an object with its community of origin. As Erica Avrami argues, ‘conservation is not simply about the objective stewardship of heritage resources, but is largely bound up in the very subjective relationships between people and places’ (2009, 178). Sharing interdisciplinary knowledge provides a relational framework and knowledge base from which to develop improved cultural engagement, and facilitate future investigations. Using this cross-disciplinary approach raised the profile and renegotiated meaning for the University of Melbourne’s Middle Eastern Manuscript (MEM) Collection.

Questions About the Manuscript

Acquisition of the texts by the University of Melbourne resulted in their decontextualisation and recontextualisation both geographically and intellectually, and removed them from their original use in teaching, scholarship and religious practice. Removal from the original custodians and communities was the first loss of cultural significance suffered by these manuscripts.

With the retirement of Professor Bowman in 1973 and the amalgamation of the Middle Eastern Studies Department at the University of Melbourne with Classics and Archaeology in the late 1980s the collection once more suffered significant loss. It was no longer accessed by students interested in its textual and cultural information, and many important records relating to the provenance of the manuscripts were also lost. A *Catalogue of Works of Art 1971* from the University of Melbourne Library, which managed the collection, identified 113 manuscripts (Pryde 2008, 1). By 1977 an additional fifty-five manuscripts had been identified in the collection (University of Melbourne Library 1977). Of these, seventy-two are listed as Persian in origin but there is little information relating to content and manufacture of the texts. In 1993 a condition survey and research program provided information on the state of the manuscripts, identifying 30% of the items as requiring stabilisation. Apart from this no further information exists in the University archives although random sources could be contained within individual archive boxes.

In recognition of the significance of the collection, and in order to build a core of information which could be shared with other scholars internationally, staff and students at the Centre for Cultural Materials Conservation (CCMC) at the University of Melbourne have developed a multi-faceted research program which examines materials used in the manuscripts, and explores culturally appropriate care and handling procedures. This dual approach of analysing the manuscripts and understanding their cultural value is important. Currently the catalogue records contain only basic information relating to the origin, date, subject and region of manufacture. Apart from being accessible to staff and students at the University of Melbourne, and being available for the occasional exhibition (*Nur Al-Quran*, Islamic Arts Museum, Malaysia Nov. 1999-Mar. 2000 and *Illuminations*, Ian Potter Museum of Art, Australia Sept. 2006-Mar. 2007, and *Love and Devotion: From Persia and Beyond*, State Library of Victoria, March-July 2012) the Collection is not used by theological or cultural communities. Without vital cultural information relating to the use and context of the material, it is difficult for collection staff to recommend the most appropriate access and storage procedures. The manuscript that forms the basis for this paper, MUL 17 *Ṣad kalamih Shāḥ Vilāyat - Manẓūmih dar Ḥajj* is listed as a seventeenth century manuscript; the text is thought to be Persian but catalogued as Arabic. An interdisciplinary approach was required to provide further information on its provenance, materials and significance.

Methodology

The decontextualisation of the University of Melbourne's MEM Collection raised significant methodological issues, in particular whether textual approaches, including literary and linguistic, would shed light on the provenance of the manuscript; whether a technical study of the materials and production methods would provide new information about provenance, such as indicating the origins of repair techniques and materials used; whether science could provide data to inform cultural context through an assessment of the pigments; and whether there were Middle Eastern scholars who could provide information on the manuscript, but who were not able to access it.

While a discipline in its own right, cultural materials conservation also provides a cross-disciplinary framework for other disciplines engaged in an enquiry such as this. Conservation offers its own criteria and assessment methods to verify and re-evaluate data provided by other branches of knowledge. Under this rubric integrated information can be developed, accumulated and made available. The process substantiates (or rejects) claims made by one disciplinary enquiry by developing a theory of best fit from which to examine unknowns against a framework of knowns. Central to the integration process is the equal engagement, assessment and respect for the contributing knowledge domains. As Heberlein (1988) points out, a danger with this approach (of which conservation research is very aware) is the possibility of giving preferential weighting to particular forms of knowledge. With this in mind the investigation of MUL 17

began with a thorough examination of the text, followed by a literature review examining related cultural, historic and scientific information. A panel of experts from the University was established to fill gaps in knowledge, verify data as it was collected and oversee the project. Finally, an analytical pathway was developed resulting in a detailed technical examination, which included the use of high level scientific instrumentation.

Analytical Methodology

Scientific analysis of cultural materials can utilise a range of techniques. Elemental identification frequently draws on x-ray fluorescence (XRF) and scanning electron microscopy – electron dispersive spectroscopy (SEM-EDS), while molecular analysis can be achieved with Raman and infra-red (IR) spectroscopy. For MUL 17, instrumental considerations included the need to undertake non-invasive in situ analysis of the organic dyes and inorganic pigments. Recent advances in optics and detector technology of Raman microscopy deliver within these parameters. Raman microscopy produces unambiguous, highly resolved data due to its high spatial (1 μm) and high spectral (1 cm^{-1}) resolution (Best et al. 1992, Clark 2007). Its ability to obtain information about organic and inorganic materials reduces the need to use more than one instrument. Furthermore Raman microscopy can differentiate between pigments of the same formula but different crystalline structures (polymorphs) (Best 1992, 69). This advantage is particularly useful for provenance, dating and authentication studies. For example the two polymorphs of titanium white, anatase and rutile are both used as pigments. The detection of anatase on an artwork links it to a time frame of 1923 compared to the date of 1948 for rutile. The red pigment realgar derived from arsenic sulphide can be distinguished from its degraded form of pararealgar, provided the sample is irradiated with a 647.1nm laser (Clark and Gibbs 1998b).

A major disadvantage associated with Raman microscopy, is the intense broadband fluorescence in the visible region associated with some pigments and binders which may swamp the inherently weak Raman spectrum. When examining the MEM texts using Raman microscopy, difficulties were experienced gaining clear spectra from several highly fluorescing green and yellow pigments (Sloggett et al. 1999). This can be effectively suppressed, by shifting to a longer wavelength of excitation; however there is a spectroscopic trade-off, resulting in an intrinsically weaker Raman spectrum (Edwards and Chalmers 2005). Another potential negative is that the high power density of the focussed laser beam can induce thermal or photochemical alteration and degrade samples. Mineral pigments observed to convert to different coloured species upon visible laser excitation are vermilion (HgS) and various lead oxides. Laser induced sample burning can be negated by lowering laser energy and shifting to longer excitation wavelengths. The above described benefits of Raman microscopy were deemed to outweigh these drawbacks and the technique was used to investigate the MEM collection.

Investigatory Results

Culture

In cultural materials investigations the origin of the item may have significant protocol implications for the way the item is handled, researched and accessed. For the MEM collection, there are restrictions detailed by Shari'ah (divine) law as to the correct handling of Islamic religious material. For example as the Holy Qur'an is the word of God, Qur'ans should be treated with due reverence and stored in a clean environment, and anyone handling a Qur'an should also have cleaned themselves appropriately (Wilson 2004, 136). Shari'ah law also dictates that Islamic manuscripts should not be in contact with 'ritually impure materials such as dog, pig, corpse, blood, semen, human urine and excrement and liquid intoxicants' (Zekrgoo and Barkeshli 2005, 96).

The University of Melbourne librarians and conservators developed cultural protocols for the management and preservation of the MEM collection. When a manuscript is first identified as containing Qur'anic textual information it is handled with clean hands and examined on a table higher than groin level. Qur'anic texts are then stored above all other subject matter to demonstrate the required level of respect and cultural reverence. All manuscripts within the collection are housed in archival quality boxes in two metal shelving units within a temperature and humidity controlled environment. Access to the manuscripts is restricted to the Special Collections Reading Room, where staff ensure appropriate handling training for researchers.

Similar measures are incorporated into materials conservation investigations and to any conservation treatment of volumes in the collection. Until more is known about the manuscripts, minimal or no intervention has been the preferred approach. On the few occasions when treatments have been necessary, manuscripts were not repaired with any pig derived gelatine adhesive products or other products which may be conflict with Shari'ah directives. Culturally appropriate adhesives, consolidants, tools and techniques were used to repair and support fragile media. Any evidence of use and historical information was also retained.

The Provenance of Manuscript MUL 17

With only basic information available relating to the origin, date and content of MUL 17, further provenance investigations were undertaken. MUL 17 is a seventeenth century manuscript entitled *Ṣad kalamih Shāh Vilāyat - Manzūmih dar Ḥajj* (University of Melbourne 1993). It is in two parts; the first, *Sad kalamih Shah Vilāyat*, is believed to be by a well-known Persian literary scholar, Rashid al-Din Vatvat (c. 1087-1142) and the second, *Manzūmeh Hajj*, is a long poem in Persian by an unknown author (Zekrgoo 2013). An inscription in English on the first folio, 'The one hundred sayings of Ali translated into Persian by Rachid-ed-Din Vatwat. Written by Schah Mahmoud Nichapuri. A description of the holy places and description of the Pilgrimage to Mecca, plans and illumination by Nezami' helps to provide some basic information related to its content, however it is unclear who wrote this description, or when it was written.

Rashid al-Din Vatvat, otherwise formally known as Mohammad ebn Abd el-Jalil Omari Balkhi, was born in Balkh (now in northern Afghanistan) and moved to Persia where he became a well-known literary scholar. The first book contains the sayings of Alī ibn Abī 'ālib (d. 40 AH / 661 CE), which were originally written in Arabic but are translated into Persian in this text. The second book, *Manzume Dar Hajj*, was inscribed by Shah Mahmoud Nichapuri (b. 1564-65 (?)), a great calligrapher of the sixteenth century. Nichapuri lived during the reign of Shah Tahmasb (1514-1576) of the Safavid dynasty (1502-1736) who was a great patron of the arts, especially the art of books. Nichapuri was a leading calligrapher at the Royal Library, and Shah Tahmasb commissioned him to produce many manuscripts, bestowing on him the title of the 'golden pen' (Haghighat 2009). Similar manuscripts by Nichapuri have no mention of an illuminator. Some of Nichapuri's manuscripts are considered to be masterpieces, such as *Khamsa* of the poet Nezami, now kept in British Library, London (Or. 2265); and *Haft Awrang* by the poet Jami in the collection of the Freer Gallery of Art, Washington (Titely 1983, 105 ; Gray 1977, 138). Given the importance of manuscripts inscribed by Nichapuri, it is likely that MUL 17 was highly valued and commissioned by Shah Tahmasb or his successors in the sixteenth century. Similar to other Persian manuscripts it is likely that there are many stakeholders involved in the production of MUL 17, some of who are specifically named and others who are not. Some of the evidence and literature is contradictory, highlighting the limitations of research on these manuscripts without language and cultural expertise. Rather than provide solid evidence, such disparate sources of information raise many uncertainties and suggest a number of possible investigatory pathways

How MUL 17 specifically became part of the University of Melbourne MEM collection also remains unanswered. There is no date of acquisition recorded, although it was most likely obtained between 1959 and 1973 when Professor Bowman was actively building the collection.

Bowman regularly acquired manuscripts from book and manuscript dealer, Mr Reynolds from 'Luzacs' in Bloomsbury, whose sources included Mr Ellis, the Keeper of Manuscripts at the British Museum (Sloggett et al. 1999, 20). Little else is known about MUL 17, however the collection of Middle Eastern manuscripts assembled by Prof. Bowman, at Leeds University prior to taking up his appointment at Melbourne, offers an avenue for future investigation.

Textural: Historical Treatise

A review of historical Persian documents and treatises provided recipes and techniques for the production of manuscripts and their pigments. These sources give valuable insight into the production of manuscripts, and include information on methods for producing pigments, dyes, binding mediums, sizing materials and commonly employed techniques such as burnishing. When material types and production processes relating to a particular place or period are known these can be compared to information available from analysis of the manuscript's materials with the view to linking it to its historical source or location of practice.

Table 1 lists a range of materials referred to in Persian historical treatises, accessible to Islamic scholars or as English translations. Important treatises include *Calligraphers and Painters: A treatise* by Qadi Ahmed and translated by Minorsky in 1959 and *Qanun us-Savar (Canons of Painting)* by Sadiqi Bek (written between 1576-1602), translated by Dickson and Welch in 1981. These treatises discuss not only pigment production techniques but also theoretical aspects of painting and application of colour. Both manuscripts contain information on pure colours such as lead white, red lead, verdigris, gold, cinnabar and orpiment and pigment mixtures. Qadi Ahmed (Minorsky 1959, 198) describes mixing lapis lazuli with cinnabar in the presence of Gum Arabic to produce a purple suitable for painting. Qadi Ahmed's treatise, which is a guide on how to become a calligrapher, included recipes for producing black ink, and details of the most appropriate techniques for burnishing and tinting papers. Information gained from the historical treatise provides known data to compare against materials identified in MUL 17.

Material Composition of Manuscript

Technical Examination

MUL 17 is a maroon leather bound manuscript with doublure and envelope flap. The envelope flap is characteristic of Islamic bindings, extending from the left side of the case (the back cover), and tucking under the front cover to protect the fore edge of the textblock (Wilson 2004). The cover is decorated with embossed and gilded central and flanking medallions. The doublure lining is uncoloured calf with inlay or cut away gold decorations similar to the outside cover (Sloggett 2008, 92). The binding structure is sound though not original and therefore was not selected for materials analysis. The text block has been re-sewn into the leather cover in reverse and as a result the envelope does not wrap around the width of the manuscript, offering it little protection.

Throughout the manuscript are intricate illuminations and miniatures depicting travels to Mecca in blue, gold, red, yellow, green, black and white pigments (see figure 1). Pages of texts are framed with coloured border lines known as *lplik*. Text pages are composed of illustrations on one sheet of laid highly burnished paper with a wider paper surrounding it to form a border, which has been toned with a light red/pink wash.

Numerous interventions and repairs over various periods are apparent, as indicated by the reuse of high quality bindings, insertion of additional pages and inconsistent text burning (a form of acid deterioration). Such interventions were common as manuscripts required regular repairs while being read, traded and reused. There is also wear along the front and back outer joints and the envelope flap joins, linked to the thinly pared leather, repeated use and fragility of the cover (Bosch et al. 1981, 63). Understanding the structure and deterioration of the text assists decision-

making for conservation studies including where to find original material from which to undertake materials analysis.

Science: Pigment Analysis

Materials analysis of the manuscript MUL 17 included identification of pigments with the aim of characterizing the artist's palette, identifying deterioration mechanisms particular to the manuscript, and to assist with dating and attribution. Non-invasive Raman microscopy was undertaken and part of the investigations included establishing a reference database of pigments most likely to have been used; with information drawn from the scientific literature and historical treatise. Tables 1 and 2 (Parts A and B) details common pigments used in the production of Middle Eastern manuscripts, as drawn from historical and scientific sources (including Chaplin et al. 2006; Jurado-Lopez 2004; Hayez et al. 2004; Bruni et al. 2001; Clark and Gibbs 1998; Ciomartan and Clark 1996; Purinton and Waters 1991). These Tables provided the basis for building a Raman spectroscopic database of 89 pigments (Sloggett 2008, 91), shared with other researchers, with the aim of providing a comparative baseline data set for the study of manuscripts held in collections around the world.

Raman Investigation

A Reinshaw Raman Microscope (Ramascope 2000), with a linearly polarised HeNe laser (Spectra Physics model #27 (632.8nm) was employed for the study. Five pages from manuscript MUL 17 were analysed, including the unwan, page 69vv, page 54R, page 44R and page 20R. Results detailed in Table 3 summarise pigments identified, their mixtures and sample maps. Some results were less conclusive than others and descriptive details are included to provide evidence used to develop a theory of best fit for comparison with other data. Lack of conclusiveness mainly applied to pigment mixtures. Overall analysis uncovered both pure and pigment mixtures and pages unwan and 69v provided the best spectral results.

Discussion

There is a high degree of correlation between the range of pigments identified and those mentioned in the historical treatise and reported in recent analytical studies (refer Table 2). The most commonly reported pigments were ultramarine blue, vermilion, orpiment, lead white and black. All were identified in MUL 17, supporting a date of production in the seventeenth century. The unwan page has intricate painted details in blue, gold, red, green, violet and yellow pigments. Of the seven samples tested for blue, all showed clear lapis lazuli or ultramarine blue with Raman band positions of 1096 and 548 cm^{-1} . Whilst it is not possible to differentiate natural lapis from synthetic ultramarine blue with Raman (both being sodium silico aluminate in a sulfur matrix), a natural source is suggested by larger irregular sized pigment grains observed via optical microscopy. Violet sample areas were less conclusive but one lapis lazuli spectrum with lead carbonate (band positions of 665, 687, 829 and 1050 cm^{-1}) was identified, with another giving an uncertain result. A historical treatise by Qada Ahmed notes cinnabar was used in mixtures to achieve violet, but on this occasion was not identified. Blue particles within the green areas indicated azurite, a basic copper carbonate pigment commonly used as a cheaper alternative to lapis. According to Table 2 and 3, use of azurite was rare. A number of red pigments were identified including vermilion (band positions 252, 282, 343 cm^{-1}), realgar (band positions 142, 164, 171, 182, 192, 220, 233, 327, 342, 354, 367, 375 cm^{-1}) with a second peak possibly from the drying agent, an orange red with charcoal and a red not identified. The unidentified red displayed a similar spectrum to other red areas analysed in the collection and may relate to a dye not in the reference database.

Folio 69v is a page from 'A description of the pilgrimage to Mecca' in the second part of the manuscript. It comprises blue, yellow, red, gold, green and brown pigments. Three blue particles in the dome were believed to be lapis lazuli, however the spectra for two of these exhibited slightly irregular lapis lazuli peaks. Artificial ultramarine in a second sample, is indicated by the observation of smaller, regular pigment particles. It may indicate a post-1830 date for the manuscript, restoration of an area not clearly evident, or a high-grade pigment source due to purification manufacturing processes. The violet colour of the dome indicates a mixture containing small amounts of lapis lazuli with red particles in a lead white matrix, providing good correlation with information contained in historical treatises. Lapis was also found in the green leaves and brown trunks of these illustrations. Yellow and red pigments within the borders showed evidence of orpiment (As_2S_3) (band positions 136, 154, 181, 202, 220, 230, 292, 309, 353, 381 cm^{-1}) and realgar (band positions above), which is natural sulphide of arsenic ($\alpha\text{-As}_4\text{S}_4$). These two pigments are similar in composition and commonly used in paintings from Iran, Turkey, Iraq, Persia and the Himalayas. They also occur frequently other manuscripts in the Collection (see Table 2). Both were used to cover large areas in MUL 17. Green palm leaves were identified to contain a combination of red (vermilion), blue (lapis lazuli and orpiment), yellow (orpiment) and white mostly probably calcium carbonate (as no lead was present in the spectra).

The remaining pages of MUL 17 provided less conclusive identifications. Spectra obtained from the same area varied, perhaps indicating a mixture of pigments or missing colourants in the reference database, including dyes potentially present in the background and washed areas in the border regions. Clearly a more comprehensive database would produce more conclusive results. Now that the research questions regarding specific parts of the manuscript have been elucidated, additional complimentary analytical techniques with non-invasive capabilities such as molecular (FTIR), elemental (like SEM-EDS, XRF, PIXE, ICP-MS, XPS), and crystalline structure based techniques (XRD & PLM) (Clark 2005; Edwards and Chalmers 2005) could be strategically employed.

Outcomes

Investigation of manuscript MUL 17 has engaged researchers in both interdisciplinary and cross-cultural investigations, bringing new knowledge to bear on the content, materials and provenance of the collection, as well as provided important information on appropriate protocols for the management and future research of the collection. This awareness of the cultural protocols required when accessing religious Islamic texts is a significant shift in the way the collection is managed. Furthermore researchers who do not have an Islamic background are now more aware of how research and scholarship should be conducted on this material. This kind of consideration has been progressed in the museum sector for some time (see for example Museum Australia's 2005 *Continuing Cultures – Ongoing Responsibilities*). The need for Raman instrument operators to set stages above genital level, and to wash appropriately prior handling this material, has led to greater cultural awareness within a group that would not necessarily consider the cultural impact of their research methodology. The analytical pathway discussed in this paper enabled a solid body of data to be collected from individual manuscripts. In turn this provided content for showcasing the collection in publications and international forums, reintroducing it to academic and professional networks where re-examination, re-assessment and re-contextualisation could occur. To date more than five papers have been published as an outcome of this project (Sloggett et al. 1999; Wilson, 2004; Sloggett, 2008; Pryde, 2008; Lewincamp, 2012), as well as an international symposium (The Symposium on the Care and Conservation of Middle Eastern Manuscripts, University of Melbourne, Nov. 2007), a book (Contributions to the Symposium on the Care and Conservation of Middle Eastern Manuscripts, 2008) and three coursework higher degree theses (Anderson, Wilkinson and Wang) and a PhD thesis (Lewincamp) either completed

or in progress. With the MEM Collection being re-introduced into an academic community has led to its digitisation in order to improve access and new engagement opportunities such as a university public lecture 'Text and Culture: Preserving Tangible and Intangible Persian Cultural Heritage' (Lewincamp et al, 2012).

Successful interdisciplinary investigations such as this rely on joint ownership of the research question, and integration of knowledge bases with a shared respect for the research question across collaborating researchers. When this project first began, the panel of experts and investigatory research team devoted substantial time to the development of the context for the research question and built a mutual understanding of content, process and expected outcomes. This included recognition of instrumental requirements and limitations, an awareness of specific documentation needs, adapting analytical tools to a cultural materials framework and organising data formats for integration. In addition the research team considered ways of increasing knowledge of the collection through raising its profile and enabling access. Strategies included publishing, a trial digitisation project, and an international symposium. The research has increased CCMC's capacity to work across disciplines and has provided a methodology for establishing protocols, which are culturally, ethically, historically and scientifically inclusive. Investigatory pathways are now established for the MEM collection providing a strong framework for research led teaching at CCMC. As universities increasingly recognise the need to cater for a changing student demographic, the preservation and study of cultural collections presents an opportunity to engage students in new forms of research. The new interdisciplinary undergraduate subject 'Learning Cultures' aims to do just that, and through use of this research as a case study shows how the synthesis of scientific investigation and cultural understanding can provide new ways of thinking and learning about ourselves.

According to the Australian Bureau of Statistics (ABS) 2011 Census there has been an increase in Islamic arrivals from 4.7% to 8.4% since 2006. The Muslim community in Australia is highly diverse, both culturally and linguistically. They are born and their ancestors were born in many different countries. According to the ABS 2011 Census there are 476,300 Muslims living in Australia. This Australian Muslim community is relatively young, 58.6% are aged 29 and under compared to 39.9% of the total Australian population in that age group. Of the Australian-born Muslims, who are usually second generation Australians, 81.8% are under 25 years. Overseas born Muslims are predominantly in the 25-44 age bracket. It is anticipated that the Australian Muslim population will considerably increase in the next decade. This collection provides a currently untapped resource for local Diaspora communities. Drawing on knowledge from these communities provides a range of benefits allowing improved understanding of the collection. As there is likely to be a significant increase in Muslims within the Australian society it is fair to conclude there will an increase in Muslim students attending higher education institutions. Through increased study, promotion and stabilisation of this collection, a new contemporary society within the University of Melbourne, and perhaps more broadly Australia, can engage with and re-discover the manuscripts.

Conclusion

Demonstrating Avrami's statement that the discipline of cultural materials conservation uses material heritage to link people with places, the study of MUL 17 drew upon a range of knowledge domains. Produced centuries earlier in a completely different context, and initially used for scholarly and/or religious purposes, texts within the collection were brought together in the second half of the twentieth century in a new intellectual configuration to provide a textual and cultural study collection for students of Middle Eastern Studies at the University of Melbourne. By the end of the twentieth century this purpose ceased and the collection was in danger of being considered obsolete. Developed within culturally appropriate protocols and informed by historical enquiry, and scientific investigation using Raman microscopy was

employed to build significant information, and enabled this collection to once again enter the world of intellectual engagement and scholarship. Most significantly the scientific study has excited a much broader group of researchers about the potential for the collection; leading to the engagement of Islamic scholars in considerations about protocols and cultural issues; has generated a higher profile for the collection which in turn provided the justification for digitization; and which will increased access to the collection, not only to interested scholars, but to community groups across Australia and overseas. As this study indicates, the value of science in society is as much about the interest it excites as the scientific results it produces. In this case the interest in the scientific investigations produced significant shifts in approaches and access to this collection. As a result not only will the conservation of this collection be better enabled, but with increased access and understanding its use, is substantially enhanced and the subsequent knowledge developed about it, and similar collections.

REFERENCES

- Australian Bureau of Statistics (ABS). 2011. Chapter 5 Population – International Migration, accessed 18 July 2012, <http://www.abs.gov.au/ausstats/abs@.nsf/bb8db737e2af84b8ca2571780015701e/918B6C069BF7E993CA2570DE000697EA?opendocument>.
- AICCM. 2000. Australian Institute for the Conservation of Cultural Material (Inc), Code of Ethics and Code of Practice, accessed 17 April 2013, http://www.aiccm.org.au/index.php?option=com_content&view=article&id=39&Itemid=38, viewed 17 April 2013.
- Arias, Teresa E., Ana L. Montes, Ana G. Bueno, Adrian D. Benito, and Rosario B. Carcia. 2008. “A Study about Colourants in the Arabic Manuscript Collection of the Sacromonte Abbey, Granada, Spain. A New Methodology for Chemical Analysis.” *Restaurator* 29: 76-106.
- Anderson, Jennifer. 2010. “A Stick will be necessary for the last group: Instructional texts on the sewing of Islamic manuscripts 11th-17th centuries.” Master’s minor thesis, University of Melbourne.
- Avrami, Erica. 2009. “Heritage, Values and Sustainability.” In *Conservation Principles, Dilemmas and Uncomfortable Truths*, edited by Alison Richmond and Alison Bracker, 177-183. London: Elsevier.
- Bailkin, Jordanna. 2005. “Indian Yellow: Making and Breaking of the Imperial Palette.” *Journal of Material Culture* 10: 197-214.
- Balfour-Paul, Jenny. 1997. *Indigo in the Arab World*, Richmond: Curzon Press.
- Barkeshli, Mandana. 2007. “Historical and scientific analysis of Iranian illuminated manuscripts and miniature paintings.” In *Contributions to the Symposium on the Care and Conservation of Middle Eastern Manuscripts*, 74-88. Melbourne: Centre for Cultural Materials Conservation.
- Barkeshli, Mandana. 1999. “The presence of saffron in Persian miniature paintings and its use as an inhibitor for the destructive effect of verdigris.” In *International Council of Museums: Committee for Conservation Triennial meeting (12th)*, Lyon, 29 August-3 September 1999: preprints. Vol. 2, pp. 489-494.
- Bersani, Danilo, Pier Paolo Lottici, Francesca Vignali, and Giuseppa Zanichelli. 2006. A study of medieval illuminated manuscripts by means of portable Raman equipments. *Journal of Raman Spectroscopy* 37: 1012-1018.
- Best, Stephen, Robin J.H. Clark, Marcus A.M. Daniels, Cheryl A. Porter and Robert Withnall. 1995. “Identification by Raman microscopy and visible reflectance spectroscopy of pigments on an Icelandic manuscript.” *Studies in Conservation* 40: 31-40.
- Best, Stephen., Robin J.H. Clark and Robert Withnall. 1992. “Non-destructive pigment analysis of artefacts by Raman microscopy.” *Endeavour*, 16: 66-73.
- Bicchieri, Marina, Michele Nardone, and Armida Sodo. 2000. “Application of micro-Raman spectroscopy to the study of an illuminated medieval manuscript.” *Journal of Cultural Heritage* 1: S277-S279.
- Bloom, Jonathan. 2001. *Paper Before Print: The History and Impact of Paper in the Islamic World*, New Haven and London: Yale University Press.
- Brown, Katherine L. and Robin J.H. Clark 2002. “Analysis of Pigmentary Materials on the Vinland Map and Tartar Relation by Raman Microprobe Spectroscopy.” *Analytical Chemistry* 74: 3658-3661.
- Brown, Katherine L. and Robin J.H. Clark. 2004a. “The Lindisfarne Gospels and two other 8th century Anglo-Saxon/Insular manuscripts: pigment identification by Raman microscopy.” *Journal of Raman Spectroscopy* 35: 4-12.

- Brown, Katherine L. and Robin J.H. Clark. 2004b. "Analysis of key Anglo-Saxon manuscripts (8-11th centuries) in the British Library: pigment identification by Raman microscopy." *Journal of Raman Spectroscopy* 35: 181-189.
- Brown, Katherine L. and Robin J.H. Clark. 2004c. "Three English manuscripts post-1066 AD: pigment identification and palette comparisons by Raman microscopy." *Journal of Raman Spectroscopy* 35: 217-223.
- Bruni, Silvia, Franco Cariati, Francesca Casadio and Vittoria Guglielmi. 2001. "Micro-Raman identification of the palette of a precious XVI century illuminated Persian codex." *Journal of Cultural Heritage* 2(4): 291-296.
- Burgio, Lucia, Robin J.H. Clark, Vânia S.F. Muralha and Tim Stanley. 2008. "Pigment analysis by Raman microscopy of the non-figurative illumination in 16th- to 18th-century Islamic manuscripts." *Journal of Raman Spectroscopy* 39: 1482-1493.
- Burgio, Lucia, Dan A. Ciomartan, and Robin J.H. Clark. 1997a. "Raman Microscopy Study of the Pigments on Three Illuminated Mediaeval Latin Manuscripts." *Journal of Raman Spectroscopy* 28: 79-83.
- Burgio, Lucia, Dan A. Ciomartan, and Robin J.H. Clark. 1997b. "Pigment identification on medieval manuscripts, paintings and other artefacts by Raman microscopy: applications to the study of three German manuscripts." *Journal of Molecular Structure* 405: 1-11.
- Cariati, Franco and Bruni, Silvia. 2000. "Raman Spectroscopy." In *Modern Analytical Methods in Art and Archaeology*, edited by Enrico Ciliberto and Giuseppe Spoto, 255-78. New York: John Wiley & Sons.
- Chaplin, Tracey D., Robin J.H. Clark, Alison McKay, and Sabina Pugh. 2006. "Raman spectroscopic analysis of selected astronomical and cartographic folios from the early 13th century Islamic 'Book of Curiosities of the Sciences and Marvels for the Eyes'." *Journal of Raman Spectroscopy* 37: 865-877.
- Chowdry, Anita. 2007. "The studio practices of painters of the Mughal ateliers." In *Contributions to the Symposium on the Care and Conservation of Middle Eastern Manuscripts*, 36-48. Melbourne, Australia: Centre for Cultural Materials Conservation.
- Ciomartan, Dan A. and Clark, Robin J.H. 1996. "Raman Microscopy Applied to the Analysis of the Pigments Used in Two Persian Manuscripts." *Journal of the Brazilian Chemical Society* 7: 395-402.
- Clark, Robin J.H. 2007. "Raman microscopy as a structural and analytical tool in the fields of art and archaeology." *Journal of Molecular Structure* 834-836: 74-80.
- Clark, Robin J.H. 2005. "Raman Microscopy in the Identification of Pigments on Manuscripts and Other Artwork." In *Scientific Examination of Art: Modern Techniques in Conservation Analysis*, 241-185. Washington, DC: The National Academies Press.
- Clarke, Mark. 2004. "Anglo-Saxon Manuscript Pigments." *Studies in Conservation* 49: 231-244.
- Clark, Robin J.H. and Jaap van der Weerd. 2004. "Identification of pigments and gemstones on the Tours Gospel: the early 9th century Carolingian palette." *Journal of Raman Spectroscopy* 35: 279-283.
- Clark, Robin J.H. 2002. "Pigment identification by spectroscopic means: an arts/science interface." *Comptes Rendus Chimie*. 5: 7-20.
- Clark, Robin J.H. 1999. "Raman microscopy: sensitive probe of pigments on manuscripts, paintings and other artefacts". *Journal of Molecular Structure* 480-481: 15-20.
- Clark, Robin J.H. and Peter J. Gibbs. 1998a. "Analysis of 16th Century Qazwini Manuscripts by Raman Microscopy and Remote Laser Raman Microscopy." *Journal of Archaeological Science* 25: 621-629.
- Clark, Robin J.H. and Peter J. Gibbs. 1998b. "Raman Microscopy of a 13th-Century Illuminated Text." *Analytical Chemistry* 70: 99A-104A.

- Clark, Robin J.H. and Peter J. Gibbs. 1997. "Identification of lead(II) sulfide and pararealgar on a 13th century manuscript by Raman microscopy." *Chemical Communications* 11: 1003-1004.
- Clark, Robin J.H. 1995a. "Pigment Identification on Medieval Manuscripts by Raman Microscopy." *Journal of Molecular Structure* 347: 417-428.
- Clark, Robin J.H. 1995b. "Raman Microscopy: Application to the Identification of Pigments on Medieval Manuscripts." *Chemical Society Reviews* 24: 187-196.
- Edwards, Howell G.M. and Chalmers, John M. 2005. *Raman Spectroscopy in Archaeology and Art History*, Cambridge: Royal Society of Chemistry.
- Eastaugh, Nicholas, Walsh, V., Chaplin, T. & Siddall, R. 2004. *The Pigment Compendium*. Oxford: Elsevier Butterworth-Heinemann.
- Jurado-Lopez, Alicia, Ornela Demko, Robin J.H. Clark, and David Jacobs. 2004. "Analysis of the palette of a precious 16th century illuminated Turkish manuscript by Raman microscopy." *Journal of Raman Spectroscopy* 35(2): 119-124.
- Gettens, Rutherford J., Robert L. Feller, and W. T. Chase, 1972. "Vermilion and Cinnabar." *Studies in Conservation* 17: 45-69.
- Gettens, Rutherford J., Hermann Kuhn and W. T. Chase, 1967. "Lead White." *Studies in Conservation* 12: 125-139.
- Gettens, Rutherford J. and Elisabeth West Fitzhugh. 1966. "Azurite and Blue Verditer." *Studies in Conservation*, 11: 54-61.
- Gettens, Rutherford J. and Elisabeth West Fitzhugh. 1974. "Malachite and Green Verditer." *Studies in Conservation*, 19: 2-23.
- Golas, Peter. J. 1999. *Mining, Science and Civilization in China* V(13). Cambridge: Cambridge University Press.
- Gruber, Christine, ed. 2010. *The Islamic Manuscript Tradition: Ten centuries of books art in Indiana University Collections*. Bloomington: Indiana University Press.
- Hayez, V., S. Denoel, Z. Genadry and B. Gilbert. 2004. "Identification of pigments on a 16th century Persian manuscript by micro-Raman spectroscopy." *Journal of Raman Spectroscopy* 35: 781-785.
- Haghighat, Albrecht. 2009. *Iranian artists, from the beginning until today*, Tehran: Koomesh Publications.
- Heberlein, Thomas A. 1988. Improving interdisciplinary research: integrating the social and natural sciences. *Society and Natural Resources* 1: 5-16.
- Islamic Arts Museum. 2000. *Nur Al'Quran*. Kuala Lumpur: Islamic Arts Museum Malaysia.
- Kuhn, Hermann. 1970. Verdigris and Copper Resinate. *Studies in Conservation*. 15: 12-36.
- Laurie, Arthur P. 1949. *The Techniques of the Great Painters*. London: Carroll and Nicholson.
- Lee, L. R., A. Thompson and V.D Daniels. 1997. "Princes of the House of Timur: Conservation and Examination of an Early Mughal Painting." *Studies in Conservation*. 42: 231-240.
- Lewincamp, Sophie, "The Future will be brighter: Managing the future possibilities for the University of Melbourne's Middle Eastern Manuscript Collection." Paper presented at The Seventh Islamic Manuscript Conference, Cambridge, United Kingdom, July 12-14 2011.
- Lewincamp, Sophie. 2012. "Watermarks within the Middle Eastern Manuscript Collection of the Baillieu Library." *The Australian Library Journal*, 16(2): 95-104.
- Lewincamp, Sophie, Mammad Aidani and Susan Scollay. "Text and Culture: Preserving Tangible and Intangible Persian Cultural Heritage". Public lecture presented at University of Melbourne, June 20, 2012.
- Minorsky, T. T. 1959. "Calligraphers and painters: a treatise by Qā'ī A'mad, son of Mīr-Munshī circa A.H. 1015/A.D. 1606." *Freer Gallery of Art Occasional Papers* 3(2).
- Murkarji, Trailokya Nath. 1890. Indian Yellow. *Bulletin of Miscellaneous Information, Royal Botanic Gardens, Kew*, 1890: 45-50.

- Museums Australia. 2005. Continuous Cultures, Ongoing Responsibilities, Principles and guidelines for Australian museums working with Aboriginal and Torres Strait Islander cultural heritage, accessed September 25, 2013
http://www.museumsaustralia.org.au/userfiles/file/Policies/ccor_final_feb_05.pdf.
- Needham, J. 1976. *Spargyrical discovery and invention: Historical survey, from cinnabar elixirs to synthetic insulin*. Science and Civilization in China V(3). Cambridge: Cambridge University Press.
- Purinton, Nancy and Mark Watters. 1991. "A Study of the Materials Used by Medieval Persian Painters." *Journal of the American Institute for Conservation* 30: 125-144.
- Pryde, Pam. 2008. "John Bowman and the University of Melbourne's Middle Eastern manuscript collection." In *Contributions to the Symposium on the Care and Conservation of Middle Eastern Manuscripts*, 1-3. Melbourne: Centre for Cultural Materials Conservation.
- Renaud, H. P. J. 1934. Colin, G. T. (translated). *Tifhat al Ahbah, Glossaire de Metiere Medical Marocaine*. Paris: Institute de Haute Etudes Marocaine.
- Richmond, Alison and Alison Bracker, eds. 2009. *Conservation Principles, Dilemmas and Uncomfortable Truths*. Oxford: Elsevier.
- Sloggett, Robyn. 2009. "Expanding the Conservation Canon: Assessing Cross-cultural and Interdisciplinary Collaborations in Conservation." *Studies in Conservation*, 54(3): 170-183.
- Sloggett, Robyn. 2008. "Raman analysis of pigments found in Middle Eastern manuscripts in the University of Melbourne Collection." *Contributions to the Symposium on the Care and Conservation of Middle Eastern Manuscripts*: 89-99. Melbourne: Centre for Cultural Materials Conservation.
- Sloggett, Robyn, Angela Kerry and Keith Nugent. 1999. "Science in the Service of Religion and Art – Analysis of Pigments in Middle Eastern Manuscripts." *The University of Melbourne Library Journal* 5(2): 20-24.
- Smith, Gregory D. and Robin J.H. Clark. 2001. "Raman microscopy in art history and conservation science." *Reviews in Conservation* 2: 92-105.
- Stuart, Barbara. 2007. *Analytical Techniques in Materials Conservation*, London: Wiley.
- Titley Norah, M. 1983. *Persian miniature paintings and its influence on the art of Turkey and India*. London: British Library.
- Trentelman, Karen and Nancy Turner. 2009. "Investigation of the painting materials and techniques of the late-15th century manuscript illuminator Jean Bourdichon." *Journal of Raman Spectroscopy* 40: 577-584.
- Vandenabeele, Peter and Luc Moens. 2004. "Pigment identification in illuminated manuscripts." In *Non-destructive microanalysis of cultural heritage materials*, edited by K Janssens and R van Grieken, 635-662. Amsterdam: Elsevier.
- Von Rosen, Lissie. 1988. *Lapis Lazuli in Geographical contexts and in ancient written sources*. Studies in Mediterranean Archaeology 93. Uppsala: Åströms förlag.
- University of Melbourne, Library. 1977. "List of Oriental manuscripts held in the University of Melbourne Library", unpublished report, The University of Melbourne Library.
- Wang, May. 2012. "Historical and scientific analysis of dyes contained within the Persian manuscripts at the University of Melbourne." Master's minor thesis, University of Melbourne.
- West Fitzhugh, Elisabeth. 1988. "Study of Pigments on Selected Paintings from the Vever Collection." In *An Annotated and Illustrated Checklist of the Vever Collection*, 425-432. Washington, D.C. and Seattle: Arthur M. Sackler Gallery, Smithsonian Institution and University of Washington Press.
- West Fitzhugh, Elisabeth, ed. 1997. *Artists' Pigments: A Handbook of their History and Characteristics*, New York and Oxford: National Gallery of Art and Oxford University Press.

- Wilson, Lousie. 2004. "Middle Eastern Manuscripts: identifying cultural sensitivities and establishing procedures for their care." In *Collaboration and Connections: Postprints of the AICCM Paper, Books and Photographic Materials Special Interest Group Symposium*, Sydney April 1-3 2004, 131-139. Canberra: Australian Institute for Conservation of Cultural Material.
- Wilkinson, Melanie. 2009. "The Digital Surrogate for an 18th century manuscript: A Method of preservation and access." Master's minor thesis, University of Melbourne.
- Zekrgoo, Amir. (MacGeorge Visiting Fellow), in discussion with Sophie Lewincamp, August 2013.

Table 1: Pigment possibilities and characteristics based on historical Persian treatises including Minorsky (1959)(translation of treatise by Qadi Ahmed circa 1608), Sadiqi Bek 16th century (Dickson & Welch 1981), Ibn Badis (11th century), Islamic Arts Museum (2000) (16th-19th century), Yves Porter (12th-19th century)

Colour	Common Name?	Persian Name	Composition	Dates	Characteristics	Uses	Source
White	Lead white	<i>Sefed-ab</i>	Lead carbonate	15 th century	Transparent with age. Lead white can turn yellow over time and exposure to heat.	To lighten colours	European?
Yellow	Tin white	<i>Isfadj-e-haf</i>					
	Orpiment	<i>zarnikh</i>	Arsenic sulphide	Since antiquity 15 th century	Bright lemon-yellow. Orpiment is unstable, colour will fade	Mixed with indigo	Iran, Turkey, Persia, Himalayas
Red	Rhubarb	<i>riwand</i>					
	Vermillion	<i>shanjarf</i>	Mercuric sulphide	15 th century but as early as 10 th century	orange to orange red colour, fine small particles.		Turkestan
Red lead		<i>zaranj</i>	Red tetroxide of lead	14 th century	Yellow orange-red colour		Persia, China
	Red orpiment/Realgar	<i>Zarnikh-e-sorkh</i>	ruby sulphur, is a red or orange arsenic disulfide		Bright orange colour, translucent medium size		Turkey, Armenian
Safflower		<i>moasfar</i>	Carthamic acid or carthamin				
Carmine		<i>kerm-e-germez</i>	fine feculences of kermes and cochineal tinctures		sensitive to light and will fade readily	Often mixed with other red pigments to enhance colour and remove its properties. "Scarlet lake" was a combination of Carmine and vermilion.	
Lac		<i>lak</i>					
Brazil wood		<i>Baqam</i>					
Red and brown earth/Haematite		<i>Okhr va omra</i>	Ferric oxide	15 th century	dark red colour similar to vermilion, opaque very small fine particles		Persia
Green	Verdigris	<i>zangar</i>	Copper acetate	16 th century	Greenish blue in appearance, clear angular particles	Often mixed with lead white	Persia
	Malachite		Copper carbonate	15 th century	Not finely ground. Grey green in colour, opaque.		Ural mountains – Sinai & Eastern desert Egypt
Blue	Lapis Lazuli	<i>lajvard</i>	mineral lazurite, an alumina-silicate	13 th century – poor quality 15 th onwards higher quality 1850s onwards	Clear blue translucent particles		Afghanistan & Oxus
	Artificial ultramarine	<i>Lajvard anali</i>					
Indigo		<i>Baghdad</i>	Vegetable dye	15-16 th century	Stable, dark blue, cooler greyer blue deeper blue than lapis	Combined with orpiment or white, mixed by artists because its colour itself was too dark	Grown in India & China.
		<i>indigo (indigo bagdadel)</i>	plant <i>indigofera</i> genus				
Azurite		<i>lazward</i>	Copper carbonate	Rarely used in Persia	Ground coarsely, blue translucent crystals with a green tone		Sinai & Eastern deserts
		<i>doodeh</i>	Amorphous carbon	Pre-history 13-14 th century	Uniform and homogenous		
Black	Lamp black	<i>tala</i>					
Metallic	Gold	<i>noghreh</i>					
	Silver	<i>berenj</i>					India
Brass		<i>mes</i>					
Copper		<i>tala</i>					
Mica							

Additional Table References: (Baik'in, 2005), (Balfour-Paul, 1997), (Barkeshli, 2007), (Bloom, 2001), (Chowdry, 2007), (Eastaugh et al., 2004a), (Eastaugh et al., 2004b), (Gettens et al., 1966), (Gettens et al., 1967), (Gettens et al., 1972), (Gettens et al., 1974), (Gruber, 2010), (Kuhn, 1970), (Laurie, 1949), (Lee et al., 1997), (Muir'sarji, 1890), (Needham, 1976), (West Fitzhugh, 1988)

Table 2: Pigment types identified on Middle Eastern Manuscript Collections:
 A: Pigment Analysis in literature; B: Historical Treatise and Secondary Sources; C: Results from Manuscript MUL 17

Publication	Pigment colours																											
	Blue			Red			Yellow			Green			White			Black	Metal											
Pigment types in English and Persian	Ultramarine (lapis lazuli)	lalevard	Azurite lazward	Indigo <i>indigo bogadadi</i>	Vermillion (cinabar) shanjaf	Red lead (minim) soranj	Iron oxide (hematite)	Realgar Zarnikh-e-sorkh	(pararealgar)	Carmine (madder) Kern-e-qermez	Red Lake	Orpiment zarnikh	Yellow ochre (goethite)	Organic yellow (saffron moasfar, Indian Y.)	Malachite (copper carbonate)	Verdigris (copper acetate)	Copper sulphates (brochantite)	Copper chloride (Atacamite)	(Emerald green)	Green earths	Lead white Seferd-ab	Calcium Carbonate	Charcoal / Lamp black doodeh	Gold				
	A. Pigment Analysis																											
	Purinton & Watters (1991) 19 (15 th – 17 th century) XRF, XRD, PLM																											
	Ciomartan & Clark (1996) RAMAN																											
	Clark & Gibbs (1997); Clark & Gibbs (1998b); (13 th century) RAMAN																											
	Clark & Gibbs (1998a) [16 th century] RAMAN																											
	Barkeshli (1999), 12 manuscripts (16 th – 20 th century)/FT-IR, XRD																											
	Bruni et al. (2001) [16 th century] RAMAN																											
	Hayez et al. (2004) [16 th century] RAMAN, XRF, XPS																											
	Jurado-Lopez et al (2004) [16 th century] RAMAN																											
	Chaplin et al (2006) [13 th century] RAMAN																											
	B. Historical Treatise and Secondary Sources																											
	Treatises: Purinton & Watters (1991); Burgio et al (2008)																											
Minorsky (1959) (translation of treatise by Qadi Ahmed circa 1608)																												
Sadqiqi Bek 16 th century (Dickson & Welch 1981)																												
Ibn Badis (11 th century) [Levey 1962]																												
Islamic Arts Museum (2000) [16 th -19 th century]																												
Yves Porter (12 th -19 th century)																												
C. Manuscript MUL 17																												
Unwan																												
Page 69L																												
Page 54R																												
Page 44R																												
Page 20R																												

ABOUT THE AUTHORS

Sophie Lewincamp: Sophie coordinates the Masters treatment subjects at the Center for Cultural Materials and specializes in paper conservation. She is also conducting PhD research into the Middle Eastern manuscript collection housed within the Melbourne University collection. She has also worked for various Australian national institutions and overseas as a conservation fellow at the Library of Congress in Washington DC.

Dr. Nicole Tse: Dr. Tse is currently an Australian Research Council Postdoctorate Fellow at the Center for Cultural Materials Conservation investigating the twentieth century through painting. This major research initiative combines the expertise of conservation, art history, materials science, chemistry, curatorial studies and heritage management, and involves ten collaborating institutions across six countries and nine researchers. On the project, she is continuing to investigate research questions raised as part of her doctoral thesis, *The Characterization of Oil Paintings in Tropical Southeast Asia*. As part of her long commitment to conservation in Southeast Asia, she has delivered a number of training workshops, research projects and diplomatic assignments in seven Southeast Asian countries. She is also a founding member of the Asia Pacific Twentieth Century Conservation Art Network.

Dr. Petronella Nel: Dr. Nel is a lecturer and researcher at the Center for Cultural Materials Conservation. She has qualifications in art and science, with a BSC (Honors), PhD in chemistry and a Master of Arts in cultural materials conservation. She is involved with the teaching and research programs at the Center for Cultural Materials Conservation. Her research interests include the non-invasive analysis of artifacts, the development of scientific techniques to conservation, and the analysis and assessment of adhesives used to repair archaeological pottery.

Marcelle Scott: Marcelle earned a Bachelor's Degree in Applied Science with a focus in cultural materials conservation, specialised in objects conservation, and a Graduate Diploma of Arts in Archaeology. She recently completed the Graduate Certificate in University Teaching from the University of Melbourne. Since joining the Center in 2001, she has been responsible for the development and delivery of our teaching and research programs. She has over twenty years of experience in the conservation profession, working in state institutions and with community museums. She was national president of the Australian Institute for the Conservation of Cultural Materials (AICCM) from 1999–2001, and is the editor of the peer-reviewed *AICCM Bulletin*. She is a recipient of the Dean's Award for Excellence in Teaching and a Citation for Outstanding Contributions to Student Learning from the Carrick Institute for Learning and Teaching in Higher Education. She was selected for one of the prestigious 2007/2008 Conservation Guest Scholar awards from the Getty Conservation Institute in Los Angeles for research in the areas of conservation pedagogy and interdisciplinarity.

Dr. Robyn Sloggett: Robyn is the Director of the Centre for Cultural Materials Conservation at the University of Melbourne. Her research interests include attribution and authentication of Australian paintings, the development of the Australian art market, collection development and history, the investigation of the materials and techniques of artists, and the preservation of cultural materials held in Australian Indigenous communities. She holds qualifications in art history, philosophy, and cultural materials conservation (applied science). She has a PhD from the University of Melbourne.

Students' Conceptions about the Nature of Sound: A Study of Their Evolution and Their Dependence on the State of Matter of the Medium

Stefanos Iconomou, Hellenic Open University, Greece
Michael Skoumios, University of Aegean, Greece

Abstract: This study focuses on exploring conceptions of Greek secondary school students about sound. In particular, it aims to: (a) identify the conceptions of students about the nature of sound, (b) investigate the evolution of such conceptions as students move from the age of 13 to the age of 15 years and (c) study their dependence on the state of matter of the medium through which sound propagates (gas, liquid, solid). As a data collection research tool, a written questionnaire designed specifically for the purposes of research, was used. This was completed by 164 secondary school students (84 thirteen year-olds and 80 fifteen year-olds) from schools in Greece. The analysis of these results identified the conceptions that students activated about the nature of sound and highlighted their durability. Moreover, the results showed that students activate alternative conceptions about the nature of sound, which are different from school-acquired knowledge (wave nature of sound). Regarding the evolution of students' conceptions about the nature of sound, it can be seen that conceptions remain almost unchanged during the "transition" of students from the age of 13 to the age of 15. Additionally, it was found that students' conceptions about the nature of sound are more unclear when the medium is in solid state than in gaseous state.

Keywords: Students' Conceptions, Context Dependence of Conceptions, Nature of Sound, Science Education

Introduction

The present study belongs to the domain of research of students' conceptions about science concepts and phenomena, which over the last forty years, has attracted the interest of researchers in science education (Carmichael, Driver, Holding, Phillips, Twigger, & Watts, 1990; Driver, Guesne, & Tiberghien, 1985; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Osborne, 1985; Pfundt & Duit, 2006). It was found that before going to school children have conceptions based on perceptual experiences from their physical and social environment, about science concepts and phenomena (Driver et al., 1985). In most cases, the initial conceptions of students are different from scientific knowledge and school-acquired knowledge.

In the international arena considerable research has been conducted in order to examine the conceptions of students regarding sound (Asoko, Leach, & Scott, 1990; Boyes & Stanisstreet, 1991; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Eshach & Schwaetz, 2006; Hapkiewicz, 1992; Hrepic, 2004; Hrepic, Zollman, & Rebello, 2002; Linder & Erickson, 1989; Linder, 1993; Menchen & Thompson, 2005; Olenick, 2009; Periago, Pejuan, Jaén, & Bohigas, 2009; Stepan, 1996; Watt & Russell, 1990; Wittmann, Steinberg, & Redish, 1999; Wittmann, Steinberg, & Redish, 2002). It has been determined that students develop conceptions which are different from school-acquired knowledge about topics relating to sound, such as the nature of sound, the production and distribution of sound, the velocity of sound and the relations between the characteristics of sound and its representation.

In particular, the research of Watt and Russell (1990) regarding the nature of sound revealed that children imagine sound to be an invisible object with specific dimensions that needs space to propagate. Linder and Erickson (1989) studied the conceptions about sound of university students, who would be teaching science in secondary education. For this purpose they conducted a range of interviews. They divided the results into two categories: (a) microscopic; where the

respondents assume that sounds are physical entities or distinct "things" and (b) macroscopic; where respondents perceive sound as a force or as a type of 'wind'. Hrepic, Zollman and Rebello (2002) in their research on how students perceive sound, achieved similar results. They distinguished two main models: (a) the model which indicates that sound is an entity whose nature is determined by the physical state of the medium and (b) the model of the wave. Eshach and Schwartz (2006) explored the conceptions of secondary school students on topics relating to sound. They found that most students imagine sound to be a material object which is difficult to propagate, when the state of matter of the medium changes. Some other students imagine sound to be inside bubbles which, when burst, release sound. The conception where students believe that sound is "composed of different materials" depending on the material through which it propagates, thus explaining why sound is heard louder in water than in air, was also uncovered. These studies focus on young children or university students and only one survey refers specifically to secondary school students (Eshach & Schwartz, 2006).

A general feature of students' conceptions about phenomena of science is their resistance to any attempt at change (Driver & Oldham, 1986; Driver, Guesne, & Tiberghien, 1985). However, relevant research literature shows that development of students' conceptions of sound during their secondary education has not been explored. In Greece, the teaching of sound takes place in the last year of high school, specifically to 14 year old students. Thus, there is no research which investigates changes in secondary school students' conceptions of sound as a result of teaching.

Apart from the durability of conceptions, their dependence on factors of context is a general feature (Clough & Driver, 1986; Driver, Guesne, & Tiberghien, 1985; Maloney & Siegler, 1993; Millar & Kragh, 1994). Students trigger different conceptions depending on the context of the question. The dependence of students' conceptions on factors of context has been studied for the conceptual domain of force (Palmer, 1997; Schecker & Gerdes, 1999) and the conceptual domain of heat (Skoumios & Hatzinikita, 2006; Yeo & Zadnik, 2001). For the conceptual domain of sound, research data on the dependence of students' conceptions of the nature of sound from the state of matter of the medium, is limited. In particular, according to the research of Eshach & Schwartz (2006), students believe that when the state of matter of the medium through which sound propagates is gaseous, sound propagates as air flow, suggesting the movement of a physical entity and when the medium is in a liquid state the students regard sound as bubbles in which sound exists and which release sound when they burst. Finally, the research of Arvanitakis, Kariotoglou & Lemonidis (2009) attempted to highlight and classify conceptions of primary school students and teachers in primary education, regarding the propagation of sound. It revealed that when the medium is in a gaseous state or in a liquid state, the predominant model is the flow of sound, giving fluid features to sound, and when the medium is the cord or the wall, the dominant model is that of a removable material "entity". Therefore, surveys to systematically study the issue of dependency of students' conceptions about the nature of sound by factors of context, and in particular the state of matter of the medium, are not available. There is a need for further research in the field of secondary education on students' conceptions of the nature of sound and their dependence on the physical condition of the state of matter of the medium (gas, solid or liquid).

This study aims to explore Greek secondary school students' conceptions about the nature of sound. In particular, the objectives of this study are the following: (a) to identify and record the students' conceptions at the age of 13 and 15 regarding the nature of sound, (b) to study the evolution of these conceptions as students move from the age of 13 to the age of 15 and (c) to investigate how the physical condition of the state of matter of the medium affects students' conceptions about the nature of sound.

Methods

Research Process and Participants

The study was conducted in three stages. In the first stage, a questionnaire was created in order to highlight students' conceptions of the nature of sound and study the dependence of these conceptions on the state of matter of the medium through which it propagates (gas, liquid, solid). In the second stage, the questionnaire was given to secondary school students in Greece. In the third stage the students' responses to the conceptual content and the subsequent statistics were analyzed.

The survey involved 164 secondary school pupils from four schools in Athens. Of these, 84 were 13 year olds and 80 were 15 year olds. To determine the sample selected, the method of simple random sampling (lottery method of sampling) was used. The 13 year old students had not attended courses on sound and its propagation. The 15 year old students had been taught about waves and sound a year earlier. The teaching of physics in secondary education in Greece usually follows the traditional approach, where knowledge is considered to be transferred from teacher to student (Duschl, 1994).

The Questionnaire

As a tool of data collection, a written questionnaire which consisted of three questions was used. The questions were 'closed', however students had the opportunity to express their own viewpoint.

The three questions in the questionnaire concerned the nature of sound. Specifically, these questions asked students to answer: "What happens to the medium when sound propagates from the source to the listener?" The factor which differentiated these questions was the physical condition of the matter of the medium through which sound propagates. In the first question the medium through which sound propagates is in a gaseous state, in the second question the medium is in a liquid state and in the third question, the medium is in a solid state. According to school-acquired knowledge, sound is a longitudinal wave, caused by the vibration of air molecules. Based on surveys which study students' conceptions, students believe that sound has the characteristics of the matter of the medium or is moving air particles or sound is shown as a longitudinal or transverse wave (Arvanitakis, Kariotoglou, & Lemonidis, 2009; Eshach & Schwartz, 2006; Hrepic, Zollman, & Rebello, 2002; Linder & Erickson, 1989; Watt & Russell, 1990). These students' conceptions were the alternative answers to all three questions. More specifically, the alternative answers to the questions were: (a) sound consists of sound particles, (b) sound is a particle of the matter of the medium through which it propagates (air, water, earth), (c) sound is a disturbance, which propagates (wave). If students did not agree with the above responses they could express their own views. The alternative responses were accompanied by appropriate visuals, similar to those used in the work of Periago, Pejuan, Jaén and Bohigas (2009).

Initially, the questionnaire was given to a small number of students. There was a brief joint discussion with the students to obtain feedback. Also the questionnaire was given to teachers and researchers to test internal validity and to correct any deficiencies or ambiguities. The observations and deficiencies which were identified in the initial stage were corrected and a more consistent approach was applied for the purpose of research, whilst making the students' version of the questionnaire more comprehensible.

Data collection and analysis

For data collection a questionnaire was used. Students needed approximately 15 minutes to complete the questionnaire. The data gathered from the survey comprised the students' responses to all the questions in the questionnaire.

The frequencies and the percentage frequencies of students' answers per question were determined. The students' answers were classified into the following categories: (a) sound consists of sound particles, (b) sound is a particle of matter of the medium through which it propagates (air, water, soil), (c) sound is a wave, and (d) unclear answer.

Regarding the study of the evolution of students' conceptions and their dependence on the physical condition of the state of matter of the medium through which sound propagates, test χ^2 was used. The detection and interpretation of the association is based on the size of both chi-square and standardized residuals (Blalock, 1987; Erickson & Nosanchuk, 1985). Thus, the relevancy tables that exist in the next section present the following values: (a) the observed values and (b) the standardized residuals (in brackets) with a sign (+, -) that indicates whether the observed values are above (+) or below (-) the expected values.

Results

Students' conceptions about the nature of sound

Table 1 presents the results of the three questions regarding the nature of sound, when the physical condition of the state of matter of the medium through which it propagates is in a gaseous, liquid or solid state.

Table 1 shows that if the medium through which sound propagates is gaseous, the response of students in the class "sound is air particles" is more popular (35.4%) compared with other categories. This is followed by the categories "sound consists of sound particles" (32.9%) and "sound is a wave" (29.2%). The responses classified as "vague response" are limited.

Table 1: Frequencies (N) and Percentage Frequencies (N%) of Students' Conceptions About the Nature of Sound When the Physical Condition of the State of Matter of the Medium Through Which it Propagates is in a Gaseous, Liquid and Solid State (For All Students, by Age).

Physical condition of the state of matter of the medium through which sound propagates	Students' conceptions about the nature of sound	13 years old students		15 years old students		Total	
		N	N%	N	N%	N	N%
Gaseous	Sound consists of sound particles	35	41.6	19	23.7	54	32.9
	Sound is a particle of matter of the medium	26	30.9	32	40.0	58	35.4
	Sound is a wave	21	25.0	27	33.7	48	29.2
	Unclear answer	2	2.4	2	2.5	4	2.4
Liquid	Sound consists of sound particles	23	27.4	17	21.3	40	24.4
	Sound is a particle of matter of the medium	26	31.0	26	32.5	52	31.7
	Sound is a wave	27	32.1	32	40.0	59	36.0
	Unclear answer	8	9.5	5	6.3	13	7.9
Solid	Sound consists of sound particles	22	26.2	20	25.0	42	25.6
	Sound is a particle of matter of the medium	25	29.8	24	30.0	49	29.9
	Sound is a wave	20	23.8	33	41.3	53	32.3
	Unclear answer	17	20.2	3	3.8	20	12.2

The table also shows that if the medium through which sound propagates is water, the most popular answer is, "sound is a wave" (36%), while the responses in the class "sound is water particles" are comparatively fewer (31.7%). Following this is the category "sound consists of sound particles" (24.4%), while the responses classified as "vague response" are limited (7.9%).

If the physical condition of the state of matter of the medium through which sound propagates is the earth, then most students expressed answers in the category "sound is a wave" (32.3%). The percentage of the responses which were classified in the category "sound is soil particles" (29.9%) is higher than the percentage which was classified in the category "sound consists of sound particles" (25.6%). Noticeable, is the increase in the percentage of category "vague response" (12.2%) compared to the other states of matter of the medium (gaseous or liquid state).

The Development of Students' Conceptions About the Nature of Sound

A comparative study of the frequencies of the responses of students' conceptions concerning the nature of sound between students of the age of 13 and 15 years old did not reveal noticeable changes (see Table 2).

Table 2: Frequencies of Students' Conceptions About the Nature of Sound (When the Physical Condition of the State of Matter of the Medium Through Which Sound Propagates is in a Gaseous, Liquid and Solid State), by Students' Age and Corresponding Standardized Residuals

Physical condition of the state of matter of the medium through which sound propagates	Students' conceptions about the nature of sound	13 years old students	15 years old students
Gaseous	Sound consists of sound particles	35 [+1.40]	19 [-1.43]
	Sound is a particle of matter of the medium	26 [-0.68]	32 [+0.70]
	Sound is a wave	21 [-0.72]	27 [+0.74]
	Unclear answer	2 [-0.03]	2 [+0.03]
Liquid	Sound consists of sound particles	23 [+0.56]	17 [-0.57]
	Sound is a particle of matter of the medium	26 [-0.12]	26 [+0.13]
	Sound is a wave	27 [-0.59]	32 [+0.60]
	Unclear answer	8 [+0.52]	5 [-0.53]
Solid	Sound consists of sound particles	22 [+0.11]	20 [-0.11]
	Sound is a particle of matter of the medium	25 [-0.02]	24 [+0.02]
	Sound is a wave	20 [-1.37]	33 [+1.41]
	Unclear answer	17 [+2.11]	3 [-3.16]

In particular, a statistically significant correlation between the students' conceptions about the nature of sound and their age (13 and 15 years old) when the physical condition of the medium is in a gas state ($\chi^2 = 6.02$, $df = 3$, $p = 0.1106$) and liquid state ($\chi^2 = 1.92$, $df = 3$, $p = 0.5892$) (see Table 2) was not found. When the medium through which sound propagates is in a solid state a statistically significant correlation between the students' conceptions about the nature of sound and their age ($\chi^2 = 13.01$, $df = 3$, $p = 0.0046$) was revealed. This correlation focuses only on the clarity of the responses of students and is due to the following tendencies of the students (see Table 2): the 13 years old students tend to exhibit vague answers regarding the

nature of sound, while 15 years old students tend to produce explicit answers about the nature of sound.

Therefore, there is a trend of resistance to change students' conceptions. Thus, students' conceptions toward school knowledge regarding the nature of sound before and after the teaching of sound do not differ significantly.

The Dependence of Students' Conceptions about the Nature of Sound from the Physical Condition of the State of Matter of the Medium through Which It Propagates

From the comparative study of the percentage of students' conceptions about the nature of sound when the state of matter of the medium through which it propagates is in a different physical state (gaseous, liquid, solid) it can be seen that while the percentage of certain conceptions changes when the physical condition of the medium is altered, in other conceptions a corresponding shift was not observed (see Table 3).

Table 3: Frequencies of Students' Conceptions About the Nature of Sound (When the Physical Condition of the State of Matter of the Medium Through Which it Propagates is in a Gaseous, Liquid and Solid State) by Students' Age and Corresponding Standardized Residuals

Students' conceptions	Physical state of matter of the medium through which sound propagates		
	Gas	Liquid	Solid
Sound consists of sound particles	54 [+1.29]	40 [-0.79]	42 [-0.50]
Sound is a particle of matter of the medium	58 [+0.69]	52 [-0.14]	49 [-0.55]
Sound is a wave	48 [-0.73]	59 [+0.78]	53 [-0.05]
Unclear answer	4 [-2.37]	13 [+0.19]	20 [+2.18]

Moreover, the study found the existence of a statistically significant correlation between students' conceptions about the nature of sound and the physical condition of the state of matter of the medium through which it propagates (gas, liquid, solid) ($\chi^2 = 14.89$, $df = 6$, $p = 0.0211$). The correlation is between the clarity of responses and is explained by the following student trends (see Table 3): when the physical condition of the state of matter of the medium through which sound propagates is in a gaseous state, students tend to develop clear answers about the nature of sound and when the physical condition is in a solid state, students tend to express vague answers about the nature of sound.

Therefore, the study found an emerging trend that shows the difficulty students have in formulating a clear conception about the nature of sound as the physical condition of the state of matter of the medium through which sound propagates becomes denser (from gas to solid).

Discussion and Conclusions

This paper aims: (a) to identify the conceptions of 13 and 15 years old Greek students about the nature of sound, (b) to study the evolution of these conceptions as students move from the age of 13 to the age of 15 years old and (c) to investigate the dependence of these conceptions on the

state of matter of the medium through which sound propagates (gas, liquid, solid). For these purposes, a questionnaire was given to 13 and 15 years old students.

With regard to the nature of sound, most students gave answers that do not comply with school-acquired knowledge (approximately 7 out of 10 students). In particular, there are students who feel that sound is "moving molecules" of the state of matter of the medium through which it propagates, while other students believe that sound is molecules which are emitted from the source of sound and move between molecules of matter of the medium. The above findings are in agreement with the results of other surveys (Eshach & Schwartz, 2006; Hrepic, Zollman, & Rebello, 2002; Linder & Erickson, 1989; Watt & Russel, 1990). In particular, Linder and Erickson (1989) found that some students believe that sound is a physical entity or composed of discrete "things". Watt and Russel (1990) found that children imagine sound to be an invisible object with specific dimensions. Hrepic, Zollman and Rebello (2002) found that for students sound is a physical entity and Eshach and Schwartz (2006) found that students believe that sound is composed of solid particles.

Regarding the origin of these conceptions, Lakoff and Johnson (1980) argue that one of the most powerful language tools that we use to give structure and to interpret natural phenomena is a set of transport-type "substance and entity". For this reason, students characterize sound as a substance and an entity to interpret sound effects. The conceptions "sound is particles that move", can also be derived from the everyday use of the term "move". In everyday conversation, sound has the ability to "travel" from one area to another. Expressions like: "sound travels through a metal rod" are common. The belief that sound is particles which move from the transmitter to the receiver is an adequate model for the student to explain sound phenomena. It is a very simple interpretive model compared to the wave model, proposed by school-acquired scientific knowledge.

Additionally, in the present work, it was found that students' conceptions about the nature of the sound did not change significantly before and after the teaching of sound. This finding confirms the general characteristic of conceptions that are resistant to conceptual change (Driver, Guesne, & Tiberghien, 1985; Hatzinikita & Christidou, 2001). The resistance of conceptions regarding the phenomena of sound appear in other studies in higher education, such as Wittmann, Steinberg and Redish (2002), where students of engineering advocate that acoustic waves are like a one-dimensional force over the transmission medium and in Arvanitakis, Kariotoglou and Lemonidis (2009), who studied the mental models which were used by kindergarteners, teachers and university students to explain the propagation of sound. Generally, the durable nature of students' conceptions about concepts and phenomena of science is well established in the relevant research literature (Brown, 1992; Gunstone, Gray, & Searle, 1992; Mestre & Touger, 1989; Skoumios & Hatzinikita, 2005).

Despite the general findings of this study, the conceptions of the 13 years old students varied in comparison to the 15 years old students. In particular, when the state of matter of the medium through which sound propagates is solid, there was a significant association between the students' conceptions about the nature of sound and their age. This association is focused only on the clarity of the students' responses regarding the nature of sound, as the older students tend to produce clear answers about the nature of sound. This fact can probably be explained by the teaching of sound in school. Most students at the age of 13 have never wondered about the nature of sound, particularly when sound propagates in a medium which is in a solid state. The propagation of sound in air is a phenomenon that they meet every day and constantly in their lives and they have created a model to explain the nature of sound. The propagation of sound in a solid medium is a new phenomenon that many students are unaware of and for these reasons they have vague conceptions about the nature of sound. This is unlike the 15 year old students who have been taught in school about sound and its propagation in a solid medium, and whose existing conceptions about the nature of sound in air seem to have been amended and so they give more precise answers.

Students often use different conceptions in order to interpret situations considered equivalent according to scientific knowledge (Driver, Guesne & Tiberghien, 1985; Skoumios & Hatzinikita, 2004). In the present study, it was found that the change of physical state of matter of the medium through which sound propagates does not affect most students' conceptions about the nature of sound. However, the existence of a statistically significant correlation between students' conceptions about the nature of sound and the physical condition of the state of matter of the medium through which it propagates (gas, liquid, solid) was revealed. In particular, when the state of matter of the medium through which sound propagates was gaseous, students tended to exhibit clear answers about the nature of sound and when it was solid, students tended to express vague answers about the nature of sound. The cause of this differentiation is probably due to the fact that the propagation of sound in air is a common occurrence for students as opposed to the propagation of sound in solids.

From this study it was found that the traditional teaching of sound, as typically followed by teachers in Greek schools (Skoumios & Savvaidou-Kambouropoulou, 2012), does not usually change the initial students' conceptions about sound in alignment with school-acquired knowledge. Specifically, the students' conceptions about the nature of sound remained unchanged during their transition from the age of 13 to the age of 15.

The findings regarding the clarity of the conceptions about the dependence between the nature of sound and the physical state of matter of the medium through which it propagates call into question the methods used to teach sound that usually use examples of only one particular state of matter of the medium (e.g. the gas state). Commonly, in textbooks, sound is approached in propagation in the gas state of matter of the medium, ignoring the other states.

This study contributes to the research field of students' conceptions because it helps to investigate the evolution of conceptions and their dependence on the physical state of matter of the medium through which sound propagates. This research has important implications in the teaching process and the evaluation process.

In teaching, the teacher usually insists on activities relating to a specific state of matter of the medium (gas state) and then asks students to apply what is taught to another state of matter of the medium (liquid or solid). The present study shows that it is difficult for students to relate what is taught in a specific state of matter of the medium (gas state) to a different state.

As regards the evaluation of students, if the teacher sets questions involving one particular state of matter of the medium (e.g. questions about the nature of sound in air) then the results of the students' conceptions cannot be generalized, because if questions were used that included other state of matter of the medium perhaps the results of the students' conceptions would be different (e.g., questions concerning the nature of sound in solids or liquids). Therefore, it is imperative that questionnaires assessing or investigating students' conceptions should have questions that cover the whole range of states of matter of the medium, because it is likely the conceptions that activate students will be affected.

It is therefore necessary to investigate the factors which affect the conceptions which the student activates about sound, as well as other concepts and phenomena in order to get a more complete picture of students' conceptual structure. This research will help both in setting up questionnaires to investigate and identify, objectively and more thoroughly, the students' conceptions and will also help to create teaching materials based on students' conceptions that have an increased chance of being more effective.

REFERENCES

- Arvanitakis, Konstantinos, Petros Kariotoglou, and Charalampos Lemonidis. 2009. "Mental models of students and teachers to spread the sound". In Proceedings for the 6th Panhellenic Conference of Science Education and ICT in Education - The multiple approached to teaching and learning about Science, edited by Petros Kariotoglou, Anna Spyrtou, and Anastasios Zoupidis, 207-216. Florina: Faculty of Education University of Western Macedonia.
- Asoko, Hilary, John Leach, and Philip Scott. 1990. "A study of students understanding of sound 5–16 as an example of action research." Paper presented at the Symposium, "Developing Students' Understanding in Science", at the Annual Conference of the British Educational Research Association at Roehampton Institute, September 2, London.
- Blalock, Hubert M. 1987. *Social statistics*. Singapore: McGraw-Hill.
- Boyes, Edward, and Martin Stanisstree. 1991. "Development of pupil's ideas about seeing and hearing – The path of light and sound." *Research in Science and Technology Education* 9: 223-251.
- Brown, David E. 1992. "Using examples and analogies to remediate misconceptions in physics: factors influencing conceptual change." *Journal of Research in Science Teaching* 29(1): 17-34.
- Carmichael, Patrick, Rosalind Driver, Brian Holding, Isabel Phillips, Daryll Twigger, and Mike Watts. 1990. *Research on students' conceptions in science: A bibliography* (1st ed.). Leeds, UK: Children's Learning in Science Research Group University of Leeds.
- Clough, Elizabeth E., and Rosalind Driver. 1986. "A Study of Consistency in the Use of Students' Conceptual Frameworks across Different Task Contexts." *Science Education* 70 (4): 473-496.
- Driver, Rosalind, Ann Squires, Peter Rushworth, and Valerie Wood-Robinson. 1994. *Making sense of secondary science: Research into children's ideas*. New York: Routledge.
- Driver, Rosalind, and Valerie Oldham. 1986. "A Constructivist Approach to Curriculum Development." *Studies in Science Education* 13: 105-122.
- Driver, Rosalind, Edith Guesne, and Andrée Tiberghien. 1985. *Children's Ideas in Science*. Philadelphia: Open University Press.
- Duschl, Richard A. 1994. "Research on the History and Philosophy of Science." In *Handbook of research in science teaching*, edited by Dorothy Gabel, 443-465. New York: Macmillan.
- Erickson, Bonnie, and Terry Nosanchuk. 1985. *Understanding data*. Milton Keynes: Open University Press.
- Eshach, Haim, and Judah Schwartz. 2006. "Sound stuff? Naïve materialism in middle-school students' conceptions of sound." *International Journal of Science Education* 7: 733–764.
- Gunstone, Richard F., Robin C. M Gray, and Peter Searle. 1992. "Some long-term effects of uniformed conceptual change." *Science Education* 76 (2): 175-197.
- Hapkiewicz, Annis. "Finding a list of Science Misconceptions." *MSTA Newsletter* 38 (Winter'92): 11-14.
- Hatzinikita, Vassilia, and Vassilia Christidou. 2001. "Importance of research on the conceptions of students." In *Teaching of Physical Sciences*, Volume A, edited by Kostas Dimopoulos and Vassilia Hatzinikita, 51-74. Patra: H.O.U.
- Hrepic, Zdeslav. 2004. *Development of a Real-Time Assessment of Students' Mental Models of Sound Propagation*. Manhattan, KS: Kansas State University.
- Hrepic, Zdeslav, Dean A. Zollmann, and Sanjay N. Rebello. 2002. "Identifying students models of sound propagation." In Proceedings for the 2002 Physics Education Research

- Conference, edited by Scott Franklin, Karen Cummings, and Jeffrey Marx, 59-62. New York: PERC Publishing.
- Lakoff, George, and Mark Johnson. 1980. *Metaphors we live by*. Chicago: The University of Chicago Press.
- Linder, Cedric, and Gaalen L. Erickson. 1989. "A study of tertiary students' conceptualizations of sound." *International Journal of Science Education* 11(5): 491–501.
- Linder, Cedric J. 1993. "University Physics Students' Conceptualizations of Factors Affecting the Speed of Sound Propagation." *International Journal of Science Education* 15(6): 655-662.
- Maloney, David, and Robert S. Siegler. 1993. "Conceptual Competition in Physics Learning." *International Journal of Science Education* 15: 283-295.
- Menchen, Katherine V. P., and John R. Thompson. 2005. "Student Understanding of Sound Propagation. Research and Curriculum Development." In Proceedings for the Physics Education Research Conference, edited by Jeffrey Marx, Paula Heron, and Scott Franklin, AIP Conf. Proc. No. 790, 81–84. New York: AIP.
- Mestre, Jose, and Jerold Touger. 1989. "Cognitive research. What's in it for physics teachers?" *The Physics Teacher* 27(6): 447-456.
- Millar, Robin, and Will Kragh. 1994. "Alternative frameworks or context-specific reasoning? Children's ideas about the motion of projectiles." *School Science Review* 75(3): 27–34.
- Olenick, Richard. 2009. *Helping Students Learn Physics Better. Preconceptions and Misconceptions. A Guide to Enhancing Conceptual Understanding*. Dallas: Department of Physics, University of Dallas. Accessed October 10, 2010. <http://phys.udallas.edu/C3P/Preconceptions.pdf>
- Osborne, Roger. 1985. "Building on Children's Intuitive Ideas." In *Learning in science. The Implications of Children's Science*, edited by Roger Osborne and Peter Freyberg, 41-50. Hong Kong: Heinemann.
- Palmer, David H. 1997. "The effect of context on students' reasoning about forces." *International Journal of Science Education* 19(6): 681-696.
- Periago, Cristina, Arcadi Pejuan, Xavier Jaén, and Xavier Bohigas. 2009. "Misconceptions about the Propagation of Sound Waves." In Proceedings for European Association for Education in Electrical and Information Engineering Annual Conference IEEE June 22–24. Valencia, Spain: Conference Publications.
- Pfundt, Helga, and Reinders Duit. 1994. *Bibliography: Students' alternative frameworks and science education*. 4th edition. Keil, Germany: Institute for Science Education at the University of Keil.
- Pfundt, Helga, and Reinders Duit. 2006. *Bibliography: Students' and teachers' conceptions and science education*. Keil, Germany: IPN.
- Schecker, Horst, and Jörn Gerdes. 1999. "Messung Von Konzeptualisierungsfähigkeit in Der Mechanik. Zur Aussagekraft Des Force Concept Inventory." *Zeitschrift für Didaktik der Naturwissenschaften* 5(1): 75-89.
- Yeo, Shelley, and Marjan Zadnik. 2001. "Introductory thermal concept evaluation: assessing students' understanding," *The Physics Teacher* 39: 496-504.
- Skoumios, Michael and Vassilia Hatzinikita, 2004. Dealing with obstacles regarding heat and temperature. In: D. Koliopoulos, & A. Vavouraki (Eds), *Science education at cross roads: meeting the challenges of the 21th century'* (p. 107-118). Athens: Science Education Association.
- Skoumios, Michael and Vassilia Hatzinikita. 2005. "The role of cognitive conflict in science concept learning." *The International Journal of Learning* 12(7): 185-193.
- Skoumios, Michael, and Vassilia Hatzinikita. 2006. "Research-based teaching about science at the upper primary school level." *The International Journal of Learning* 13(5): 29-42.

- Skoumios, Michael and Maria Savvaidou-Kambourolopoulou, 2012. "Investigating Pupils' Images of Science Teaching Using Drawings." *The International Journal of Science in Society*, 3(2): 179-192.
- Stepans, Joseph. *Targeting Student's Science Misconceptions*. Florida: Idea Factory Inc., 1996.
- Watt, Dorothy and Terry Russell. 1990. *Sound. Primary SPACE Project Research Report*. Liverpool: Liverpool University Press.
- Wittmann, Michael C., Richard N. Steinberg, and Edward F. Redish. 1999. "Making sense of how students make sense of mechanical waves." *The Physics Teacher* 37(1): 15–21.
- Wittmann, Michael C., Richard N. Steinberg, and Edward F. Redish. 2002. "Understanding and affecting student reasoning about sound waves." *International Journal of Science Education* 25(8): 991-1013.

ABOUT THE AUTHORS

Stefanos Iconomou: Stefanos Iconomou obtained a first degree in Physics from the National and Kapodistrian University of Athens in 2001, a Master's in Electronics and Telecoms from the National and Kapodistrian University of Athens in 2003 and a second Master's degree in Education from the Hellenic Open University in 2011. His research interests include science concept learning and teaching science in secondary schools. He is currently teaching Science in secondary education in High School (Greece).

Dr. Michael Skoumios: Michael Skoumios obtained a first degree in Physics from the National and Kapodistrian University of Athens in 1987, a second degree in Education from the University of Aegean in 1992 and his PhD in Science Education from the Hellenic Open University in 2005. His research interests include science concept learning and teaching science in primary and secondary schools. He is currently teaching Science Education in the Department of Primary Education of the University of the Aegean (Greece).

The Effect of Participants' Race and Gender on Perceptions of STEM and Non-STEM Images of Women

Shane T. Warren, Mississippi State University, USA
Joon Soo Lim, Syracuse University, USA
John Nicholson, Mississippi State University, USA
Emily D. Ryalls, Mississippi State University, USA
Skye C. Cooley, Mississippi State University, USA
Mark Goodman, Mississippi State University, USA
Bonnie Oppenheimer, Mississippi University for Women, USA
James Codling, Mississippi State University, USA
Thomas Robinson, Mississippi State University, USA
Laci Kyles, Mississippi State University, USA

Abstract: A total of 208 participants provided assessments of STEM (Science, Technology, Engineering, or Mathematics) or non-STEM images. The participants viewed 36 images of women. Participants in one survey viewed the 36 images, which were assigned a STEM job title. Participants in the second survey viewed the same 36 images, which were assigned a non-STEM job title. Images were assessed for attractiveness and job-related factors, such as creativity, job performance, intelligence, and organization. Differences were found based upon the race and gender of the participant and the race, gender, and body size of the women represented in the images. Perceptions of the images differed based upon the assignment of a STEM or non-STEM job title. African-American women evaluated STEM images more favorably overall than Caucasian women. Female participants evaluated the STEM images of Caucasians more favorably than male participants. Our results confirm that cultural stereotypes affect people's perceptions of women in the STEM fields.

Keywords: STEM, Race, Gender, Non-STEM, Images, Body Size

In over a decade of research Mahzarin R. Banaji and Nilanjana Dasgupta, working together and with other scholars, conducted a series of studies that connects stereotypes to perceptions that women and members of some minority groups do not belong in STEM fields (Science, Technology, Engineering, and Mathematics). This connection between the cultural stereotypes of women and minorities and the perception of where women and minorities fit into STEM fields is important because it helps explain why STEM remains the domain of males. More than 20 years after STEM fields began recruiting women, the number of women going into computer science, engineering, and hard sciences has dropped.¹ In their multiple research studies, Banaji and Dasgupta argue that cultural stereotypes of women and minorities influence who selects STEM degrees and careers; however, they never proved the stereotypes existed. Accordingly, we review their line of questioning and extend it by testing for the existence of female STEM stereotypes among college students at a land grant university.

An article in *The New York Times*¹¹ lays out the premises of the STEM stereotype: Nerdy white males and Asians with poor writing skills go into science and mathematics, which are considered harder disciplines than the arts or humanities. Popular, attractive girls do not choose calculus, physics, or other higher science and mathematics offerings in high school because they will then be considered nerds by their peers. In the words of the article's writer, Eileen Pollack: "It is deemed uncool within the social context of U.S.A. middle and high schools to do

mathematics for fun; doing so can lead to social ostracism. Consequently, gifted girls, even more so than boys, usually camouflage their mathematical talent to fit in well with their peers.”

In their first study in 1998, Banaji and Dasgupta explained that stereotypes work on both the conscious and unconscious level. When individuals are aware of their biases, they may cognitively choose to follow those biases or ignore them. Banaji and Dasgupta concluded that race is an especially important signifier of bias.ⁱⁱⁱ However, culturally understood material may affect cognitive judgment without conscious thought, they explained. In 1999, Dasgupta, Banaji, and Abelson argued that the more an individual is seen as a member of a cohesive group (for example, a group based on race or gender), the more likely the individual is to be assigned the negative attributes of the group.^{iv} In addition, physical similarities can be used as a basis for drawing psychological and cognitive conclusions about members of a group. “Such beliefs could play a role in the development of new stereotypes by making perceivers search for similar or typical members and explain away atypical ones as not being diagnostic of the group,” they explained.^v “This process would promote homogeneous impressions and produce new stereotypes even for groups that are fairly diverse.”

In 2001, Dasgupta and Greenwald pointed out that media culture is partially responsible for the creations of stereotypes. “...[I]f media representations were to become more balanced, reminding people of both admired members of out-groups and less-than-stellar members of in-groups with emphasis on their group membership, the combined effect may be able to shift implicit prejudice and stereotypes,” they argued.^{vi} In 2004, Nosek, Banaji, and Greenwald connected gender stereotypes to STEM. They argued there is a correlation between gender identity and mathematics. Liking mathematics reduces the sense of being female and the sense of being female reduces the liking of mathematics, they explained.^{vii} Social learning teaches individuals what the norm is for a social group; identity with the social group shapes behavior. Nosek, et. al., recognized that women have the opportunity to enter STEM fields, but that is not enough. “The appearance of free choice, however, does not preclude the possibility that group membership and group expectancies have a subtle relationship with personal preference and choice,” Nosek, et. al., explained.^{viii} “Thoughts and feelings that occur outside conscious awareness or control may provide a basis for understanding the relationships among personal preferences and choices, on the one hand, and group identity and stereotypes, on the other.”

One way of overcoming stereotypes for women is to see other women in non-stereotypical roles, Dasgupta and Asgari explained in 2004. When younger women saw older women in teaching roles or leadership positions, the younger women were able to picture themselves in those roles, they concluded. However, role models did not necessarily move the younger women into STEM fields. Women sometimes still chose more stereotypical caregiving roles, such as pediatrics and veterinary medicine. However, Dasgupta and Asgari conclude, “...the more women see counterstereotypic ingroup members in their immediate environment the more it undermines their automatic gender stereotypes even in the absences of specific motivation and effort on their part to change such beliefs.”^{ix}

In 2011, Stout and Dasgupta sought a deeper understanding for why women were not selecting STEM opportunities. Women in mathematics and science are devalued, they argued. “Thus, even when an individual is not personally ostracized, situations that ostracize his or her ingroup may feel aversive and have detrimental effects on the person’s sense of belonging, motivation, and behavior,” they write.^x Stout and Dasgupta point out that their arguments are consistent with other research, which found that black students felt devalued when there were no other members of their race present.^{xi} Similarly, Cheryan, Plaut, Davies and Steele reported a drop in feelings of inclusivity by women when they were exposed to masculine cues in a computer science setting.^{xii} In a later study, Cheryan, Siy, Vichayapai, Drury, and Kim found that women tended to underestimate their abilities to be successful in STEM fields, demonstrating again the influence of stereotypes.^{xiii} These results were consistent with the conclusions drawn by Stout, Dasgupta, Hunsinger, and McManus in 2010. “At every stage of

development, girls and women are exposed to the message that their ingroup is worse in science and math compared with their male peers,” they write.^{xiv} “Clearly, the skewed gender ratio of STEM experts in academic environments undermines female students’ identification with, positive attitudes about, and self-efficacy in STEM and saps their motivation to pursue careers in science, engineering, or technology.”^{xv} The Stout et al. study, conducted in Calculus I classes, found that “even though the female students in this study clearly had strong ability in math and, as a group, outperformed their male peers, they were less confident about their performance when their professor was a man compared with when she was a woman.”

All of the above studies took for granted that college students held stereotypes that influenced their perceptions of career paths and, therefore, their selection of majors. However, none of those studies actually verified the existence of the stereotypes. Our first goal is to empirically validate the existence of the stereotypes, which have previously been assumed to exist among college students. We tested for the existence of those stereotypes by running two studies. In the first study, we showed survey participants 36 images of women labeled with a STEM job title. In the second study, we changed the job titles to non-STEM careers; all other elements remained the same. Here is a sample picture, which is sized smaller in this paper than in the surveys.

Nurse
(works in a hospital)



Study 1

Mathematician
(works with numbers)



Study 2

This project extends our previous research. We found that middle school students took into account the variables of race, age, and body size when assessing images of adult women.^{xvi} In that study the middle school students were asked to state their perceptions of the images of women for job performance, organization, intelligence, creativity, and attractiveness. The gender and race of the participants also were variables influencing the ratings of the images.

Hypotheses

If stereotypes relating to STEM, gender, and race exist among a population of college students, then we can test for those stereotypical views by showing college students images of Caucasian and African-American women and asking them to report their perceptions of the pictured women based upon the STEM/non-STEM job title assigned to the image.

H1: Based on the sizes of the women in the images, participants will differentiate for: (a) job competence, and (b) attractiveness.

H2: Based on the races of the women in the images, participants will differentiate for: (a) job competence, and (b) attractiveness.

H3: Based on the ages of the women in the images, participants will differentiate for: (a) job competence, and (b) attractiveness.

H4: Based on STEM/non-STEM job titles assigned to the images of all women, participants will differentiate job for: (a) job competence, and (b) attractiveness.

Method

To examine the effects of STEM/non-STEM job titles, body size and race on the evaluations of job competence and attractiveness of women, this study employed a survey-embedded experiment.^{xvii} An experiment was embedded within a Web-based survey manipulating the job description (STEM/non-STEM), body size (self-selected dress size), age (under 25 vs. 25-35 vs. over 35), and race (White vs. African-American) of the images of women. Thirty-six images in total were created and randomized. The images, each 150 pixels wide, featured women in everyday clothing. The images were equally distributed among the following groups: Caucasian/African-American; self-selected dress size <small 8/medium 8-14/large >14; and age <25/25-35/>35. Each grouping (race, dress size, age) contained two images. In one experimental condition, participants were pointed to a STEM job description, the image, and five questions. In the other condition, each image was associated with a non-STEM job description; everything else was constant.

SurveyMonkey.com hosted the web-based experiment, which was administered at a land grant university in the southeastern U.S. Upon receiving IRB approval, undergraduate students from various majors were recruited through classes to participate in the study. Students were randomly assigned to STEM or non-STEM conditions. All participation was voluntary; some students received extra credit for participating. A total of 116 participants completed the survey with the condition in which each image was associated with a STEM job title. The composition of the participants was 97 females, 19 males; 29 African-Americans, 84 Caucasians, 1 Hispanic, and 2 marked other. A total of 92 students completed participation in the non-STEM condition in which the same images were associated with a non-STEM job title. In the second study, there were 37 males, 53 females; 4 Asians, 17 African-Americans, 65 Caucasians, 2 Hispanics, 1 other, and 3 declined to identify their race.

Participants were asked to rate the woman in each image on a 1 to 7 scale for job competence, organizational skills, intelligence, attractiveness, and creativity.^{xviii} Four of the questions were chosen because they are attributes assigned to job performance (competence, organization, intelligence, and creativity). Attractiveness was measured because of its stereotypical association with STEM and non-STEM fields (Holland, 2004; Carter and Steiner, 2004; Meehan, 1983).^{xix} The STEM job titles we used were mathematician, mechanical engineer, astronomer, computer programmer, software designer, civil engineer, chemical engineer, physicist, and meteorologist. Each job title, which was briefly explained, was assigned to four different images. The non-STEM job titles were nurse, artist, English teacher, musician, athletic trainer, police officer, secretary, newspaper reporter, and lawyer. Each job title, which was briefly explained, was also assigned to four different images.

Results

A series of multiple analyses of variance (MANOVAs) was performed to interpret data findings utilizing four independent variables (age, body size, race, and STEM/non-STEM image condition) and five dependent variables (job performance, organization, intelligence, creativity, and attractiveness). All statistics were computed using PASW statistics package 19.

Hypothesis 1 stated that participants would make differentiations in their evaluations of job competence and attractiveness based on the body size of women in the research images. This hypothesis was partially supported. African-American participants evaluated images more favorably overall than did Caucasians. African-Americans rated images of small, medium, and large women higher than Caucasians for attractiveness. They also rated women who were of medium and of large body sizes higher than Caucasians for organization.

For body size, statistically significant main effects were found for the independent variable of race on organization (Wilk's $\lambda = .921$, $F(3,160) = 4.6$, $p < .01$, partial $\eta^2 = .08$). Inspection of the between-subjects effects showed a statistically significant difference in both the medium body size group ($F(1, 162) = 12.14$, $p < .01$, partial $\eta^2 = .07$) and the large body size image ($F(1, 162) = 7.80$, $p < .01$, partial $\eta^2 = .05$). For the medium body size images, African-American participants ($M = 4.67$, $SD = .82$, $N = 39$) rated the images as being more organized than did Caucasian participants ($M = 3.96$, $SD = .65$, $N = 131$). For the large body size images, African-American participants ($M = 4.37$, $SD = .85$, $N = 39$) also rated the images as being more organized than did Caucasian participants ($M = 3.98$, $SD = .67$, $N = 131$).

Statistically significant main effects were also found for ethnicity on the variable of intelligence for all three body size categories (Wilk's $\lambda = .992$, $F(3,160) = 4.5$, $p < .01$, partial $\eta^2 = .08$). In the small body size category, African-American participants ($M = 5.12$, $SD = .76$, $N = 39$) rated the images higher on intelligence ($F(1, 162) = 7.25$, $p < .01$, partial $\eta^2 = .04$) than the Caucasian participants ($M = 4.69$, $SD = .67$, $N = 131$). In the medium body size category, African-American participants ($M = 4.90$, $SD = .75$, $N = 39$) rated the images higher on intelligence ($F(1, 162) = 12.92$, $p < .01$, partial $\eta^2 = .07$) than the Caucasian participants ($M = 4.19$, $SD = .69$, $N = 131$). In the large body size category, African-American participants ($M = 4.89$, $SD = .91$, $N = 39$) rated the images higher on intelligence ($F(1, 162) = 10.84$, $p < .01$, partial $\eta^2 = .06$) than the Caucasian participants ($M = 4.18$, $SD = .73$, $N = 131$). No other differences were statistically significant in regards to the sizes of the women in the images.

Table 1 F Statistic Study for Differences Based on Body Size of the Image

Significant Results for Hypothesis 1

Variable	Significant Factor	Significant Comparison within Factor	F	df	Partial η^2
Body Size	Organization	Medium Body Size	12.14*	1, 162	.07
		Large Body Size	7.80*	1, 162	.05
	Intelligence	Small Body Size	7.25*	1,162	.04
		Medium Body Size	12.92*	1,162	.07
		Large Body Size	10.84*	1,162	.06

*significant at the $p < .01$ level

Hypothesis 2 stated that participants would make differentiations in their evaluations of job competence and attractiveness based on the races of the women in the research images. This hypothesis was partially supported. African-American participants rated images of Caucasian and African-American women higher than did Caucasian participants.

For race of the person in the image, statistically significant main effects were found for the independent variable of race on the dependent variable of intelligence (Wilk’s $\lambda = .926$, $F(2,162) = 6.43$, $p < .01$, partial $\eta^2 = .07$). Inspection of the between-subjects effects showed a statistically significant difference for both the African-American images ($F(1, 163) = 11.52$, $p < .01$, partial $\eta^2 = .07$) and the Caucasian women in the images ($F(1, 163) = 11.52$, $p < .01$, partial $\eta^2 = .07$). Specifically, African-American participants ($M = 4.89$, $SD = .85$, $N = 39$) rated the intelligence of the African-American images higher than the Caucasian participants ($M = 4.17$, $SD = .69$, $N = 132$). In regards to the Caucasian women in the images, African-American participants ($M = 5.10$, $SD = .75$, $N = 39$) rated the intelligence of the image higher than the Caucasian participants ($M = 4.53$, $SD = .61$, $N = 132$). No other differences were statistically significant in regard to the race of the women in the images.

Table 2 F Statistic Study for Race Differences Based on the Race of the Woman in the Image

Significant Results for Hypothesis 2

Variable	Significant Factor	Significant Comparison within Factor	F	df	Partial η^2
Race of Image	Intelligence	African-American Image	11.52*	1, 163	.07
		Caucasian Image	11.52*	1, 163	.07

*significant at the $p < .01$ level

Hypothesis 3 stated based on the ages of the women in the images, participants will differentiate for: (a) job competence, and (b) attractiveness.

Although statistically significant main effect differences were found, the data did not conform to the necessary assumptions of MANOVA and, therefore, were excluded from the analysis.

Hypothesis 4 stated that participants in this research would make differentiations in evaluating the job competence and attractiveness based on the job titles of the women in the research images. This hypothesis was partially supported when the images were of Caucasian women, but not supported when the images were of African-American women. Participants rated Caucasian women with STEM job titles higher for organization, intelligence, and attractiveness than images of the same women associated with non-STEM job titles.

When we compared all responses (body size, age, and race) to all questions (job performance, organizational skills, intelligence, attractiveness, and creativity) from the STEM survey to all responses from the non-STEM survey, we found seven significant differences. Participants rated the images of the Caucasian women higher ($t = 3.45, p < .01$) on the STEM survey for job performance than on the non-STEM survey (STEM $N = 99; M = 4.76; SD = .79$; non-STEM $N = 73, M = 4.38, SD = .74$). Participants rated the images of the Caucasian women higher ($t = 4.27; p < .01$) on the STEM survey for organization than on the non-STEM survey (STEM $N = 99; M = 4.53; SD = .67$; non-STEM $N = 73; M = 4.24; SD = .58$). Participants rated the images of the Caucasian women higher ($t = 4.19; p < .01$) on the STEM survey for intelligence than on the non-STEM survey (STEM $N = 99; M = 4.56; SD = .85$; non-STEM $N = 72; M = 4.03; SD = .71$). Participants rated the images of the Caucasian women higher ($t = 2.62; p = .01$) on the STEM survey for attractiveness of the large image than on the non-STEM survey (STEM $N = 98; M = 2.60, SD = .93$; non-STEM $N = 72; M = 2.23; SD = .81$). Participants rated the images of the Caucasian women higher ($t = 3.24; p < .01$) on the STEM survey for job performance/over 35 than on the non-STEM survey (STEM $N = 99; M = 4.78; SD = .87$; non-STEM $N = 73; M = 4.40; SD = .81$). Participants rated the images of the Caucasian women higher ($t = 4.57; p < .01$) on the STEM survey for intelligence/over 35 than on the non-STEM survey (STEM $N = 99; M = 4.81; SD = .76$; non-STEM $N = 73; M = 4.30; SD = .71$). Participants rated the images of the Caucasian women higher ($t = 2.81; p < .01$) on the STEM survey for attractiveness/over 35 than on the non-STEM survey (STEM $N = 98; M = 3.00; SD = .99$; non-STEM $N = 73; M = 2.53; SD = .94$). No other differences were statistically significant when comparing the results of the STEM survey to the non-STEM survey.

Table 3 F Statistic Study for Race Differences Based on the Job Title Associated With the Image

Significant Results for Hypothesis 4

Variable	Significant Factor	STEM Mean (SD) n = 99	Non-STEM Mean (SD) n = 73	t-value
Caucasian Image	Job Performance (overall)	4.76 (.79)	4.38 (.74)	3.45*
	Organization (overall)	4.53 (.67)	4.24 (.58)	4.27*
	Intelligence (overall)	4.56 (.85)	4.03 (.71)	4.19*
	Attractiveness/Large Body Size Image	2.60 (.93)	2.23 (.81)	2.62*
	Job Performance/ Image Over 35	4.78 (.87)	4.40 (.81)	3.24*
	Intelligence/ Image Over 35	4.81 (.76)	4.30 (.71)	4.57*
	Attractiveness/Image Over 35	3.00 (.99)	2.53 (.94)	2.81*

*significant at the $p < .01$ level

Overall, these results indicate that African-Americans generally evaluated women higher for job competency and attractiveness than Caucasians. Participants associated a STEM job title with a higher rating for job competency and attractiveness than non-STEM job titles. No significant interaction effects were reported in the study.

Discussion and Conclusions

In their work, Dasgupta, Banaji, and their colleagues established that culturally assigned stereotypes of both race and gender associate STEM signifiers to white males interested in mathematics and the sciences and devalue women interested in STEM fields. These stereotypes are reinforced in the classroom and workplace by cues of male preference and domination.

Our research suggests that there is another dimension to the STEM stereotypes. In our study, women and African-Americans assigned higher values to images of women associated with STEM fields than with non-STEM fields. The participants may have placed value on STEM identifiers because they did not see themselves in those STEM positions. In other words, they did not associate themselves with STEM success and so they valued and had a positive view of those job titles which were signifiers of success in science and mathematics. A future study could use a similar survey design administered to students based on major to determine if their choices in major may have been influenced by STEM stereotypes.

We also identified the significance of race of both the participants and of the women in the images in the assessments of those images. African-American participants consistently rated women in our study higher for intelligence and attractiveness than Caucasian participants. These African-American participants also rated the images of Caucasian women higher than those of African-American women. In effect, the participants viewed the images through the lens of their own race. Accordingly, these results verify the premise of Dasgupta and Banaji that there are

cultural stereotypes for race. Our hypothesis was that the race of the woman in the image was the independent variable. However, our results indicate it is the race of the person making the evaluation that differentiates the higher and lower assessments on both intelligence and attractiveness for images of African-American and Caucasian women. This both confirms and complicates the stereotype. If African-American women perceive themselves and other African-American women through a lens colored by a negative stereotype, we would expect them to have ongoing difficulty seeing themselves, and those they perceive in their in-group, as legitimate members of STEM careers. Further complicating the issue was our finding that the means of the African-American participants' ratings were higher than the means of the Caucasian participants' ratings.

The current study provides empirical support for the presence of stereotypes related to women in STEM careers and adds complexity to our understanding of the stereotypes. We found that the attractiveness ratings of STEM images, while very low, were actually higher than the attractiveness ratings of many of the non-STEM images. We wonder if there is perhaps a compensation effect in response to stereotypes that lead us to believe that women in STEM fields are very unattractive. If so, respondents' expectations might have been that women in STEM careers would be so unattractive, that an average looking woman in a STEM profession might be rated higher in attractiveness than the same women in a non-STEM profession because the participant was expecting to see someone quite unattractive in the STEM profession.

Future studies may want to consider the influence of body size, age, and race in addition to STEM and non-STEM labels. Researchers might want to assign multiple job titles (e.g. a nurse, a police officer, a mathematician, and a chemist) to the image of a woman through several iterations to see if her body size, age, and race similarly impact perceptions of attractiveness in different career fields, particularly STEM fields.

A limitation of this study was that the participants were college students. Future studies should include a much larger and diverse respondent pool to assess the presence of the stereotype among a broader population.

End Notes

-
- ⁱ Catherine Hill, Christianne Corbett, and Andresse St. Rose, *Why So Few? Women in Science, Technology, Engineering, and Mathematics*. Washington, D.C., AAUW, 2010: 9.
- ⁱⁱ Eileen Pollack (3 Oct. 2013), "Why Are There Still So Few Women in Science?" *The New York Times*.
- ⁱⁱⁱ Mahzarin R. Banaji and Nilanjana Dasgupta, "The Consciousness of Social Beliefs: A Program of Research on Stereotyping and Prejudice," in *Metacognition: Cognitive and Social Dimensions*, edited by Vincent V.Y. Yzerbyt, Guy Lories, Benoit Dardenne (Thousand Oaks: Sage, 1988), 16.
- ^{iv} Nilanjana Dasgupta, Mahzarin R. Banaji, and Robert P. Abelson, "Group Entitativity and Group Perception: Associations Between Physical Features and Psychological Judgment," *Journal of Personality and Social Psychology*, 77(1999): 1001.
- ^v *Ibid.*
- ^{vi} Nilanjana Dasgupta and Anthony G. Greenwald, "On the Malleability of Automatic Attitudes: Combating Automatic Prejudice with Images of Admired and Disliked Individuals," *Journal of Personality and Social Psychology*, 81(2001): 808.
- ^{vii} Brian A. Nosek, Mahzarin R. Banaji and Anthony G. Greenwald, "Math = Male, Me = Female, Therefore Math (= /) Me," *Journal of Personality and Social Psychology*, 83(2002): 57.
- ^{viii} *Ibid.*, 44.
- ^{ix} Nilanjana Dasgupta and Shaki Asgari, "Seeing is Believing. Exposure to Counterstereotypic Women Leaders and Its Effect on the Malleability of Automatic Gender Typing," *Journal of Experimental Social Psychology*, 40 (2004): 647.
- ^x Jane Stout and Nilanjana Dasgupta, "When *He* Doesn't Mean *You*: Gender-exclusive Language as Ostracism," *Personality and Social Psychology Bulletin*, 38(2011):758
- ^{xi} See Gregory M. Walton and Geoffrey Cohen, "A Question of Fit: Race, Social Fit, and Achievement," *Journal of Personality and Social Psychology*, 92(2007): 82-96.
- ^{xii} Sapna Cheryan, Victoria C. Plaut, Paul G. Davies and Claude M. Steele, "Ambient Belonging: How Stereotypical Cues Impact Gender Participation in Computer Science," *Journal of Personality and Social Psychology*, 97(2009): 1045-1060.
- ^{xiii} Sapna Cheryan, John Oliver Siy, Marissa Vichayapai, Benjamin J. Drury, and Saenam Kim, "Do Female and Male Role Models Who Embody STEM Stereotypes Hinder Women's Anticipated Success in STEM?" *Social Psychology and Personality Science*, 2(2011): 1-9.
- ^{xiv} Jane G. Stout, Nilanjana Dasgupta, Matthew Hunsinger, and Melissa A. McManus, "STEMing the Tide: Using Ingroup Experts to Inoculate Women's Self-Concept in Science, Technology, Engineering, and Mathematics (STEM)," *Journal of Personality and Social Psychology*, 100 (2010): 255-270.
- ^{xv} *Ibid.*, p. 2.
- ^{xvi} John Nicholson, Shane T. Warren, Bonnie Oppenheimer, Jim Codling, Thomas Robinson, and Jee Young Chung, "STEM Research: What the Pictures Tell Us," *The International Journal of Science and Society*, 4(2013).
- ^{xvii} See Jaeho Cho, Homero Gil de Zuniga, Dhavan V. Shah, and Douglas M. McLeod, "Cue Convergence: Associative Effects on Social Intolerance," *Communication Research*, 33(2006): 136-154.
- ^{xviii} The actual questions used to rate the images were: Q. 1 Would you expect this person to be good at her job? (1-not very good at her job; 4-neutral; 7-good at her job); Q. 2 Would you expect this person to be organized? (1-not very organized; 4-neutral; 7-very organized); Q. 3 How would you rate this person's intelligence? (1-not very intelligent; 4-average intelligence; 7-very intelligent); Q. 4 Do you find this person attractive? (1-not very attractive; 4-attractive; 7-very attractive); Q. 5 Would you expect this person to be creative? (1-not very creative; 4-creative; 7-very creative).
- ^{xix} See Patricia Holland, "The Politics of the Smile: 'Soft News' and the Sexualization of the Popular Press," in *Critical Readings: Media and Gender*, edited by Cynthia Carter and Linda Steiner (Maidenhead: Open University Press, 2004), 68-86. Cynthia Carter and Linda Steiner, "Mapping the Contested Terrain of Media and Gender Research," in *Critical Readings: Media and Gender*, edited by Cynthia Carter and Linda Steiner (Maidenhead: Open University Press, 2004), 11-35. Diana M. Meehan, *Ladies of the Evening: Women Characters of Prime-time Television* (London: The Scarecrow Press, Inc, 1983).

ABOUT THE AUTHORS

Shane T. Warren: Shane is an instructor in the Department of Counseling and Educational Psychology at Mississippi State University, USA.

Dr. Joon Soo Lim: Dr. Joon Soo Lim received his PhD from the University of Florida. He is an assistant professor in the S. I. Newhouse School of Public Communications at Syracuse University. His research focuses on persuasion and the social influence of public relations campaigns that leverage social media strategies.

Dr. John Nicholson: Dr. Nicholson graduated from the University of Iowa (Ph.D., 1998) and has participated in multiple interdisciplinary projects including the current STEM research presented here. His other research areas include sibling research and family nickname research.

Emily D. Ryalls: Emily is an Assistant Professor in the Department of Communication at Mississippi State University, USA.

Skye C. Cooley: Skye is an Assistant Professor in the Department of Communication at Mississippi State University, USA.

Dr. Mark Goodman: Dr. Goodman has studied at Southwest Missouri State University (BA History & Journalism), Southwest Missouri State University (MA History), and University of Missouri (PhD Communication). He has taught courses in Mass Media, Public Relations, and Speech at Mississippi State University, USA.

Dr. Bonnie Oppenheimer: Dr. Oppenheimer teaches mathematics classes for education majors at Mississippi University for Women. A certified high school teacher, she has long been interested in why women do not choose the STEM fields. She helped form our research group, and has led the group's efforts to pursue the STEM research questions.

Dr. James Codling: Dr. Codling is an Instructor in the College of Education at Mississippi State University, USA.

Thomas Robinson: Thomas is a Research Assistant at Mississippi State University, USA.

Laci Kyles: Laci is a Research Assistant at Mississippi State University, USA.

Two Contrasting Paradigms of Science: Cartesian Mechanism and Undivided Wholeness

Siddharth G. Chatterjee, SUNY College of Environmental Science and Forestry, USA

Abstract: Building on the ideas of the theoretical physicist David Bohm, this paper postulates that Cartesian Mechanism (CM), which is the current philosophical paradigm of modern science, is derived from a more fundamental paradigm – one that is based on undivided wholeness (UW). After a discussion on the nature of scientific theory, the paper contrasts the chief elements of CM, which postulates that an entity or a process (i.e., a whole) can be broken down into a certain number of fundamental parts (e.g., a photograph), against those of UW according to which the whole is primary while a part is a conceptual abstraction from the whole, which the part also contains (e.g., a hologram). The two worldviews are illustrated by simple examples. Two phenomena are then examined from the chemical engineering field. Mathematical models are presented for (a) unsteady-state physical gas absorption in a liquid, and (b) adsorption of a species in a single, spherical adsorbent pellet. The theoretical expressions for the instantaneous rates of absorption and adsorbate uptake exhibit holographic features, i.e., they contain or enfold the entire process history up to that instant. Only under special circumstances, e.g., when the turbulence level is high [case (a)] or at large times [cases (a) and (b)], they reduce or collapse into their standard, widely-used photographic forms (i.e., effect of past history is insignificant). Thus, the mechanistic (i.e., unfolded) order of everyday experience in which events appear to be separated in time and space may be a projection from a deeper (i.e., enfolded) order of reality. This has profound implications for the physical sciences and for present-day humanity that is rent by social divisions of various kinds.

Keywords: Paradigms, Cartesian Mechanism, Undivided Wholeness, Adsorption, Gas Absorption

Introduction

The objective of science is the comprehension of phenomena that occur in our universe. Scientific theories impart a logical or rational structure to such phenomena so that they can be grasped or understood by the human mind. According to Einstein (1949), a scientific theory has both intuitive and logical elements as shown in Fig. 1. Starting from some basic axioms or concepts, the aim of theory is to correlate or coordinate the empirical or phenomenal world of sense experiences.

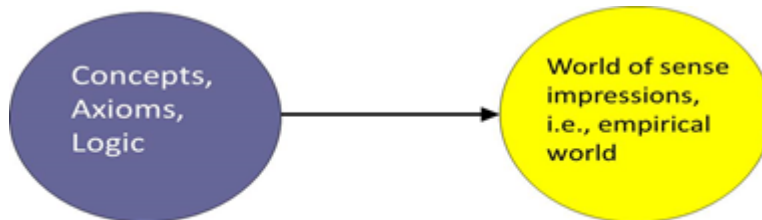


Figure 1: Structure of a Scientific Theory

Source: Einstein 1949

Two examples (Gupta and Chatterjee 2003a; Gupta and Chatterjee 2003b) are shown in Figs. 2 and 3, which concern the diffusion of moisture in paper – a topic of considerable practical interest since the moisture content of paper has a profound effect on its mechanical and electrical properties.

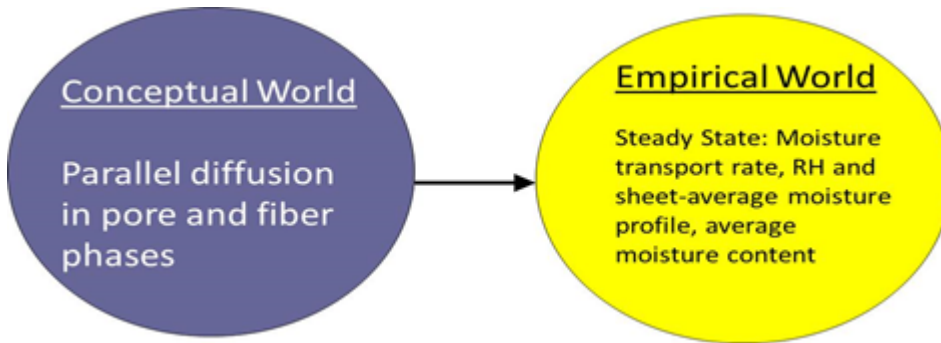


Figure 2: Steady-State Diffusion of Moisture in Paper. RH = Relative Humidity
 Source: Gupta and Chatterjee 2003a

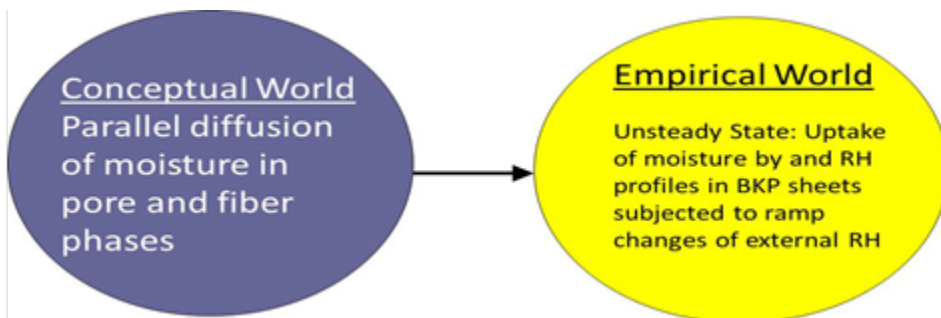


Figure 3: Unsteady-State Diffusion of Moisture in Paper. RH = Relative Humidity, BKP = Bleached Kraft Paperboard
 Source: Gupta and Chatterjee 2003b

In a recent article, Chatterjee (2012) has summarized the views of Einstein (1954) on the nature of a scientific theory. In a letter written to his friend Maurice Solovine on 7 May 1952, Einstein (1993) offered a sketch on the nature of a scientific theory (Fig. 4). He also recommended two desirable features in a scientific theory: it should have the fewest possible logically independent elements (basic concepts and axioms), and it should enable the closest and most complete coordination of the totality of sense experiences (Einstein 1949).

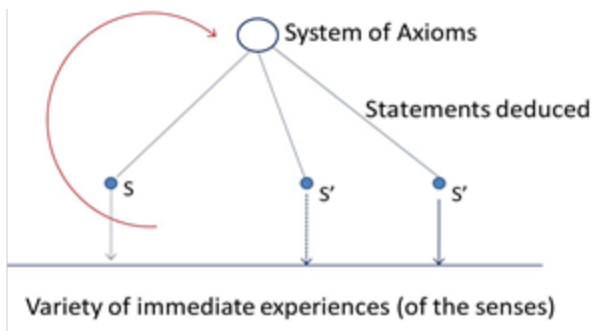


Figure 4: Nature of a (Constructive) Scientific Theory
 Source: Einstein 1993

According to theoretical physicist David Bohm (1980), the word ‘theory’ is derived from the Greek ‘theoria’ which has the same root as ‘theatre.’ It means to view or to make a spectacle and is a form of insight, i.e., a way of looking at the world, and not a form of knowledge of how the world is. Theories (i.e., insights) are neither true nor false – they are clear in certain domains and unclear when extended beyond those domains.

Philosophy of Cartesian Mechanism

The current paradigm of science is the philosophy of Cartesian Mechanism (CM) (Bohm 1980). According to CM, an entity or a process (i.e., a whole) can be broken up into a fixed number of fundamental parts or entities, qualities and laws. This philosophy can be expressed as

$$\text{Whole} = \Sigma \text{ parts} \tag{1}$$

in which the parts are thought to be independent, unchanging and self-existent. Figure 5 shows a few simple examples of CM. Another example of CM is offered in Fig. 6 which shows a photograph of flowers. If this photograph is cut into four pieces, these have to be juxtaposed together in order to reconstitute the original picture. Thus in CM, a higher dimensional entity (i.e., object or process) is thought to be constituted of lower dimensional entities, which are taken to be fundamental in some sense.

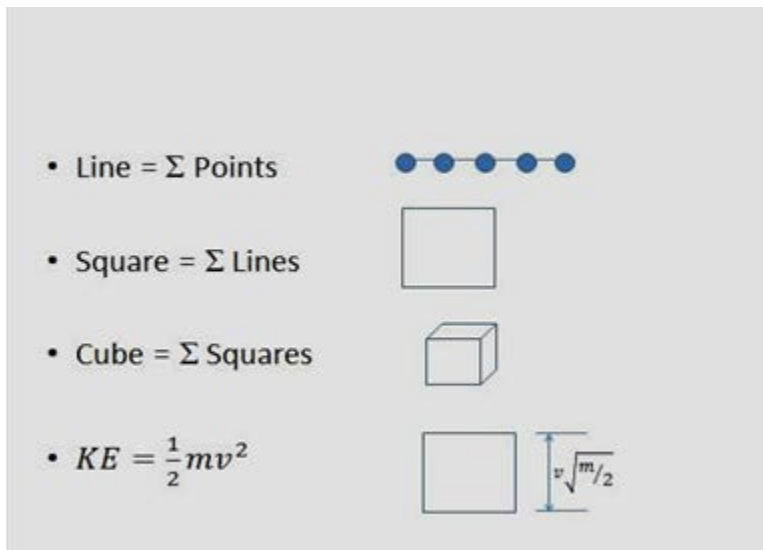


Figure 5: Examples of CM. KE = Kinetic Energy, m = Mass, v = Velocity

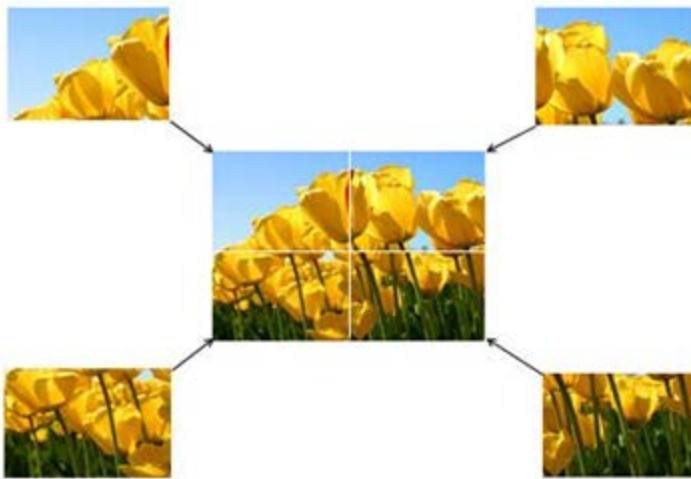


Figure 6: Philosophy of CM: A Photograph Constituted of Four Parts

Philosophy of Undivided Wholeness

Bohm (1980) has made the following criticisms of CM: (a) A part is a conceptual abstraction from the whole; (b) the progress of science has revealed that nature may be qualitatively infinite (i.e., there is no fundamental “part” or “particle”); (c) reciprocal relationships between things and entities can cause fundamental qualitative changes in their modes of being; and (d) any law of nature is approximate and of relative character, and holds in a limited domain, i.e., there are no final or absolute laws of nature.

The philosophy of undivided wholeness (UW) can be captured in the formula

$$\text{Part} \equiv \text{Whole} \tag{2}$$

i.e., the part contains the whole or is identical with it. As pointed out by Chatterjee (2009), an example of UW is offered by the Laplace transform of a function $z(t)$, which is defined as

$$\bar{z}(S) \equiv \int_0^{\infty} z(t)e^{-St} dt \tag{3}$$

If the time coordinate is denoted as t -space and the transformed coordinate as S -space, and if $z(t)$ is considered to be the amplitude of a wave whose magnitude depends upon its location t in t -space, then, according to the transformation represented by Eq. (3), all such waves of amplitudes varying from $z(t = 0)$ to $z(t = \infty)$ in t -space are transformed or enfolded into a single point in S -space. This transformation can be metaphorically described by drawing an analogy with a holographic plate every point of which ‘enfolds’ or ‘carries’ the entire information of an illuminated structure (Bohm 1980), which is in sharp contrast to a simple point-to-point correspondence between the structure and its image on a photographic plate. Since this change between the object and its holographic image is much more radical than a geometric transformation (translation, rotation or dilation), Bohm (1980) used the word ‘metamorphosis’ to refer to such a transformation, i.e., a change “in which everything alters in a thorough going

manner while some subtle and highly implicit features remain invariant.” Figure 7 shows an example that embodies the philosophy of UW.

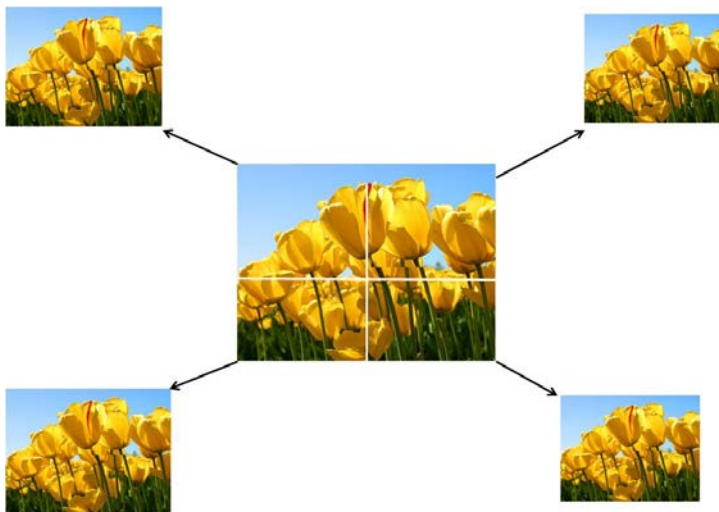


Figure 7: Philosophy of UW: A Hologram Divided into Four Parts

According to Bohm (1980), to a first approximation, there are two orders of reality. The first is the order which is immediately perceptible to our senses, which he called the “explicate” order and which forms the ground of the Cartesian mechanistic framework that has been adopted in much of science. Under this explicate order lies another “implicate” or enfolded order, which is beyond the reach of our sense perceptions. The implicate order is more fundamental in that it gives rise to the three-dimensional explicate order of ordinary experience, which emerges from the former by a process of unfoldment. The emergent (transient) structures in the explicate order are relatively invariant and stable. For more details on explicate and implicate orders and their relation to quantum mechanics, we refer the reader to Bohm (1980) and Hiley (2010).

This paper will illustrate the above two philosophies of CM and UW, embodied by the photograph (Fig. 6) and the hologram (Fig. 7), respectively, by examining two widely-studied physical phenomena taken from the field of chemical engineering, whose mathematical descriptions show the ordinary Cartesian order emerging from a deeper enfolded or “mixed” order of reality when certain conditions are fulfilled. However, the examples also have bearing on the reduction/emergence debate in the philosophy of science, an overview of which has been presented by Batterman (2002), and it is to this topic that we turn to next before presenting the examples.

Reduction and Emergence

In the common “scientific” or “physicist’s” concept of reduction, a finer or more refined theory (T_f) is said to reduce to a coarser theory T_c as a fundamental parameter $\varepsilon \rightarrow 0$, which can be represented by the scheme

$$\lim T_f (\varepsilon \rightarrow 0) = T_c \quad (\text{A})$$

According to Batterman (2002), the equality in Eq. (A) can only hold if the limit is regular in which case the equations of T_f will smoothly approach the corresponding equations in T_c . For such cases it can be said that the limiting behavior as $\varepsilon \rightarrow 0$ is equal to the behavior in the limit when $\varepsilon = 0$. Batterman (2002) offers as an example the quadratic equation:

$$x^2 + x - \varepsilon 9 = 0 \tag{B}$$

where ε is a small perturbation parameter. The roots of Eq. (B) are given by

$$x = \frac{-1 \pm \sqrt{1 + 36\varepsilon}}{2} \tag{C}$$

As $\varepsilon \rightarrow 0$, it can be observed from Eq. (C) that x smoothly approaches the solutions of the unperturbed ($\varepsilon = 0$) equation

$$x^2 + x = 0 \tag{D}$$

which are $x = 0, -1$.

In contrast, the equation

$$\varepsilon x^2 + x - 9 = 0 \tag{E}$$

has two roots for any $\varepsilon > 0$, which are

$$x = \frac{-1 \pm \sqrt{1 + 36\varepsilon}}{2\varepsilon} \tag{F}$$

These roots do not smoothly approach the root $x = 9$ of Eq. (E) when $\varepsilon = 0$ for which there is a reduction in the order of Eq. (E). Thus, according to Batterman (2002), “the character of the behavior [of Eq. (E)] in the limit $\varepsilon = 0$ differs fundamentally from the character of its limiting behavior,” and it is in such asymptotic regimes or “borderlands” where new physics emerges. In the abstract of a 1995 paper, Batterman provided a succinct summary of intertheoretic relations as follows:

This paper addresses a relatively common “scientific” (as opposed to philosophical) conception of intertheoretic reduction between physical theories. This is the sense of reduction in which one (typically newer and more refined) theory is said to reduce to another (typically older and “coarser”) theory in the limit as some small parameter tends to zero. Three examples of such reductions are discussed: First, the reduction of Special Relativity (SR) to Newtonian Mechanics (NM) as $(v/c)^2 \rightarrow 0$; second, the reduction of wave optics to geometrical optics as $\lambda \rightarrow 0$; and third, the reduction of Quantum Mechanics (QM) to Classical Mechanics (CM) as $\hbar \rightarrow 0$. I argue for the following two claims. First, the case of SR reducing to NM is an instance of a genuine reductive relationship while the latter two cases are not. The reason for this concerns the nature of the limiting relationships between the theory pairs. In the SR/NM case, it is possible to consider SR as a regular perturbation of NM; whereas in the cases of wave and geometrical optics and QM/CM, the perturbation problem is singular. The second claim I wish to support is that as a result of the singular nature of the limits between these

theory pairs, it is reasonable to maintain that third theories exist describing the asymptotic limiting domains. In the optics case, such a theory has been called “catastrophe optics”. In the QM/CM case, it is semiclassical mechanics. (Batterman 1995)

Another example of intertheoretic relations is in the contrast of hydrodynamics with molecular dynamics in analyzing the behavior of breaking droplets (e.g., a dripping faucet). As detailed by Batterman (2006), the science of hydrodynamics, which is based on the hypothesis that the fluid is a continuum, is unable to explain the double cone structure of nanojets as predicted from molecular dynamical simulations. However, a stochastic modification of the hydrodynamic equations yields solutions that are in remarkable agreement with this double cone shape. This suggests that the ontologically more fundamental molecular dynamics still needs a less “fundamental” theory like hydrodynamics to explain universal patterns of behavior.

Although the two physical illustrations presented below can be cited as examples of theories that smoothly (i.e., in a regular fashion) approach their limiting values as some parameter or variable tends toward an extremum, the philosophical viewpoint advanced in this paper is much wider in scope and encompassing than a simple reductive exercise or relation between theories. This viewpoint, which is concerned about the nature of reality (which is modeled by our theories), is that the “whole” is primary or fundamental, while the “part” is derived from the whole and is an aspect of or a mental abstraction from it, and is, therefore, secondary (Bohm 1980). And even in the case of singular or emergent theoretical structures like catastrophe optics, as admitted by Batterman (2002), they are in some sense contained within the fundamental theory (e.g., Schrödinger wave equation), although not predictable from it. Thus, the equation $x - 9 = 0$ is contained within Eq. (E) although its root $x = 9$ is not predictable or derivable from Eq. (F) when $\varepsilon = 0$.

Unsteady-State Physical Gas Absorption in a Liquid

In the theory of gas absorption in liquids, the rate of physical absorption is usually expressed as the product of a mass-transfer coefficient and a concentration-driving force (Astarita 1967; Danckwerts 1970). While this linear-driving-force (LDF) form of the absorption rate can be rigorously derived from the film, penetration, surface-renewal, and film-penetration models of mass transfer for steady-state conditions, its use in unsteady-state situations is an a-priori assumption, which is open to theoretical inquiry. For example, the oxygen-transfer model that is widely used in the analysis of diffused and surface aerators under unsteady-state conditions is expressed as (Tchobanoglous and Burton 1991)

$$\frac{dc_L(t)}{dt} = K_L a (c_L^{\text{sat}} - c_L(t)) \quad (4)$$

where $c_L(t)$ and c_L^{sat} are the dissolved-oxygen (DO) concentration in the bulk liquid at time t and the saturation DO concentration, respectively, and $K_L a$ is an overall volumetric mass-transfer coefficient. The ASCE (American Society of Civil Engineers) standard model is based on Eq. (4) and so are also the improved two-zone oxygen-transfer models proposed for diffused and surface aerators (McWhirter and Hutter 1989; McWhirter, Chern, and Hutter 1995; Chern and Yu 1997).

In this section, we provide a theoretical justification for Eq. (4) using the surface-renewal model of mass transfer, which is considered to be more realistic than the film and penetration models. To our knowledge, this has not been attempted previously in the literature. Specifically, it will be shown that Eq. (4) results from a more general expression for the rate of oxygen transfer to the bulk liquid (conventionally assumed to be the same as the rate of oxygen absorption at the gas-liquid interface) under a sufficiently high rate of surface renewal; i.e., when

the mass-transfer process is gas-phase controlled. This is in contrast to the assertion commonly made in the literature that the absorption of sparingly soluble gases like oxygen is liquid-phase controlled, i.e., the dominant resistance to mass transfer resides in the liquid phase (McWhirter and Hutter 1989; McWhirter, Chern, and Hutter 1995; Chern and Yu 1997). In the analysis presented below, the bulk gas-phase concentration (y_b) of the species being absorbed in the liquid is assumed to be independent of time (similar to the ASCE model); otherwise mathematical complexities increase greatly.

In the surface-renewal model (see Fig. 8), fresh liquid elements are visualized as being continuously brought from the bulk liquid to the gas-liquid interface. A liquid element resides at the surface for a definite amount of time after which it returns to the bulk liquid. During its exposure time at the interface, mass transport of dissolved gas is assumed to occur in it by unsteady-state diffusion in a semi-infinite medium. Due to the surface-renewal mechanism there is a continuous exchange of liquid elements between the bulk liquid and the gas-liquid interface, with a resulting net transfer of dissolved gas to the bulk liquid from the interface. The net rate of transfer of dissolved gas R_{trans} (i.e., the rate of transfer of absorbed gas) to the bulk liquid which, as will be seen later, is not in general equal to the rate of gas absorption R_{abs} at the gas-liquid interface (due to accumulation of absorbed gas in the surface elements), and forms a part of the mass balance for dissolved gas in the bulk liquid.

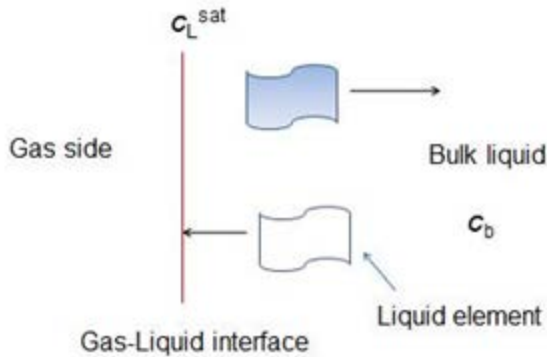


Figure 8: Surface-Renewal Model of Gas Absorption

At any time t since the start of the absorption process, the surface of the liquid in which the gas is being absorbed is visualized as being composed of a mosaic of elements having different ages, which range from zero to t . A liquid element is assumed to be isolated from the bulk liquid during its residence at the gas-liquid interface. The unsteady-state diffusion of dissolved gas in a specific liquid element (assumed to be infinitely deep) during its exposure time θ at the interface can be described by the following equations (Astarita 1967; Danckwerts 1970):

$$\frac{\partial c}{\partial \theta} = D \frac{\partial^2 c}{\partial x^2} \tag{5}$$

with initial and boundary conditions given by

$$c = c_b (\theta = 0) \text{ at } \theta = 0 \text{ for } 0 \leq x \leq \infty \tag{6}$$

$$c = c_b (\theta = 0) \text{ for } \theta > 0 \text{ at } x = \infty \quad (7)$$

$$k_G (y_b - Hc) = -D \left(\frac{\partial c}{\partial x} \right)_{x=0} \text{ for } \theta > 0 \text{ at } x = 0 \quad (8)$$

In the above, c and c_b are concentrations of dissolved gas at a location x (measured from the gas-liquid interface) in the element at time θ , and in the bulk liquid, respectively, D is the diffusion coefficient of the dissolved gas in the liquid, k_G is the gas-phase mass-transfer coefficient, and H is Henry's constant. Equation (5), which is sometimes referred to as Fick's second law, is a mass balance for dissolved gas in the liquid element while Eq. (8) expresses the mass balance at the gas-liquid interface (i.e., at $x = 0$). The solution of Eq. (5), subject to Eqs. (6) to (8), is given by (Carslaw and Jaeger 1959; Crank 1964)

$$c(x, \theta) = c_b (\theta = 0) + \left(\frac{y_b}{H} - c_b (\theta = 0) \right) \left[\operatorname{erfc} \left(\frac{x}{2\sqrt{D\theta}} \right) - \exp(hx + h^2 D\theta) \operatorname{erfc} \left(\frac{x}{2\sqrt{D\theta}} + h\sqrt{D\theta} \right) \right] \quad (9)$$

where

$$h = \frac{k_G H}{D} \quad (10)$$

Differentiating Eq. (9) gives the rate of absorption of the gas in the liquid element as

$$R(\theta) = -D \left(\frac{\partial c}{\partial x} \right)_{x=0} = Dh \left[y_b / H - c_b (\theta = 0) \right] e^{h^2 D\theta} \operatorname{erfc} (h\sqrt{D\theta}) \quad (11)$$

Consider a liquid element with an age of τ at time t . Because θ is the time elapsed since the element first arrived at the gas-liquid interface, $\theta = 0$ corresponds to a time of $t - \tau$ while $\theta = \tau$ corresponds to a time of t . Thus, the concentration profile $c(x, \tau, t)$ and rate of absorption $R(\tau, t)$ in the liquid element are given by Eqs. (9) and (11), respectively, with $\theta = 0$ replaced with $t - \tau$ and θ replaced by τ . Denoting the age-distribution function of surface elements by $f(\tau, t)$, the age-averaged transient rate of absorption $R_{\text{abs}}(t)$ of the gas in the liquid can be expressed as

$$R_{\text{abs}}(t) = \int_0^t R(\tau, t) f(\tau, t) d\tau \quad (12)$$

Assuming random surface renewal it can be shown theoretically that (Koltuniewicz and Noworyta 1994; Hasan et al. 2013)

$$f(\tau, t) = \frac{S e^{-S\tau}}{1 - e^{-St}} \quad (13)$$

where S is the rate of renewal of liquid elements at the gas-liquid interface. Equation (13) is the unsteady-state form of the well-known Danckwerts age-distribution function (Danckwerts 1970). Substituting Eq. (13) into Eq. (12) yields

$$R_{\text{abs}}(t) = \int_0^t R(\tau, t) \frac{S e^{-S\tau}}{1 - e^{-S\tau}} d\tau \quad (14)$$

It therefore follows from Eqs. (11) and (14) that

$$R_{\text{abs}}(t) = \frac{DSh}{1 - e^{-St}} \int_0^t [y_b / H - c_b(t - \tau)] \operatorname{erfc}(h\sqrt{D\tau}) e^{-(S-h^2D)\tau} d\tau \quad (15)$$

which can also be written as

$$R_{\text{abs}}(t) = \frac{Dh}{1 - e^{-St}} \int_0^{St} g(t - \alpha / S) \operatorname{erfc}(h\sqrt{D\alpha / S}) e^{-(1-h^2D/S)\alpha} d\alpha \quad (16)$$

where

$$\alpha = S\tau \quad (17)$$

and

$$g(t - \alpha / S) = y_b / H - c_b(t - \alpha / S) \quad (18)$$

An expression for the transient net rate of transfer $R_{\text{trans}}(t)$ of dissolved gas into the bulk liquid in unsteady-state physical absorption is derived next. This aspect of the surface-renewal model has not received much attention in the literature. As mentioned before, due to surface renewal, there is a constant movement of liquid elements between the bulk liquid and the gas-liquid interface with a resultant net transfer of dissolved gas to the bulk liquid from the interface. Using the film-penetration model, Loffler and Merchuk (1972) and Merchuk (1985) have presented the general form of the equation for R_{trans} for the case of absorption with a first-order reaction in a continuous-flow stirred-tank reactor, assuming no gas-phase resistance to mass transfer. Recently, Chatterjee (2009) has derived expressions for R_{trans} for absorption with a first-order reaction under steady-state conditions using the surface-renewal and film-penetration models, which included finite gas-phase mass-transfer resistance. The expression for R_{trans} is given by

$$R_{\text{trans}}(t) = S \int_0^t \int_0^x [c(x, \tau, t) - c_b(t - \tau)] \frac{S e^{-S\tau}}{1 - e^{-S\tau}} d\tau dx \quad (19)$$

where the first and second terms on the right-hand-side of Eq. (19) represent the convective transfer (due to surface renewal) of dissolved gas to the bulk liquid from the gas-liquid interface, and that from the bulk liquid to the interface, respectively. Using Eq. (9) [with $\theta = 0$ replaced with $t - \tau$ and θ replaced with τ] in Eq. (19), integrating with respect to x , and noting that

$$\int_0^{\infty} \operatorname{erfc}\left(\frac{x}{2\sqrt{D\tau}}\right) dx = 2\sqrt{D\tau/\pi} \quad (20)$$

and

$$\int_0^{\infty} e^{hx} \operatorname{erfc}\left(\frac{x}{2\sqrt{D\tau}} + h\sqrt{D\tau}\right) dx = \frac{1}{h} \left\{ e^{-h^2 D\tau} - \operatorname{erfc}\left(h\sqrt{D\tau}\right) \right\} \quad (21)$$

yields

$$R_{\text{trans}}(t) = \frac{S}{1 - e^{-St}} \int_0^{St} g(t - \alpha/S) \left[2\sqrt{\frac{D\alpha}{\pi S}} - \frac{1}{h} \left\{ 1 - e^{h^2 D\alpha/S} \operatorname{erfc}\left(h\sqrt{D\alpha/S}\right) \right\} \right] e^{-\alpha} d\alpha \quad (22)$$

For a large rate of surface renewal ($S \rightarrow \infty$), i.e., when liquid-phase resistance to mass transfer is insignificant, it can be shown that Eqs. (16) and (22) collapse into

$$R_{\text{abs}}(t) \approx R_{\text{trans}}(t) \approx k_G H [y_b / H - c_b(t)] \quad (23)$$

which is of the LDF form (with $K_L = k_G H$) and is the basis for Eq. (4), with the quantity y_b/H being the solubility of the gas in the liquid, c_L^{sat} .

In a continuous-flow stirred-tank absorber, c_b will eventually attain a constant value as $t \rightarrow \infty$, i.e., when steady state is reached. Under this situation, Eqs. (16) and (22) simplify to the well-known expression

$$R_{\text{abs}}(t \rightarrow \infty) \approx R_{\text{trans}}(t \rightarrow \infty) \approx K_{\text{OL}} (y_b / H - c_b) \quad (24)$$

where

$$\frac{1}{K_{\text{OL}}} = \frac{1}{k_L} + \frac{1}{Hk_G} \quad (25)$$

and

$$k_L = \sqrt{DS} \quad (26)$$

In deriving Eq. (24), use has been made of the relation (Abramowitz and Stegun 1965)

$$\int_0^{\infty} \operatorname{erfc}\left(h\sqrt{D\tau}\right) e^{-(s-h^2 D)\tau} d\tau = \frac{1}{\sqrt{S}\left(h\sqrt{D} + \sqrt{S}\right)} \quad (27)$$

Therefore, it is to be noted from the above that the commonly-used law of addition of resistances [Eq. (25)] is strictly valid only under steady-state conditions.

Comparing Eqs. (16) and (22) it becomes evident that $R_{\text{abs}}(t) \neq R_{\text{trans}}(t)$ in general, which, as mentioned earlier, is due to the accumulation of absorbed gas in the surface elements. Only for a sufficiently high rate of surface renewal ($S \rightarrow \infty$) or under steady-state conditions ($t \rightarrow \infty$), $R_{\text{abs}}(t)$ approaches $R_{\text{trans}}(t)$ and attains the LDF form given by either Eq. (23) or Eq. (24).

It is observed that unlike Eq. (24), which is valid for steady-state physical gas absorption (e.g., in a packed section of an absorption column), the transient rate of absorption (e.g., in a stirred cell) given by Eq. (16) depends upon a convoluted form of the concentration-driving force, i.e., the rate of absorption at any time t contains the entire history of this driving force

[multiplied by the weighting factor $\text{erfc}\left(h\sqrt{D\alpha/S}\right)e^{-(1-h^2D/S)\alpha}$] starting from time $t = 0$

onwards. If $g(t)$ is taken to be the amplitude of a wave at time t , then all such waves, whose amplitudes vary from $g(0)$ to $g(t)$, are transformed or enfolded into the instantaneous or point value of the absorption rate $R_{\text{abs}}(t)$ at time t . As mentioned earlier, Bohm (1980), who used the example of the Green's function, described such a transformation as a metamorphosis. Only for a sufficiently large rate of surface renewal ($S \rightarrow \infty$), or under steady-state conditions ($t \rightarrow \infty$) when the past history is insignificant, Eq. (16) reduces approximately to the familiar LDF form given by Eq. (23) or Eq. (24), respectively, which can be compared metaphorically to the ordinary point-to-point correspondence between a structure and its image on a photographic plate, i.e., there is a one-to-one mapping or correspondence between the instantaneous concentration driving force [$y_b/H - c_b(t)$] and the absorption rate [$R_{\text{abs}}(t)$] at that instant. The same conclusion is reached with regard to the rate of transfer of dissolved gas to the bulk liquid; i.e., the holographic form of $R_{\text{trans}}(t)$ given by Eq. (22) collapses into the appropriate photographic form as $S \rightarrow \infty$ or as $t \rightarrow \infty$.

Equations (16) and (22) therefore reflect in a clear fashion the ancient philosophical principle of wholeness, i.e., the part contains the whole or is a reflection of the whole, which can be contrasted with the CM philosophical framework of modern science according to which an entity or a process is believed to be comprised of a certain number of fundamental and unchanging parts and their pre-assigned interactions from which the whole is postulated to be derived (Bohm 2003). For a scientific discussion on the concept of wholeness, its contrast with mechanism and the notion of different orders of reality, the reader is referred to the profound work of Bohm (1980). Although we have used the Danckwerts (unsteady-state) age-distribution function for the surface elements [Eq. (13)], the philosophical conclusion about the holographic nature of the rates of gas absorption at the gas-liquid interface and dissolved-gas transfer to the bulk liquid would remain the same if any other age-distribution function had been used instead; only the details of Eqs. (16) and (22) would be different.

In a cyclic heat- or mass-transfer process in which the temperature- or concentration-driving force varies strongly with time, one can expect that the history of the driving force will have a significant effect. Aidoun and Ternan (2004) measured the unsteady-state heat flux in a cyclical chemical heat pump reactor containing carbon fibers impregnated with CoCl_2 . They found that the steady-state heat-transfer equation, which is an analogue of Eq. (24), was not able to represent their unsteady-state heat-transfer data. A plot of the experimental unsteady-state heat flux versus the temperature-driving force instead of yielding a straight line (with slope equal to the overall heat-transfer coefficient) as the standard steady-state heat-transfer equation suggests, gave a looped curve (see Figure 6 in their paper). According to these authors, the shape of this curve "was completely unexpected and suggested a complex relationship." When they calculated a time-dependent instantaneous overall heat-transfer coefficient (obtained from the steady-state equation), the heat-transfer coefficient varied with cycle time and had a maximum value that was seven times larger than its minimum value. The authors concluded that in cyclical chemical heat pumps, the description of the heat-transfer rate in terms of a single-valued overall heat-transfer coefficient obtained from the steady-state heat-transfer equation (i.e., LDF or photographic form) was not appropriate.

Adsorbate Uptake by a Spherical Adsorbent Pellet

In the adsorption literature, there is a well-known approximation known as the Glueckauf approximation that is used to describe the uptake of adsorbate by a porous adsorbent pellet (Tien 1994). The uptake rate has the LDF form

$$\frac{dq}{dt} = k_p [q_s(t) - q(t)] \quad (28)$$

where $q_s(t)$ and $q(t)$ are the surface and average concentrations of the adsorbate in the pellet at time t , respectively, while k_p is an intraparticle mass-transfer coefficient, which for a sphere of radius a_p , is given by

$$k_p = \frac{15D_e}{a_p^2} \quad (29)$$

where D_e is the effective diffusion coefficient of the adsorbate in the pellet. We note the photographic form of Eq. (28) in which there is a one-to-one correspondence between the instantaneous uptake rate and the concentration driving force at that instant.

Consider a spherical adsorbent pellet of radius a_p , initially (i.e., when $t = 0$) free of adsorbate, whose surface is subjected to an arbitrary concentration $q_s(t)$ from $t = 0$ onwards. It can be shown that (Carslaw and Jaeger 1959)

$$q = \frac{6D_e}{a_p^2} \sum_{n=1}^{\infty} \int_0^t \exp\left[-\frac{D_e n^2 \pi^2}{a_p^2}(t-\lambda)\right] q_s(\lambda) d\lambda \quad (30)$$

and therefore

$$\frac{dq}{dt} = \frac{6D_e}{a_p^2} \sum_{n=1}^{\infty} \left\{ q_s(t) - \frac{D_e n^2 \pi^2}{a_p^2} \int_0^t \exp\left[-\frac{D_e n^2 \pi^2}{a_p^2}(t-\lambda)\right] q_s(\lambda) d\lambda \right\} \quad (31)$$

According to Eq. (31), the rate of adsorbate uptake by the pellet at any time t contains the entire history of the surface concentration $q_s(t)$ starting from time $t = 0$ onwards. When t becomes large, all terms except the first become insignificant in Eqs. (30) and (31); under this situation it can be shown that

$$\frac{dq}{dt} = \frac{6D_e}{a_p^2} \left(q_s(t) - \frac{\pi^2}{6} q \right) \quad (32)$$

which is of the LDF form but with a smaller intraparticle mass-transfer coefficient and concentration driving force compared to the Glueckauf approximation [Eqs. (28) and (29)], whose mathematical derivation has been provided by Tien (1994). This approximation has a photographic form [Eq. (28)], which crystallizes out of the more general holographic form [Eq. (31)] at large values of t when the past history becomes unimportant.

Consider a surface concentration variation of the form:

$$q_s(\tau_d) = 1 + \sin(\omega\tau_d) \tag{33}$$

where τ_d is dimensionless time ($= D_e t/a_p^2$) and ω is a dimensionless frequency. The exact formulae Eqs. (30) and (31) then yield

$$q(\tau_d) = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \left[1 - \exp(-n^2\pi^2\tau_d) + \frac{1}{1 + \left(\frac{w}{n^2\pi^2}\right)^2} \left\{ \sin(\omega\tau_d) - \frac{w}{n^2\pi^2} \cos(\omega\tau_d) + \frac{w}{n^2\pi^2} \exp(-n^2\pi^2\tau_d) \right\} \right] \tag{34}$$

and

$$\frac{dq}{d\tau_d} = 6 \sum_{n=1}^{\infty} \left[\exp(-n^2\pi^2\tau_d) + \frac{\frac{\omega}{n^2\pi^2}}{1 + \left(\frac{w}{n^2\pi^2}\right)^2} \left\{ \cos(\omega\tau_d) + \frac{w}{n^2\pi^2} \sin(\omega\tau_d) - \exp(-n^2\pi^2\tau_d) \right\} \right] \tag{35}$$

Figures 9 and 10 compare the uptake rate from the LDF approximation [Eqs. (28) and (29)] to that calculated from the exact solution [Eq. (35)] as a function of the driving force (DF) for values of $w = 0$ (step change in surface concentration) and $w = 1$ (sinusoidal surface concentration), respectively. It is observed that the exact uptake rate departs greatly from that given by the LDF approximation when DF is large (i.e., at small values of τ_d), and approaches it with a slope of 15 as DF tends towards zero (i.e., for large τ_d). Although the LDF approximation has been used to represent unsteady-state mass and heat transfer in adsorption (Tien 1994), evaporative cooling (van der Smaan 2003; Mittal et al. 2006) and moisture diffusion in paper (Chatterjee 2008), it is well known that this approximation is valid only at long time.

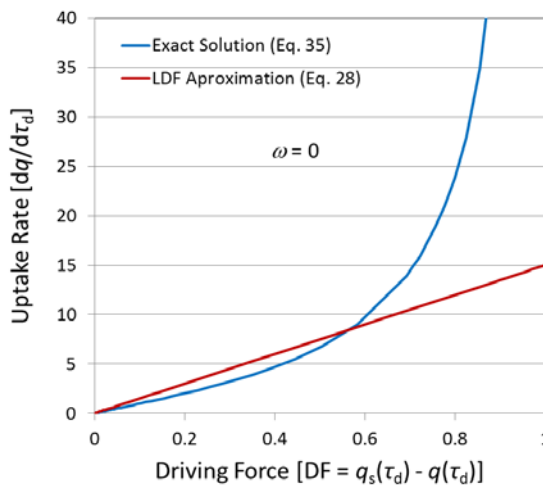


Figure 9: Uptake Rate of a Spherical Adsorbent Pellet as a Function of Driving Force for a Step Change in Surface Concentration

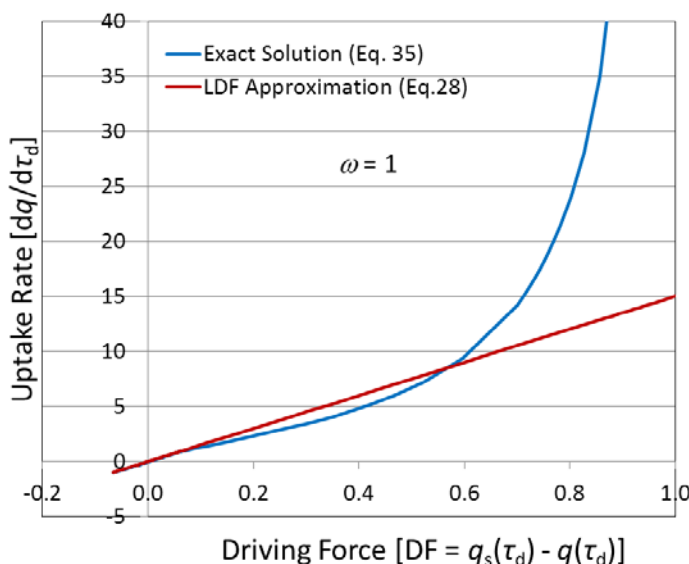


Figure 10: Uptake Rate of a Spherical Adsorbent Pellet as a Function of Driving Force for a Sinusoidal Variation in Surface Concentration

Concluding Remarks

This work suggests that the mechanistic (unfolded) order of everyday experience in which events appear to be separated in time and space may be a projection from a deeper (enfolding) order of reality; i.e., the gross is a condensation of the subtle, and not vice versa. Thus, the sensually perceived separation of objects and events on a Cartesian grid of time and space may be illusory as indicated by the phenomenon of quantum entanglement of two elementary particles. The Cartesian mechanistic framework permeates scientific and human thinking today. While this mode of thought, which is the philosophical foundation of any complex machine, has led to great developments in science and society which have created the modern world, it is limited when one wants to obtain a deeper insight into the workings of an organic system (e.g., natural processes, evolution of living systems, etc.), or ameliorate the great social, economic and ecological problems that currently beset humanity. Incorporation of the philosophy of wholeness into science and society, which is a great challenge, will lead to new, revolutionary advances. In the realm of science, one can envision some of the following developments: (a) Models of physical processes that are holographic rather than photographic in nature; (b) computational techniques which incorporate the philosophy of wholeness (i.e., the part contains the whole), thus removing the current schism between classical mathematics and numerical methods; (c) treatment methods for diseases and disorders that consider the various aspects of the human being in a holistic manner or as a totality (i.e., physiological, psychological and social/economic); and (d) new ecologically friendly industrial processes that mimic those occurring in nature (e.g., constructed wetlands) and within any living organism (inside of which the various organs and cells cooperate with one another in order to ensure the health and survival of the whole organism). Today, human society is rent by divisions of various kinds like race, caste, economic class, nation, etc. that are causing tremendous problems like conflicts, wars, and ecological devastation, which are imperiling the earth and the biosphere. The primary reason for this state of affairs is a fragmentary mode of thinking in which the part (individual, race, caste or nation) is beheld as being primary or fundamental. If instead, the whole (e.g., humanity, earth, etc) was realized to be

primary, and the part as being a conceptual abstraction from it (with no real independent existence), such problems could be solved rapidly.

The two examples presented in this work also exhibit the feature of universality which Batterman (2002) has defined as “an expression of behavioral similarity in diverse systems.” The LDF approximations for the rates of physical gas absorption (and transfer) in a turbulent liquid [Eq. (23)] and adsorbate uptake by a spherical adsorbent pellet [Eq. (28)] are of the same form, i.e., the rate is a product of an appropriately defined mass-transfer coefficient and a concentration driving force, a form that is very common in the theoretical description of heat- and mass-transfer phenomena.

According to Bohm (1980), a new science would be based on the more fundamental, implicate order rather than on the Cartesian explicate order as is prevalent today. The explicate order of space and time will unfold out from the deeper implicate order, which will yield radically new perspectives.

Nomenclature

- a = gas-liquid interfacial area of mass-transfer per unit volume of liquid (m^{-1})
- a_p = radius of adsorbent pellet (m)
- c = concentration of solute gas at any location x in a liquid element at time θ (kmol/m^3) or speed of light (m/s)
- c_b = concentration of solute gas in the bulk liquid (kmol/m^3)
- c_L = concentration of dissolved oxygen in the bulk liquid (kmol/m^3)
- c_L^{sat} = saturation concentration of dissolved oxygen in the liquid or y_b/H (kmol/m^3)
- D = diffusion coefficient of solute gas in the liquid (m^2/s)
- D_e = effective diffusion coefficient of adsorbate in the pellet (m^2/s)
- $f(\tau, t)$ = age-distribution function of liquid elements at the gas-liquid interface (s^{-1})
- $g(t)$ = defined by Eq. (18) (kmol/m^3)
- h = defined by Eq. (10) (m^{-1})
- \hbar = reduced Planck constant [$1.054571726(47) \times 10^{-34}$ J.s]
- H = Henry's constant ($\text{Pa m}^3/\text{kmol}$)
- k_G = gas-phase mass-transfer coefficient [$\text{kmol}/(\text{m}^2 \text{ s Pa})$]
- k_L = liquid-phase mass-transfer coefficient (m/s)
- k_p = intraparticle mass-transfer coefficient (s^{-1})
- K_L = overall mass-transfer coefficient in Eq. (4) (m/s)
- K_{OL} = overall mass-transfer coefficient defined by Eq. (25) (m/s)
- n = index of summation (1, 2, 3, ...)
- q_s = surface concentration of adsorbate in the pellet (kg/kg)
- q = average concentration of adsorbate in the pellet (kg/kg)
- $R(\theta)$ = instantaneous rate of physical absorption in a liquid element with residence time θ [$\text{kmol}/(\text{m}^2 \text{ s})$]
- $R(\tau, t)$ = instantaneous rate of physical absorption in a liquid element with residence time τ at process time t [$\text{kmol}/(\text{m}^2 \text{ s})$]
- R_{abs} = rate of absorption of solute gas [$\text{kmol}/(\text{m}^2 \text{ s})$]
- R_{trans} = net rate of transfer of dissolved gas to the bulk liquid due to surface renewal [$\text{kmol}/(\text{m}^2 \text{ s})$]
- S = Laplace transform parameter in Eq. (3) or rate of renewal of liquid elements at the gas-liquid interface (s^{-1})
- t = process time (s)
- v = velocity (m/s)
- x = variable in Eqs. (B) and (E), or distance into a liquid element measured from the gas-liquid interface (m)

y_b = partial pressure of solute gas in the bulk gas phase (Pa)

$z(t)$ = function of t

$\bar{z}(S)$ = Laplace transform of $z(t)$ defined by Eq. (3)

α = defined by Eq. (17)

ε = small parameter

λ = variable of integration in Eqs. (30) and (31), or wavelength (m)

θ = time of exposure of a liquid element at the gas-liquid interface (s)

τ = age of a liquid element at the gas-liquid interface at process time t (s)

τ_d = dimensionless time, $D_e t / a_p^2$

ω = dimensionless frequency

REFERENCES

- Abramowitz, Milton, and Irene A. Stegun, eds. 1965. *Handbook of Mathematical Functions: With Formulas, Graphs, and Mathematical Tables*. New York: Dover Publications.
- Aidoun, Zine, and Marten Ternan. 2004. "The Unsteady State Overall Heat Transfer Coefficient in a Chemical Heat Pump Reactor: The $\text{NH}_3\text{-CoCl}_2$ System." *Chemical Engineering Science* 59:4023–4031.
- Astarita, Giovanni. 1967. *Mass Transfer with Chemical Reaction*. Amsterdam: Elsevier.
- Batterman, Robert W. 1995. "Theories between Theories: Asymptotic Limiting Intertheoretic Relations." *Synthese* 103:171–201.
- . 2002. *The Devil in the Details: Asymptotic Reasoning in Explanation, Reduction, and Emergence*. New York: Oxford University Press.
- . 2006. "Hydrodynamics versus Molecular Dynamics: Intertheory Relations in Condensed Matter Physics." *Philosophy of Science* 73:888–904.
- Bohm, David. 1980. *Wholeness and the Implicate order*. London: Routledge & Kegan Paul.
- . 2003. "The Causal–Ontological Interpretation and Implicate Orders." In *The Essential David Bohm*, edited by Lee Nichol, 183–198. London: Routledge.
- Carlslaw, Horatio S., and John C. Jaeger. 1959. *Conduction of Heat in Solids*. London: Oxford University Press.
- Chatterjee, Siddharth G. 2008. "A Simple Description of Transient Moisture Diffusion in Paper." *Indian Chemical Engineer* 50:34–46.
- . 2009. "A Theoretical Analysis of Dissolved-Gas Transfer to the Bulk Liquid in Gas Absorption with a First-Order Reaction." *Indian Chemical Engineer* 51:177–193.
- . 2012. "The Nature of Scientific Theory." *Current Science* 102:386–388.
- Chern, Jia-Ming, and Cheng-Fu Yu. 1997. "Oxygen Transfer Modeling of Diffused Aeration Systems." *Industrial & Engineering Chemistry Research* 36:5447–5453.
- Crank, John. 1964. *The Mathematics of Diffusion*. London: Oxford University Press.
- Danckwerts, Peter V. 1970. *Gas–Liquid Reactions*. New York: McGraw-Hill.
- Einstein, Albert. 1949. "Autobiographical Notes." In *Albert Einstein: Philosopher–Scientist*, edited by Paul A. Schilpp, 2–94. Evanston, Illinois: The Library of Living Philosophers.
- . 1954. "What is the Theory of Relativity?" In *Ideas and Opinions*, 227–232. New York: Crown Publishers.
- . 1993. *Letters to Solovine*. New York: Citadel Press.
- Gupta, Hemant, and Siddharth G. Chatterjee. 2003a. "Parallel Diffusion of Moisture in Paper. Part 1: Steady–State Conditions." *Industrial & Engineering Chemistry Research* 42:6582–6592.
- . 2003b. "Parallel Diffusion of Moisture in Paper. Part 2: Transient Conditions." *Industrial & Engineering Chemistry Research* 42:6593–6600.
- Hasan, Asif, Catherine R. Peluso, Timothy S. Hull, John Fieschko, and Siddharth G. Chatterjee. 2013. "A Surface–Renewal Model of Cross–Flow Microfiltration." *Brazilian Journal of Chemical Engineering* 30:167–186.
- Hiley, Basil J. 2010. "Some Remarks on the Evolution of Bohm's Proposals for an Alternative to Standard Quantum Mechanics." http://www.bbk.ac.uk/tpru/BasilHiley/History_of_Bohm_s_QT.pdf.
- Koltuniewicz, Andrzej, and Andrzej Noworyta. 1994. "Dynamic Properties of Ultrafiltration Systems in Light of the Surface Renewal Theory." *Industrial & Engineering Chemistry Research* 33:1771–1779.
- Loffler, Daniel G., and Jose C. Merchuk. 1972. "Steady and Unsteady State Absorption with First Order Chemical Reaction in a CFSTR, Evaluated with Film–Penetration

- Model.” *Latin American Journal of Chemical Engineering and Applied Chemistry* 2:175–183.
- McWhirter, John R., Jia-Ming Chern, and Joseph C. Hutter. 1995. “Oxygen Mass Transfer Fundamentals of Surface Aerators.” *Industrial & Engineering Chemistry Research* 34:2644–2654.
- McWhirter, John R., and Joseph C. Hutter. 1989. “Improved Oxygen Mass Transfer Modeling for Diffused/Subsurface Aeration Systems.” *AIChE Journal* 35:1527–1534.
- Merchuk, Jose C. 1985. “On the Use of the Film Model for Analysis of Gas–Liquid Reactions in CSTR.” *Chemical Engineering Communications* 39:389–390.
- Mittal, Ashutosh, Tarun Kataria, Gautam K. Das, and Siddharth G. Chatterjee. 2006. “Evaporative Cooling of Water in a Small Vessel Under Varying Ambient Humidity.” *International Journal of Green Energy* 3:347–368.
- Tchobanoglous, George, and Franklin L. Burton. 1991. *Wastewater Engineering: Treatment, Disposal, and Reuse*. Third ed. Metcalf & Eddy, Inc. New York: McGraw-Hill.
- Tien, Chi. 1994. *Adsorption Calculations and Modeling*. Boston: Butterworth-Heinemann.
- van der Smaan, Ruud G. M. 2003. “Simple Model for Estimating Heat and Mass Transfer in Regular–Shaped Foods.” *Journal of Food Engineering* 60:383–390.

ABOUT THE AUTHOR

Dr. Siddharth G. Chatterjee: Dr. Chatterjee received his Bachelor’s Degree in Technology with Honors from the Indian Institute of Technology, Kharagpur, and M.S. and Ph.D. degrees from Rensselaer Polytechnic Institute, Troy, New York, all in Chemical Engineering. He has taught courses on air pollution engineering, water pollution engineering, engineering economics, engineering design, mathematical methods in chemical engineering, ordinary differential equations for engineers and scientists, partial differential equations for engineers and scientists, bioprocess plant design, air quality, thermodynamics and heat transfer, and bioprocess engineering design. He has worked in the areas of hydraulic design of tray and packed towers, hydraulic design of mist eliminators and liquid distributor, process and fluid-flow simulation, air and water pollution control, gas absorption, membrane filtration, adsorption, distillation, renewable energy, moisture transport in paper, evaporative cooling, and autohydrolysis of wood. His research interests are in the areas of philosophy of science, air and water pollution control, alternative energy, heat and mass transfer, separation processes, reaction engineering, mathematical modeling, and simulation. Besides having publications in scientific journals in the above-mentioned fields, he is the co-author of a book titled *When Worlds Unite - East meets West* (SONTA, Kolkata, India, 2012).

The Persistence of Students' Conceptions about Buoyancy in Gases

Anastasia Pantazopoulou, Hellenic Open University, Greece
Michael Skoumios, University of Aegean, Greece

Abstract: Over the last forty years, a significant part of research in science education was focused on investigating students' conceptions about science concepts. While students' conceptions of buoyancy in liquids have been widely investigated, the study of students' conceptions about buoyancy in gases was relatively limited. Investigating the evolution of students' conceptions on buoyancy during their education was never done. This study focuses on high school students' conceptions on buoyancy in gases. Specifically, it aims to investigate how the students develop conceptions about the factors that affect buoyancy in gases before and after an instruction of the topic buoyancy in the classroom. The research tool used for collecting the data was a written questionnaire answered by 213 high school students in Greece (106, 13-year and 107, 14-year-old students). The 14-year-old students were taught the concept of buoyancy and the factors affecting it while the 13-year-old students were not taught about this concept. Absolute frequencies and percentage frequencies of students' responses and justifications were calculated based on the values of χ^2 and standardised residuals- the relationship between students' conceptions about buoyancy in gases and their age. The analysis of the results allowed the identification of students' conceptions about buoyancy in gases and as well as their resistance to some conceptions. More specifically, it appears that students' conceptions about the factors that affect the buoyancy in gases do not differ significantly for the two groups of students (13-year-old and 14-year-old). The results of this study can contribute to the construction and development of instructional materials for a more effective instruction of buoyancy in gases.

Keywords: Students' Conceptions, Buoyancy, Science Education

Introduction

Extensive research works were conducted and investigated during the last forty years on students' conceptions about science concepts and phenomena (Driver, Guesne & Tiberghien, 1985; Pfundt & Duit, 2006). From these studies, it emerged that in most cases students' conceptions differ from the views of school knowledge and often resist any attempt to their modification and thus are hardly affected or reconciled by instruction (Chi, Kristensen, & Roscoe, 2012).

One of the fundamental issues in science is the problem of the forces exerted on an object floating in a liquid; in which that force is buoyancy. There are conflicting ideas or issues about buoyancy among students and in order to resolve such problems, there is a need to incorporate the topic on buoyancy in the curriculum and has to be taught in the classroom. Besides, the concept of buoyancy is applied and encountered in everyday life activities.

Research on students' conceptions about buoyancy has focused its interest mainly on the buoyancy exerted on objects floating in liquids (Alurralde & Salinas, 2006; Biddulph & Osborne, 1984; Butts, Hofman & Anderson, 1993; Dentici, Grossi, Borghi, De Ambrosis & Massara, 1984; Havu-Nuutinen, 2005; Joung, 2009; Stepan, Dyche & Beiswenger, 1988). But there is no research work yet investigating the effects of the instruction on how the students develop or evolve their conceptions about buoyancy in gases.

The evolution of students' conceptions of the factors affecting buoyancy in gases – before and after its teaching in secondary education – is the object of the present research paper.

Theoretical Framework

As children develop in their natural and social environment, they enter the educational process holding certain conceptions about the world around them instead of being “tabula rasa” (Pine, Messer & John, 2001). These conceptions are often different from scientists’ conceptions (Treagust, 1988). Some conceptions recorded by the research seem to be quite widespread among the students. Instruction does not always lead the students to adopt school knowledge. After instruction, the students may continue having both the conceptions presented by the teacher and their prior conceptions (Driver, 1982). It is also possible that the conceptions could merge. Students’ conceptions often resist any attempt to their modification and follow the students until they come of age. They are hardly affected by instruction, while learning results are usually short-lived (Driver, Guesne & Tiberghien, 1985; Kang, Scharmann & Noh, 2004; Lemmer, 2013).

The necessity for conducting research on students’ conceptions results from the three assumptions adopted by the present study. The first assumption is connected with the constructivist view of instruction, according to which knowledge is not passively absorbed but is constructed by the student (Driver, 1983; Osborne & Freyberg, 1985; Scott, 1987). Learners construct “their own meanings for the knowledge they acquire” (White & Gunstone, 1992, p. 13). The belief that students construct knowledge means that it is them who will decide on changing their conceptions. The second assumption refers to the finding that before they start their school education, students have already formed their own conceptions about science concepts and phenomena (Driver, Guesne & Tiberghien, 1985; Driver, Squires, Rushworth, & Wood-Robinson, 1994). The third assumption concerns the relationship between conceptions and instruction. Knowing students’ conceptions allows better organization of a more effective instruction (Baviskar, Hartle, & Whitney, 2009; Driver & Oldham, 1986). Learning can be promoted by assessing students’ conceptions and understanding and incorporating them in curriculum development and instruction design (Shepardson, 2002).

In other words, students’ conceptions are the onset of the learning process: “conceptions are the fundamental link the child may have with new knowledge; they are the personal model whose development we should take care of. We may not ignore them for one simple reason: if we ignore conceptions, they do not disappear – they are just inhibited” (Sanner, 1983, p. 173).

Literature Review

Extensive research has been conducted at global level, studying students’ conceptions about buoyancy in liquids and the factors affecting it. More specifically, it has been found that students believe that the buoyancy exerted on an object in a liquid depends on its mass/weight (Alurralde & Salinas, 2006; Butts, Hofman & Anderson, 1993; Dentici, Grossi, Borghi, De Ambrosis & Massara, 1984; Havu-Nuutinen, 2005). It emerges that students do not have a clear idea of the role volume plays as a factor affecting buoyancy in liquids and, therefore, some students believe that buoyancy depends on the volume of the object floating in a liquid, while others believe that buoyancy in liquids does not depend on the object’s volume (Alurralde & Salinas, 2006; Biddulph & Osborne, 1984; Butts, Hofman & Anderson, 1993; Havu-Nuutinen, 2005; Joung, 2009). A lot of students consider that the object’s density is a factor affecting the buoyancy exerted on an object floating in a liquid (Alurralde & Salinas, 2006; Dentici, Grossi, Borghi, De Ambrosis & Massara, 1984; Havu-Nuutinen, 2005; Joung, 2009; Stepan, Dyche & Beiswenger, 1988). Moreover, it has been found that students believe that the buoyancy exerted on an object floating in a liquid depends on the position of the object in the liquid (Biddulph & Osborne, 1984; Joung, 2009) and the volume of the liquid in which the object is placed (Biddulph & Osborne, 1984; Joung, 2009). As to the factors buoyancy in liquids depends on, the above research findings show that the students activate conceptions that are often different from those

incorporated in school knowledge. In particular, it emerged that the students consider that buoyancy in liquids depends on the mass/weight, density, volume and position of the object floating in the liquid as well as on the density and volume of the liquid.

Although students' conceptions about the factors affecting buoyancy in liquids have been extensively investigated, there is no research investigating students' conceptions about buoyancy exerted on an object floating in a gas. Also, there is no research studying the evolution of students' conceptions about buoyancy in gases before and after the concept is taught at school. In Greece, buoyancy is taught at high school, that is, when the students are at the age of 13.

Objective of the Study

The present study involves 13-year-old (before buoyancy is taught) and 14-year-old (after buoyancy has been taught) students, and focuses on their conceptions about the factors buoyancy in gases depends on. In particular, this paper aims to investigate the evolution of high school students' conceptions (13 and 14-year-old) about the factors affecting buoyancy exerted on an object floating in a gas depends on, both before and after buoyancy is taught in school.

Method

Overview of the Study

The present study was carried out in three stages. In the first stage, a written questionnaire was prepared in order to investigate students' conceptions about buoyancy in gases. In the second stage, the questionnaire floated to the high school students. Finally, in the third stage, was the analysis of data collected.

Buoyancy in Greece is taught in high school, when the students are 13 years old, and teachers usually follow the "traditional approach" (Skoumios & Savvaidou-Kambouropoulou, 2012). According to this method, the instruction is considered a process of transferring knowledge from the teacher to the students (Symington & Kirkwood, 1995). The teacher plays the role of a knowledge transmitter, while the students have to listen carefully to the teacher so that they can obtain the information provided. The teacher or the students confirm scientific principles by doing experiments proposed by the teacher (Ashiq, Azeem & Shakoor, 2011).

Participants

The research sample consisted of 213 male/female high school students in Greece. 106 students were the 13-year-old students and 107, were the 14-year-old. They came from schools of Thessaloniki, the second biggest city in Greece next to Athens. The 13-year-olds had not been taught buoyancy before, while the 14-year-olds had been taught the concept about one year ago. The students were born into families of various financial and social classes and they participated voluntarily.

The Questionnaire

Data collection was made through a questionnaire. There were multiple choice questions that provided the students with the opportunity to justify their responses, while the question text was accompanied by appropriate images.

The questions aimed to investigate students' conceptions about the factors affecting buoyancy in gases. The creation of the possible responses to the questions included in the questionnaire was based on research results concerning students' conceptions about buoyancy in liquids (Alurralde & Salinas, 2006; Biddulph & Osborne, 1984; Butts, Hofman & Anderson, 1993; Dentici, Grossi, Borghi, De Ambrosio & Massara, 1984; Havu-Nuutinen, 2005; Joung,

2009; Stepan, Dyché & Beiswenger, 1988). As regards to students' conceptions about the factors affecting buoyancy in liquids, the relevant bibliography showed that students associate buoyancy in liquids with the weight, the shape, the density, the length, the material, the hardness and the position of the object floating in the liquid. They also believed that buoyancy is affected by the volume of the liquid in which the object is placed, or the depth.

The questionnaire was originally distributed to ten students and a discourse was held with these students so that any comments and remarks could be obtained. In addition, the questionnaire was also given to secondary education teachers and two science education researchers. Any corrections made were based on the resulting remarks and the questionnaire took its final form.

The questionnaire included six questions. More specifically, the students were asked for predictions and justifications concerning the comparison between the buoyancy exerted on two air balloons A and B when:

- (a) they have the same volume and float in the same gas but balloon B has double the mass of balloon A (question 1),
- (b) they have the same mass and float in the same gas but B has double the volume of A (question 2),
- (c) they have the same volume and float in the same gas but are filled with gases of different density (question 3),
- (d) they have the same volume and float at the same height and in the same gas but A is placed in a lower space than B (question 4),
- (e) they have the same volume and mass and float in the same gas but A floats at a lower height than B (question 5), and
- (f) they have the same volume and float at the same height but A floats in a gas of lower density than B (question 6).

Data Collection and Analysis

Permission was asked of the high school principals to float the questionnaire. They were informed about the objectives and the content of the research after which they gave their consent or approval. In a similar manner, the students' parents also gave their consent after being informed of the objectives of the study.

The questionnaire was handed to the students during their science class and in the presence of their science teachers, the students completed answering the questionnaire for about an hour. Students' responses to the questions along with their justifications constituted the research data. A total of 1278 student responses were collected.

Then the absolute frequencies and percentage frequencies of students' responses were calculated and the relationship between students' conceptions and their age (13 and 14 years old) was determined through χ^2 test. The identification and interpretation of the correlations was based on χ^2 and standardized residual values (Blalock, 1987; Erickson & Nosanchuk, 1985).

Results

Evolution of Students' Conceptions About the Relationship Between Buoyancy and Mass/Weight of Objects With Equal Volume That Float in the Air

The comparative study of the frequencies of students' conceptions shows that the percentage of 14-year-old students who consider that an object of larger mass is subject to stronger buoyancy is higher (59.81%) than the respective percentage of 13-year-old students (29.25%) (Table 1). On the other hand, the percentage of 13-year-old students who consider that objects of different masses are subject to the same buoyancy is higher (34.91%) than the respective percentage of 14-

year old students (13.08%). Finally, there are similar percentages of 13-year-olds (29.25%) and 14-year-olds (25.23%) who consider that an object of smaller mass is subject to stronger buoyancy.

Table 1: Conceptions of 13-Year-Old and 14-Year-Old Students About the Relationship Between Buoyancy and Mass/Weight of Objects: Frequencies and Standardized Residuals (N, N% & R)

Conceptions	13-year-old students			14-year-old students		
	N	N%	R	N	N%	R
Buoyancy depends on the object's mass. The object with the smaller mass is subject to stronger buoyancy.	31.00	29.25	[+0.54]	27.00	25.23	[-0.52]
Buoyancy depends on the object's mass. The object with the larger mass is subject to stronger buoyancy.	31.00	29.25	[-2.22]	64.00	59.81	[+2.16]
Buoyancy does not depend on the object's mass. The objects are subject to equal buoyancy.	37.00	34.91	[+2.46]	14.00	13.08	[-2.39]

Furthermore, there is a statistically significant correlation between these students' conceptions and their age ($\chi^2 = 21.95$, $df = 2$, $p < 0.0001$). This correlation is due to the following tendencies of the students (see Table 1):

- (a) 14-year-old students tend to consider that an object of larger mass is subject to stronger buoyancy rather than that objects of different masses are subject to equal buoyancy.
- (b) 13-year-old students tend to consider that objects of different masses are subject to equal buoyancy rather than that an object of larger mass is subject to stronger buoyancy.

Evolution of Students' Conceptions About the Relationship Between Buoyancy and Volume of Objects With Equal Mass/Weight That Float in the Air

The data analysis shows that the percentage of 14-year-old students who consider that objects of different volume are subject to equal buoyancy is higher (40.19%) than the respective percentage of 13-year-old students (30.19%) (Table 2). On the other hand, the percentage of 13-year-old students who consider that an object with larger volume is subject to stronger buoyancy is higher (39.62%) than the respective percentage of 14-year-old students (30.84%). Finally, there are similar percentages of 14-year-olds (20.56%) and 13-year-olds (17.92%) who consider that an object of smaller volume is subject to stronger buoyancy. However, despite the above differences, it emerges that there is no statistically significant correlation between these students' conceptions and their age ($\chi^2 = 2.78$, $df = 2$, $p = 0.2491$) (Table 2).

Table 2: Conceptions of 13-year-old and 14-year-old students about the relationship between buoyancy and volume of objects: frequencies and standardized residuals (N, N% & R)

Conceptions	13-year-old students			14-year-old students		
	N	N%	R	N	N%	R
Buoyancy depends on the object's volume. The object with the smaller volume is subject to stronger buoyancy.	19.00	17.92	[-0.22]	22.00	20.56	[+0.21]
Buoyancy depends on the object's volume. The object with the larger volume is subject to stronger buoyancy.	42.00	39.62	[+0.91]	33.00	30.84	[-0.88]
Buoyancy does not depend on the object's volume. The objects are subject to equal buoyancy.	32.00	30.19	[-0.75]	43.00	40.19	[+0.73]

Evolution of Students' Conceptions About the Relationship Between Buoyancy and Density of Objects With Equal Volume That Float in the Air

Table 3 shows that there are slight differentiations between the percentages of 13-year-old and 14-year-old students with regard to the conceptions they formulate. For example, there are a higher percentage of 14-year-old students (52.34%) who consider that the object with the lower density is subject to stronger buoyancy than the respective percentage of 13-year-old students (36.79%). However, it emerges that there is no statistically significant correlation between these students' conceptions and their age ($\chi^2 = 5.8$, $df = 2$, $p=0.0550$) (Table 3).

Table 3: Conceptions of 13-Year-Old and 14-Year-Old Students About the Relationship Between Buoyancy and Density of Objects: Frequencies and Standardized Residuals (N, N% & R)

Conceptions	13-year-old students			14-year-old students		
	N	N%	R	N	N%	R
Buoyancy depends on the object's density. The object with the lower density is subject to stronger buoyancy.	39.00	36.79	[-0.88]	56.00	52.34	[+0.83]
Buoyancy depends on the object's density. The object with the higher density is subject to stronger buoyancy.	29.00	27.36	[-0.14]	34.00	31.78	[+0.13]
Buoyancy does not depend on the object's density. The objects are subject to equal buoyancy.	26.00	24.53	[+1.51]	15.00	14.02	[-1.43]

Evolution of Students' Conceptions About the Relationship Between Buoyancy and the Height of the Space in Which Objects of Equal Volume and Mass Float

With regard to 13-year-old and 14-year-old students' conceptions about the relationship between buoyancy and the height of the space in which the objects float, it emerges that there are no significant differences (Table 4).

The percentage of 14-year-old students (44.86%) who consider that the object inside a higher space is subject to stronger buoyancy is higher than the respective percentage of 13-year-old students (37.74%). However, there are a higher percentage of 13-year-old students (27.36%) who consider that, although the objects float in spaces of different height, they are subject to the same buoyancy than the respective percentage of 14-year-old students (19.63%). Also, there are a higher percentage of 13-year-old students (27.36%) who consider that although the object floats inside a space of lower height, it is subject to stronger buoyancy than the respective percentage of 14-year-old students (22.43%) that adopt the same conception.

Despite the above differences, it emerged that there is no statistically significant correlation between these students' conceptions and their age ($\chi^2 = 2.35$, $df = 2$, $p=0.3088$) (Table 4).

Table 4: Conceptions of 13-Year-Old and 14-Year-Old Students About the Relationship Between Buoyancy Exerted on Objects and the Heights of the Spaces in Which They Float: Frequencies and Standardized Residuals (N, N% & R)

Conceptions	13-year-old students			14-year-old students		
	N	N %	R	N	N%	R
Buoyancy depends on the height of the space in which the object floats. The object in a space of lower height is subject to stronger buoyancy.	29.00	27.36	[+0.35]	24.00	22.43	[-0.36]
Buoyancy depends on the height of the space in which the object floats. The object in a space of greatest height is subject to stronger buoyancy.	40.00	37.74	[-0.77]	48.00	44.86	[+0.79]
Buoyancy does not depend on the height of the space in which the object floats. The objects are subject to equal buoyancy.	29.00	27.36	[+0.66]	21.00	19.63	[-0.68]

Evolution of Students' Conceptions About the Relationship Between Buoyancy and the Height at Which Objects With the Same Volume and Mass Float in the Air

With regard to the relationship between buoyancy and the height at which the object floats in the gas, it emerged that the conception “an object floating at a greater height is subject to stronger buoyancy” is more widespread than the other conceptions (Table 5). The percentage of 13-year-old students is higher (48.11%) than the respective percentage of 14-year-old students (46.73%).

Also, the percentage of 14-year-old students who consider that an object floating at a lower height is subject to stronger buoyancy is higher (29.91%) than the respective percentage of 13-year-old students (19.81%). The idea that buoyancy exerted on two objects of equal volume in spaces of different height is the same for both objects is adopted by 16.98% of 13-year-olds and by 25.23% of 14-year-olds. However, despite the above differences, it emerges that there is no statistically significant correlation between these students' conceptions and their age ($\chi^2 = 1.77$, $df = 2$, $p=0.4127$) (Table 5).

Table 5: Conceptions of 13-Year-Old and 14-Year-Old Students About the Relationship Between Buoyancy and the Height at Which the Objects Float in the Air: Frequencies and Standardized Residuals (N, N% & R)

Conceptions	13-year-old students			14-year-old students		
	N	N%	R	N	N%	R
Buoyancy depends on the height at which the object floats in the gas. An object floating at a lower height is subject to stronger buoyancy.	21.00	19.81	[-0.82]	32.00	29.91	[+0.78]
Buoyancy depends on the height at which the object floats in the gas. An object floating at a greater height is subject to stronger buoyancy.	51.00	48.11	[+0.46]	50.00	46.73	[-0.43]
Buoyancy does not depend on the height at which the object floats. The objects are subject to equal buoyancy.	18.00	16.98	[+0.23]	18.00	16.82	[-0.22]

Evolution of Students' Conceptions About the Relationship Between Buoyancy and Density of Gases in Which Objects With Equal Volume Float

Table 6 shows that almost half the students consider that the object floating in the gas with the higher density is subject to stronger buoyancy (45.28% for 13-year-olds and 46.73% for 14-year-olds), while the percentage of the students who consider that buoyancy is lower in the case of an object floating in the gas with the lower density is lower (27.36% for 13-year-olds and 30.84% for 14-year-olds).

Table 6: Conceptions of 13-Year-Old and 14-Year-Old Students About the Relationship Between Buoyancy Exerted on Objects and Density of the Gases in Which the Objects Float: Frequencies and Standardized Residuals (N, N% & R)

Conceptions	13-year-old students			14-year-old students		
	N	N%	R	N	N%	R
Buoyancy depends on gas density. The object in the gas with the lower density is subject to stronger buoyancy.	29.00	27.36	[-0.03]	33.00	30.84	[+0.03]
Buoyancy depends on gas density. The object in the gas with the higher density is subject to stronger buoyancy.	48.00	45.28	[+0.28]	50.00	46.73	[-0.26]
Buoyancy does not depend on gas density. The objects are subject to equal buoyancy.	11.00	10.38	[-0.48]	16.00	14.95	[+0.45]

There are fewer students who consider that the density of the gas in which the objects float does not affect buoyancy and, as a result, the objects are subject to the same buoyancy (10.38% for 13-year-olds and 14.95% for 14-year-olds). In addition, it emerges that there is no statistically significant correlation between these students' conceptions and their age ($\chi^2 = 0.58$, $df = 2$, $p = 0.7483$) (Table 6).

Conclusions and Discussion

Students' conceptions about the factors affecting buoyancy in gases and the evolution of these conceptions have not been systematically investigated yet. The present paper aimed to investigate the evolution of high school students' conceptions about the factors affecting the buoyancy exerted on an object floating in a gas. The research was carried out with the help of a written questionnaire, which was completed by 213 high school students (106 13-year-olds and 107 14-year-olds). The 14-year-old students had been taught the concept of buoyancy and the factors affecting it, while the 13-year-old students had not been taught the concept before.

The data analysis allowed the identification of students' conceptions about the factors buoyancy in gases depends on. These factors include the mass/weight, the volume and the density of the object, the height of the space in which the object floats, the density of the gas as well as the position in which the object floats in the gas.

Students' conceptions of the factors affecting buoyancy in gases depends on can be attributed to some general characteristics of students' mode of thinking, the limited focus and the undifferentiated concepts (Driver, Guesne & Tiberghien, 1985). Students tend to pay attention to and take into account only some aspects of the situations they study, ignoring others (Driver, Guesne & Tiberghien, 1985). As regards buoyancy in gases, it is possible that the students focus exclusively on characteristics of either the object or the gas and consider that buoyancy depends on these characteristics. Moreover, students usually hold undifferentiated concepts which have different meanings according to scientific knowledge (Driver, Guesne & Tiberghien, 1985; Smith, Carey & Wiser, 1985). What is more, the students do not necessarily realize the transition that takes place from one meaning to another. Thus, the students that do not distinguish among the concepts of volume, mass, density, weight and buoyancy express conceptions maintaining that if two objects have the same volume/weight/mass/density, they will be subject to the same

buoyancy exerted by the gas, while if they have a different volume/weight/mass/density, they will be subject to different buoyancy.

Furthermore, it emerged that conceptions linking buoyancy with the volume and the density of the object, the height and the density of the gas as well as with the position in which the object floats in the gas do not change significantly in the case of 13 and 14-year-old students. That means that students' conceptions do not differ before and after the instruction of buoyancy. There was a statistically significant correlation between students' conceptions about the relationship of buoyancy and the mass/weight of objects and their age. In particular, 14-year-old students tended to consider that the object with the larger mass is subject to greater buoyancy, while 13-year-old students tended to consider that objects with different mass are subject to the same buoyancy. In other words, there was a differentiation in these conceptions, though not in the direction of school knowledge.

The above finding about the resistance of students' conceptions about the factors affecting buoyancy in gases is in line with the results of other research studies, which show that students' conceptions about science concepts are described by resistance (Giordan & Vecchi, 1990; Brown, 1992; Gunstone, Gray & Searle, 1992; Mestre & Touger, 1989; Skoumios & Hatzinikita, 2005; 2006). Resistance is a general characteristic of students' conceptions, while the conceptual change, whenever it occurs, is a slow and long-lasting process (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985; Thornton & Sokoloff, 1998).

The findings of this paper prove that a "traditional instruction" (in which knowledge is transferred from the teacher to the students) of buoyancy does not affect students' conceptions. Consequently, there emerges a need for changing the way buoyancy is taught. An instructional approach that could contribute to the modification of students' conceptions about science concepts and phenomena is the constructivist approach. According to this approach, learning is an active process in which the students construct new knowledge of natural phenomena through an interaction of their prior conceptions with the educational environment (Phillips, 2000; Widolo, Duit & Muller, 2002). Teachers should identify learners' current conceptions and then facilitate the learners to construct their own knowledge based on these (Kerr, Beggs & Murphy, 2006). One constructivist teaching model is the "Constructivist-Instruction-Model", proposed by Driver and Oldham (1986). The "Constructivist-Instruction-Model" dictates that at first students' conceptions should be emphasized and the students should realize the disagreements among them (elicitation stage). Then comes the stage of reconstructing the above conceptions whereas the students are encouraged to check their conceptions in order to modify or replace them (construction of new conceptions stage). They are also asked to implement their new knowledge and correlate it with experiences from everyday life (application of conceptions stage). Finally, the students compare the new with the prior knowledge (prior conceptions) and realize the process through which the new knowledge was obtained (review stage). There are several constructivist-inspired teaching models (Driver & Oldham 1986; Hewson & Hewson, 1984; Hondson, 1985; Posner et al, 1982; Yager, 1991). In all of them we can find the view of science learning as a conceptual change in three basic steps: (a) an elicitation phase of pupils' conceptions, making them conscious of the plausibility and fruitfulness of those conceptions, (b) a restructuring phase, creating cognitive conflict, generating pupils' dissatisfaction with their current conceptions and preparing them for the introduction of scientific conceptions and (c) an application phase which gives opportunities for using the new conceptions in different contexts and consolidating them.

In the present paper the limited sample restricts the research and its results. In addition, data collection in this study was made through a questionnaire. The use of an interview or the use of a questionnaire together with an interview could possibly contribute to a thorough investigation of students' conceptions about buoyancy in gases (Tsai, 2003).

Despite the above restrictions, this paper makes a positive contribution to the research on students' conceptions because it studies the evolution of students' conceptions about the factors

affecting buoyancy in gases depends on – an issue that lacked research data. The results of this paper can contribute to both supporting research activities and designing teaching material for the instruction of buoyancy in gases.

Students' conceptions do not exist isolated from the context in which they appear (Schultz, Säljö & Wyndhamn, 2001) or they consist of pieces of knowledge that are combined in response to contextual features of the particular situation (diSessa, 1993; diSessa & Sherin, 1998; Hammer, 2000). Thus, students often use different conceptions in order to interpret situations considered equivalent according to scientific knowledge (Driver, Guesne & Tiberghien, 1985; Skoumios & Hatzinikita, 2004). However, the present study did not investigate the dependence of students' conceptions about buoyancy on factors of the context. Further research is required so that any factors of the context affecting the conceptions about buoyancy the students activate can be identified.

The constructivist-inspired teaching models could form the basis for designing teaching material on buoyancy that will take into account students' conceptions, as they emerged in this study. Further research is required so that the teaching material that will be accumulated could be implemented in the students and its learning results could be evaluated.

REFERENCES

- Alurralde, Estela and Julia Salinas. 2006. "A Methodology to Study Students' Explanatory Models for Buoyant Force: Spiraled Explanatory Inquiry and Hypotheses Testing." Proceedings of the GIREP Conference "Modeling in Physics and Physics Education". Amsterdam, Netherlands, 222-226.
- Ashiq Hussain, Muhammad Azeem, Azra Shakoor. 2011. "Physics teaching methods: scientific inquiry vs traditional lecture." *International Journal of Humanities and Social Science* 1(19): 269-276.
- Baviskar, Sandhya, Todd Hartle and Tiffany Whitney. 2009. "Essential criteria to characterize constructivist teaching: derived from a review of the literature and applied to five constructivist-teaching method articles." *International Journal of Science Education*, 31(4): 541-550.
- Biddulph Fred and Roger Osborne. 1984. "Pupils' ideas about floating and sinking." *Research in Science Education* 14: 114-124.
- Blalock, Hubert M. 1987. *Social statistics*. Singapore: McGraw-Hill.
- Butts David, Helenmarie Hofmann and Margaret Anderson. 1993. "Is hands-on experience enough? A study of young children's views of sinking and floating objects." *Journal of Elementary Science education* 5(1): 50-64.
- Brown, David E. 1992. "Using examples and analogies to remediate misconceptions in physics: factors influencing conceptual change." *Journal of Research in Science Teaching* 29(1): 17-34.
- Chi Michelene T. H., Agnieszka Kosminska Kristensen and Rod Roscoe. 2012. Misunderstanding emergent causal mechanism in natural selection. In K. Rosengren, S. Brem, & G. Sinatra (Eds.), *Evolution Challenges: Integrating Research and Practice in Teaching and Learning about Evolution* (pp. 145-173). Oxford University Press.
- Dentici Ornella, Marcello Grossi, Luca Borghi, Anna De Ambrosis, Carla Massara. 1984. "Understanding floating: A study of children aged between six and eight years." *European Journal of Science Education* 6(3), 235-243.
- diSessa, Andrea. 1993. "Toward an epistemology of physics." *Cognition & Instruction* 10: 105-225.
- diSessa, Andrea and Bruce Sherin. 1998. "What changes in conceptual change?" *International Journal of Science Education* 20: 1155-1191.
- Driver, Rosalind. 1983. *The Pupil as Scientist?* Milton Keynes, Open University Press.
- Driver, Rosalind. 1982. "Children's Learning in Science." *Educational Analysis* 4: 69-79.
- Driver Rosalind, Edith Guesne and Andree Tiberghien (Eds). 1985. *Children's Ideas in Science*, Milton Keynes, UK: Open University Press.
- Driver Rosalind, Ann Squires, Peter Rushworth and Valerie Wood-Robinson. 1994. *Making sense of secondary science: research into children's idea*. London, RoutledgeFalmer.
- Driver, Rosalind and Valerie Oldham. 1986. "A constructivist approach to curriculum development." *Studies in Science Education* 13: 105-122.
- Erickson, Bonnie, and Terry Nosanchuk. 1985. *Understanding data*. Milton Keynes: Open University Press.
- Giordan, André and Gérard de Vecchi. 1987. *Les origines du savoir, Des conceptions des apprenants aux concepts scientifiques*. Neuchâtel: Delachaux et Niestlé Delachaux.
- Gunstone, Richard F., Robin C. M Gray and Peter Searle. 1992. "Some long-term effects of uniformed conceptual change." *Science Education* 76(2): 175-197.
- Hammer, David. 2000. "Student resources for learning introductory physics." *American Journal of Physics* 68: 52-59.

- Havu-Nuutinen, Sari. 2005. "Examining young children's conceptual change process in floating and sinking from a social constructivist perspective." *International Journal of Science Education* 27(3): 259-279.
- Hewson, Peter and Mariana Hewson. 1984. "The Role of Conceptual Conflict in Conceptual Change and the Design on Science Instruction," *Instructional Science*, 13(1): 1-13.
- Hodson, Derek. 1985. "Philosophy of science, science and science education." *Studies in Science Education* 12: 25-57.
- Joung, Yong Jae. 2009. "Children's typically perceived situations of floating and sinking." *International Journal of science education* 31(1): 101-127.
- Kang Sukjin, Lawrence Scharmann and Taehee Noh. 2004. "Reexamining the role of cognitive conflict in science learning", *Research in Science Education*, 34: 71-96.
- Kerr Karen, Jim Beggs and Colette Murphy. 2006. "Comparing children's and student teachers' ideas about science concepts." *Irish Educational Studies* 25(3): 289-302.
- Lemmer, Miriam. 2013. "Nature, Cause and Effect of Students' Intuitive Conceptions Regarding Changes in Velocity." *International Journal of Science Education* 35(2): 239-261.
- Mestre, Jose, and Jerold Touger. 1989. "Cognitive research. What's in it for physics teachers?" *The Physics Teacher* 27(6): 447-456.
- Osborne, Roger, and Peter Freyberg. 1985. *Learning in Science: The implications of Children's Science*. London: Heinemann.
- Pfundt, Helga and Reinders Duit. 2006. *Bibliography - Students alternative frameworks and science education*. University of Kiel, Institute for Science Education, Kiel, Germany.
- Phillips, Denis Charles. 2000. *Constructivism in education*. Chicago, IL: University of Chicago Press.
- Pine, Karen, David Messer and Kate John. 2001. "Children's misconceptions in primary science: A survey of teachers' views." *Research in Science & Technological Education* 19(1): 79-96.
- Posner George, Kenneth Strike, Peter Hewson and William Gertzog. 1982. "Accommodation of a scientific conception: Toward a theory of conceptual change". *Science Education*, 66(2): 211-227.
- Sanner, Michel. 1983. *Du concept au fantasme*, PUF, Paris.
- Schultz Jan, Roger Saljo and Jan Wyndhamn. 2001. "Heavenly talk: Discourse, artifacts, and children's understanding of elementary astronomy." *Human Development* 44: 103-118.
- Scott, Phil. 1987. *A Constructivist View of Teaching and Learning*. Leeds, Children's Learning in Science Project, University of Leeds.
- Shepardson, Dan. 2002. "Bugs, butterflies, and spiders: children's understandings about insects." *International Journal of Science Education* 24(6): 627-643.
- Skoumios, Michael and Vassilia Hatzinikita, 2004. Dealing with obstacles regarding heat and temperature. In: D. Koliopoulos, & A. Vavouraki (Eds), *Science education at cross roads: meeting the challenges of the 21st century'* (p. 107-118). Athens: Science Education Association.
- Skoumios Michael and Vassilia Hatzinikita. 2005. "The role of cognitive conflict in science concept learning." *The International Journal of Learning* 12(7): 185-193.
- Skoumios Michail and Vassilia Hatzinikita. 2006. "Research-based teaching about science at the upper-primary school level" *The International Journal of Learning* 13 (5): 29-42.
- Skoumios, Michael. and Maria Savvaidou-Kambouropoulou, 2012. "Investigating Pupils' Images of Science Teaching Using Drawings." *The International Journal of Science in Society*, 3(2): 179-192.
- Smith Carol, Susan Carey and Marianne Wiser. 1985. "On differentiation: A case study of the development of the concepts of size, weight, and density". *Cognition*, 21(3): 177-237.

- Stepans Joseph, Steven Dyche and Ronald Beiswenger. 1988. "The effect of two instructional models in bringing about o conceptual change in the understanding of science concepts by prospective elementary teachers." *Science Education* 72 (2): 185-195.
- Symington, David and Valda Kirkwood. 1995. "Science in the Primary School Classroom". In B. Hand & V. Prain (Eds.) *Teaching and learning in science: the constructivist classroom*. Sydney: Harcourt Brace, 193-210.
- Thornton, Ronald and David Sokoloff. 1998. "Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curricula." *American Journal of Physics* 66(4): 338-343.
- Treagust David. 1988. "Development and use of diagnostic tests to evaluate students' misconceptions in science." *International Journal of Science Education* 10: 159-169.
- Tsai, Chin-Chung. 2003. "Taiwanese Science Students' and Teachers' Perceptions of the Laboratory Learning Environments: Exploring Epistemological Gaps." *International Journal of Science Education*, 25(7): 847-860.
- White, Rihard and Rihard Gunstone. 1992. *Probing understanding*. London, Falmer Press.
- Widodo Ari, Reinders Duit and Christoph Muller. 2002. "Constructivist views of teaching and learning in practice: Teachers' views and classroom behaviour." Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, New Orleans.
- Yager, Robert. 1991. "The constructivist learning model: Towards real reform in science education." *The Science Teacher*, 58(6): 53-57.

ABOUT THE AUTHORS

Anastasia Pantazopoulou: Anastasia Pantazopoulou obtained a first degree in Physics from the University of Crete in 1991 and a Master in Education from the Hellenic Open University in 2012. Her research interests include science concept learning and teaching science in primary and secondary schools. She is currently giving physics lessons to students of secondary schools.

Dr. Michael Skoumios: Michael Skoumios obtained a first degree in Physics from the National and Kapodistrian University of Athens in 1987, a second degree in Education from the University of Aegean in 1992 and his PhD in Science Education from the Hellenic Open University in 2005. His research interests include science concept learning and teaching science in primary and secondary schools. He is currently teaching Science Education in the Department of Primary Education of the University of the Aegean (Greece).

Talk to Me—Biometrically Adaptive Consumer Packaging: The Effects of Emotion Relative to a Consumer’s Purchasing Decisions

Daniel E. Hutcherson, Clemson University, USA
R. Andrew Hurley, Clemson University, USA
Shaundra B. Daily, Clemson University, USA
Andrew D. Ouzts, Clemson University, USA

Abstract: Alternative methods of packaging evaluation are researched to represent the interactions held between a consumer and product packaging in retail environments. Biometrics are used as a means to document visual and physical attention during experiments of adaptive packaging. An experiment is designed as a pilot test to precede future costly production runs of predestined design failures. Newly prototyped packages are created as design stimuli and tested within a scripted environment. An intersection between the contrasting fields of art and science are merged to distinguish the production and future evolution of packaging design. Descriptive patterns are examined from biometric data visualizations to confirm that a person’s emotions have an effect on one’s purchasing decisions. An increase in visual attention and descriptive physiological reactions describe the effects of the packaging—similar to a conversation held between two people. Strategies are discussed to enhance the design of consumer packaging in response to real-time consumer reactions. After strategically analyzing one’s behavior, a population of packages in different retail environments can globally adapt to meet a consumer’s needs. Packaging designers are provided with a process to rely on consumer-justified designs rather than merely designer-justified decision making. In order to increase market success in packaging, “Talk to Me,” starts the conversation on a personal and individual level between consumers and packaging design.

Keywords: Packaging Design, Biometrics, Eye Tracking, Consumer Emotions, Retail Environments

Introduction

A history of marketing reflects the directive that emotion leads to action. Indeed, studies have shown that 95% of thinking is unconsciously realized in brief phasic events where consumers make (Blakeslee 2004, 10) purchasing decisions based on emotion rather than rational thought (Ciprian-Marcel et al. 2004, 804; Lindstrom 2010, 3). As a result, the design and development of most products in the marketplace attempt to utilize a person’s emotional triggers (Pawle and Cooper 2006, 39; Thaler et al. 2009, 1-39). For designers, however, there is no shared view on how to record, systemize, and reproduce the process of a successful design based on these triggers in a range of advertising including packaging design. Researchers have, instead, largely relied on focus group sessions as a means of self-report measures to gain valuable insight into consumer perception in packaging designs (Folch-Lyon and Trost 1981, 444; Zaccai 2012). Self-report measures are not a reliable source of consumer feedback because it is difficult for consumers to express their emotional reactions (Valentino-DeVires 2010; Zaccai 2012). Focus groups facilitate conscious decision-making, opposite to the real-life, unconscious decisions made in the shopping environment. Consequently, the consumer’s unconscious experience is instantly falsified and misinterpreted (Sukhvinder 2011, 162). With the majority of thinking being unconsciously realized, how is it that researchers can rely on the conscious efforts of focus groups (Ciprian-Marcel et al. 2004, 804)? Traditional methods of research in packaging must be updated to accurately measure a consumer’s emotion in reaction to packaging designs.

A biometric device, for example, is a recording machine that documents forms of physiological responses. The use of eye tracking in packaging design is now common; however,

additional devices and their acceptable methodologies have not been established in packaging design (Hurley 2011; Tonkin 2011). Researchers in the fields of marketing agree that emotions should be investigated with biometric devices; however, an acceptable and realistic methodology must be found (Chamberlain and Broderick 2007, 199; Stewart 1982, 29-33). Liao provides a beginning foundation for physiological research in measuring emotional responses from packaging beyond eye tracking (Liao 2012). Liao's study looks at reaction times in relation to package aesthetics. Here, uncomfortable biometric measures were used (fMRI) and the experiment was not conducted in a realistic shopping environment, necessary to provide consumers with a series of choices (Reimann et al. 2010, 439-440). Van der Lann et al. provide further research using fMRI where they use the data to aid consumers in making healthy purchase decisions. While previous research places biometric research in a positive light, our paper provides alternative devices (eye tracking and EDA) to reduce research costs and increase the immersive shopping quality of the study participant (Van der Lann et al. 2012, 5-10).

Background

Packaging Design

Packaging has been named the silent "salesman on the shelf" that sells products in a competitive environment (Rettie and Brewer 2000, 56). Successful package designs look to strike the emotion necessary to lead the consumer into making a quick decision (Silayoi and Speece 2004, 607). The overall creativity and design of the package should strike an emotional appeal with the consumer to persuade someone into making a purchase decision (Rundh 2009, 988). Packaging designers aim to employ shapes and graphics in packaging designs to be emotionally appealing and compatible with a certain brand (Raghubir and Greenleaf 2006, 95). Anthropomorphization, attributing human form to things non-human, is a technique that some designers and marketing professionals rely on to provide a close connection between the humanized consumer and the desirable product (Landwehr et al. 2011, 132). Design factors in packaging are researched to gain consumer praise. These types of factors involved in the design process include the following: shape or form, size, orientation (up or down), alignment (left or right), color, color combinations, and imagery (Westerman et al. 2013, 8). Specific to packaging design, vivid and attractive imagery is the most positive influence towards a successful packaging design (Silayoi and Speece 2004, 607). The packaging designs that appear in this study are based solely on the graphic design of the package. An attempt to isolate this design variable is executed in order to build a methodology towards measuring consumer behavior with packaging stimuli. Eye tracking and electrodermal activity are two biometric tools that are investigated to understand possible applications towards packaging design evaluation.

Eye Tracking

Eye tracking is a useful technique in recording what consumers look at when shopping. Focusing on the consumer's field of view allows researchers to see where attention is diverted, forming descriptive regions of interest. Eye trackers can record the geographic location of fixations on a retail shelf in consumer studies. Head mounted, mobile eye tracking glasses, such as the Tobii glasses (figure 5), provide a lightweight and unobtrusive means of monitoring eye movements (Duchowski 2007, 87; Chandon 2002, 3). Packaging studies reveal how longer fixation times correlate to increased sales or higher purchasing decisions (Hurley et al. 2012, 1). Eye tracking is useful in documenting the geographic locations of eye movements, however, eye tracking does not reveal the emotional valence of the fixations (Duchowski 2007, 208-211).

Electrodermal Activity (EDA)

Balanced activity within the sympathetic and parasympathetic divisions of the autonomic nervous system supports the regulation of physiological states of arousal. The parasympathetic nervous system (PNS) and sympathetic nervous system (SNS) are often compared to the brakes and gas of a car respectively; helping "rest and digest" versus "fight and flight" activities. While the PNS dilates blood vessels leading to the digestive tract, stimulates salivary glands, and constricts the bronchioles of the lungs, the SNS prepares the body to act on changing environmental conditions by accelerating heart rate, constricting blood vessels, and raising blood pressure. When SNS activity increases, sympathetic fibers that surround eccrine sweat glands modulate the production of sweat. The skin, in turn, momentarily becomes a better conductor of electricity (i.e., electrodermal activity). This electrodermal activity can be measured as conductance (skin conductance) or resistance by different sensors.

There are limitations of EDA as a measure of emotion. First, EDA is capable of detecting changes in levels of arousal in a participant; however, the valence of the arousal is not distinguished. In other words, EDA alone cannot describe the positive/negative quality of an experience. Additional methods are needed to supplement the EDA recording such as other physiological measures or post experiment surveys and interviews (Picard and Daily 2005). Next, response time in EDA is a complexity when comparing multiple participants and the data must be normalized. Researchers estimate that a person can experience a lag time in response to a stimulus of approximately 1-5 seconds (Latulipe et al. 2011, 1851). Finally, a wide distribution of responses in EDA data could be related to differences in sweat gland distribution across types or skin sudomotor innervation (Poh et al. 2010, 1249). This study will use EDA to annotate arousal levels within the consumer.

Hypotheses

Three hypotheses have been constructed to frame the validity of EDA and eye-tracking as biometric tools in consumer shopping tests, used to gather responses to package designs.

1. Visible peaks in electrodermal activity will be produced when consumers experience the emotionally designed packaging stimuli.
2. An increase in electrodermal activity can be related to higher purchase intent when the consumer terms the arousal as positive.
3. Eye tracking will reveal higher fixation counts per the negative packaging stimulus.

Methods and Materials

Participants

There were a total of 18 undergraduate participants (11 male and 7 female), ages 18-29 years (mean 21.9 years, median 22 years). Survey data confirmed that none of the participants suffered from glaucoma, cataracts, or any other eye impairments.

Stimulus

Cereal boxes were chosen as the type of packaging stimuli due to the large surface area available for advertising graphics. Three different packaging stimuli were fabricated for the EDA experiment: Negative (figure 1A), Positive (figure 1B), and Neutral (figure 1C).



Figure 1: Negative (A), Positive (B), and Neutral (C) Stimuli

The following keywords were used to design the positive package: sustainable, all-natural, sunshine, happy, healthy, recycled, smiling, green, yellow, and blue. The positive package used graphic design elements that appeared to be happy and healthy while the negative package implemented contrasting graphics. Keywords including: hazardous, warning, tetrachloroethane, harmful, dangerous, and the color black, were used to influence the negative package’s design. A 5-point Likert scale (negative, neutral, positive) was used in the post-experiment survey to rate the design keywords. In addition to surveying the study participants (n=18), a larger online survey (n=126) was conducted to understand the perceived valence of the packaging stimuli. This online study utilized the Self-Assessment Manikin (S.A.M.) as a self-reporting measure of emotion. The S.A.M. utilizes a scale of graphic manikins in place of words to allow a participant to universally describe an emotion (Bradley and Lang 1994, 49). These self-report measures were recorded to validate the packaging designer’s design decisions and to describe the valence of any emotional responses recorded through EDA.

Apparatus

Two biometric devices were used to record participants’ interactions within the shopping environment. An Affectiva Q-Sensor Curve was the unit used to measure electrodermal activity (figure 2A). Two electrodes are located on the inner face of the device, which come in contact with the skin. The Q-Sensor was set to sample at 32 Hz.



Figure 2: Affectiva Q-Sensor Curve (A), Tobii Mobile Eye Tracking Glasses (B)

Source: Will Keown, <http://willkeown.com/>

The second biometric recording device used in the EDA experiment was a mobile eye-tracker, the head-mounted Tobii Glasses (figure 2B). These glasses resemble ordinary glasses, however they are monocular, only sampling from the right eye. A handheld recording assistant and shelf markers record the participant’s eye movements. The sampling rate for the Tobii glasses is set at 30 Hz.

Experimental Design

The experiment was conducted in a realistic shopping environment, named CUshop™ (figure 3). The cereal was located on a full 16ft shelving section across from the produce section (figure 4). Signs above each aisle directed the participants to the different products within the store.

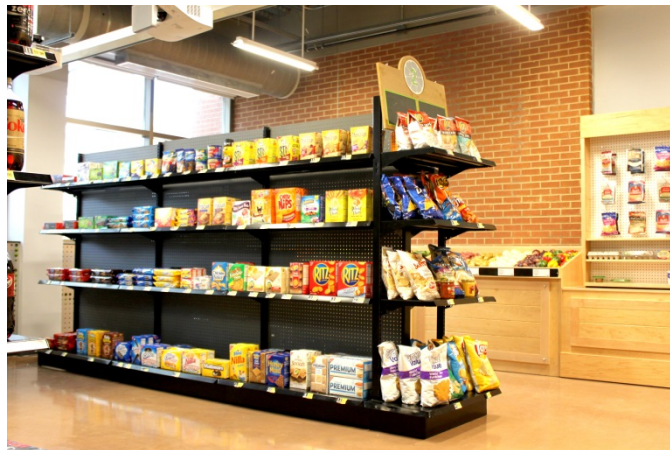


Figure 3: CUshop™, a realistic shopping environment



Figure 4: Positive Stimulus in Neutral Context

The participants were divided into four separate groups (figure 5). Each of the groups was exposed to one of the packaging stimuli (Negative, Positive, or Neutral). The first three groups experienced the packaging stimuli in an isolated cereal aisle where all of the surrounding boxes were white with simple brand name labels. The labels were all printed in the same size and color: black, Helvetica typeface (figures 1C and 4). The packaging stimuli were then placed in the direct center of the aisle at eye-level. The last group experienced something slightly different; the negative packaging stimuli were used within a modified context. Real, store-bought cereal packages replaced the white, surrounding boxes to create a more realistic cereal aisle (figure 5B). The negative package was chosen as the stimuli for this last group of participants because of its unnatural and highly contrasting design. If the negative package design would not be able to obtain an emotional response, recorded on the Q-Sensor, then it would be hard to hypothesize a standard package emoting a response at all. A Witmer-Singer presence questionnaire was implemented in the post-experiment survey to understand if interaction within the environment was realistic to the participants. The questionnaire provided nine questions, arranged into the following sections (examples follow): involvement, immersion, sensory fidelity, and interface quality.

- Involvement: How completely were you able to actively survey or search the environment using vision?
- Immersion: Did you feel that CUshop was a realistic shopping experience?
- Sensory Fidelity: How much did your experiences in the environment seem consistent with your real world experiences?
- Interface Quality: How much did the control devices (wrist sensors and glasses) interfere with the performance of assigned tasks or with other activities?



Figure 5: Negative Stimulus in Neutral Context (A), Negative Stimulus in Realistic Context (B), Positive Stimulus in Neutral Context (C), Neutral Stimulus in Neutral Context (D)

Procedure

1—EDA Calibration

Each participant was first calibrated to the Q-Sensor (figure 2A), in order to build an appropriate moisture barrier between the skin and the electrodes. Two sensors were used, one on each wrist.

First, the participant was asked to sit in a sterile environment (a small conference room) and listen to 5 minutes of calming classical music. After 5 minutes, the experiment proctor would return and ask the participant to blow up a large balloon, until it nearly pops. This would force an increase in arousal consequently forcing the EDA reading on the sensor to spike. After the balloon exercise, the participant was left alone to listen to an additional 5 minutes of calming music. This allowed the subject to return to a baseline recording. The combination of relaxing music and blowing up a balloon would help establish a minimum (baseline) and maximum skin conductance level for each participant as well as allow time for moisture to build up on the participant's skin.

2—Eye Tracking Calibration

Following calibration of the Q-sensor, the participant was asked to stand 1m away from a wall, where he/she was calibrated to the Tobii eye-tracking glasses (figure 2B). The glasses calibration is a simple process where the participant wears the glasses and follows, with their eyes, the location of an infrared marker along the surface of the wall. Once the glasses were successfully calibrated, the participant was asked to press the Q-Sensor button in front of their right eye. This was completed to log an instance on the eye tracking video and a marker on the Q-Sensor data, needed for post experiment data synchronization. This concluded the calibration of the two biometric devices to the participant.

3—Shopping Task

Following successful calibration, the participant was provided a shopping list of 5 items on a clipboard and asked to “shop as you normally would shop.” The five items were placed around the grocery store and appeared on the shopping list in the following order: (1) laundry detergent, (2) cookies, (3) cereal, (4) pasta, and (5) toilet paper. The subject would then be allowed to enter the CUshop™ shopping environment to complete the experimental task.

4—Post Experiment Survey

After completion of the shopping task, the participant was asked to remove the glasses and remain wearing the wrist sensors. A survey followed including four main segments: (1) basic demographic information, (2) a self-report extended response question, (3) a 5-point Likert scale on design elements (extremely negative-extremely positive), and (4) a modified Witmer Singer Presence Questionnaire. A self-report question (open response) started by prompting the participant to press their Q-Sensor button. This was asked to mark an instance in the EDA data denoting the point at which the participant consciously reported their feelings towards the packaging stimuli. The question provided an image of the packaging stimuli previously viewed in CUshop™. The participant was asked to write in 2-3 sentences on how they felt emotionally towards the package. This survey question was paired with EDA to see if there was a change in arousal while consciously thinking about the stimulus. A 5-point Likert scale also asked them to rate the emotional quality of the design (extremely negative-extremely positive). A modified Witmer-Singer Presence Questionnaire was inserted into the survey to see how realistic the consumer felt when shopping around the cereal aisle, which at some times appeared uncommon with the selection of neutral white packages (Witmer and Singer 1998, 225-238).

5—Post Experiment Interview

After completion of the survey, the participant was asked to participate in a quick, 5-minute interview on their personal EDA data. The EDA data and eye-tracking video were quickly synchronized for immediate play back to the participant. Peaks on the EDA timeline were noted

in the Q-Sensor software as well as the Tobii Studio software. A video playback of the experience was shown to the consumer, starting one minute before and after each peak. The participant was asked to respond with personal thoughts in relation to each video clip. This interview data was used to confirm any emotional reactions to the packaging stimuli or the experimental design.

Dependent Measures

Eye Tracking Metrics

Eye tracking metrics were studied to correlate the geographic location of the eyes to a participant’s arousal levels. The eye tracking data was needed to confirm fixation on the package stimuli being studied. First fixation and last fixation on the packaging stimuli was recorded. Measures analyzed were Time to First Fixation (TFF), Total Fixation Duration (TFD), and Fixation Count (FC).

Electrodermal Activity Measures

The electrodermal activity of the participants was used to illustrate the arousal levels of the participant throughout the study. Peaks (Skin Conductance Responses, SCR) were located using software provided by the manufacturer of the Q Sensor called, Affectiva Q Analytics. The software analyzed the EDA outputs (μS , microSiemens) of each participant, using peak detection to report the time, height (EDA), and duration of any abrupt increases in the skin’s conductance (figure 6).

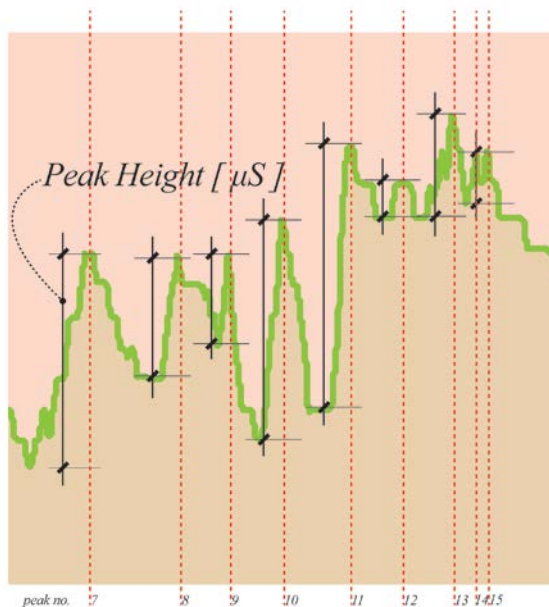


Figure 6: EDA peak height (μS , microSiemens)

An EDA arousal ratio is calculated per stimuli. The following equation is used based on a person’s range of extraneous individual differences. The individual’s EDA can be expressed as a

proportion of their individualized range. This calculation normalizes the EDA data from person to person (Dawson 2007, 159-181):

$$EDA \text{ arousal ratio} = \frac{(EDA_{peak} - EDA_{min})}{(EDA_{max} - EDA_{min})}$$

EDA_{peak} = EDA recording at the peak's maximum

EDA_{min} = overall personal minimum EDA recording

EDA_{max} = overall personal maximum EDA recording

This is a measure of arousal calculated by viewing the peaks within a +5 seconds interval from the first and last fixations of the stimuli (figure 7). This number does not describe the valence of the arousal, whether positive or negative. The emotional reactions were confirmed with post-experiment interviews.

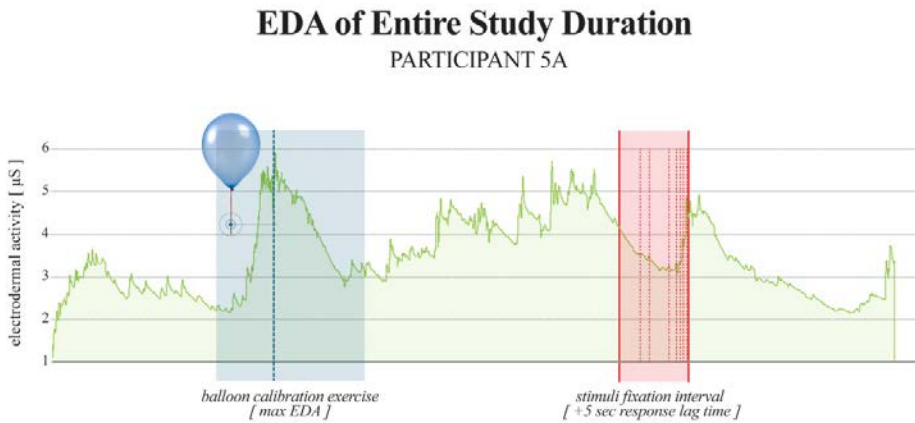


Figure 7: EDA Example Recording, Full Experiment Duration

EDA peaks, or skin conductance responses (SCRs), are measured as abrupt increases in the conductance of the skin. Characteristic of SCRs are faster rise times than decay times.

Results and Discussion

Due to the small sample size of the EDA study (n=18) the variances of the means were very large. The results will be presented in an exploratory nature. It is recommended that future studies involve larger sample sizes.

Three self-report measures were used to evaluate the experimental design and to document the valence of the packaging stimuli. It is complicated to research EDA within consumer studies because of the difficulty found when isolating variables within a realistic environment. The experimental set-up is likely to suffer when variables are isolated, causing an unrealistic perception of the shopping scene. The results to the Witmer-Singer Presence Questionnaire

report high involvement, immersion, sensory fidelity, and interface quality with no significant difference between the groups (figure 8). It is interesting to note how participant presence decreases in most categories during the “neutral” stimulus, the most unrealistic retail construct. No experimental area appears to show significance; therefore we cannot report a decrease in reported presence, even though it may appear that way. Otherwise, as scores appear above the half-mark, the conclusion can be made that the participants were generally immersed in the shopping environment. This helps in interpreting the validity of the eye tracking and EDA data.

EDA Witmer-Singer Presence Survey

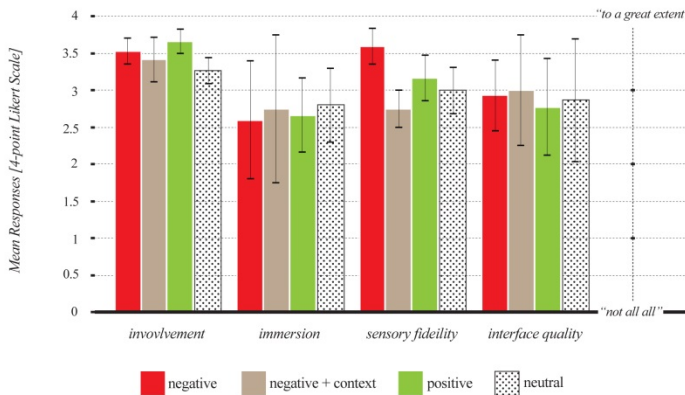


Figure 8: Witmer-Singer Presence Survey Results

The participant’s perceived valence of the packaging stimuli was also evaluated (part 4 of the procedure), confirming the emotional associations towards the design keywords (figure 9) and the packaging stimuli (figure 10). Each of the three package designs is closely located near their respective area on the scale. The valence of 17 design keywords was surveyed to confirm the design decisions used to create the emotional packaging (figure 9). In addition to surveying the immediate study participants, a large online S.A.M. survey reported significant findings ($p < 0.01$), supporting the packaging designer’s claims. The positive package was rated as being happier and more pleasant, while the negative package was rated as being sad and more depressing (figure 11).

Valence of Stimuli Design Keywords

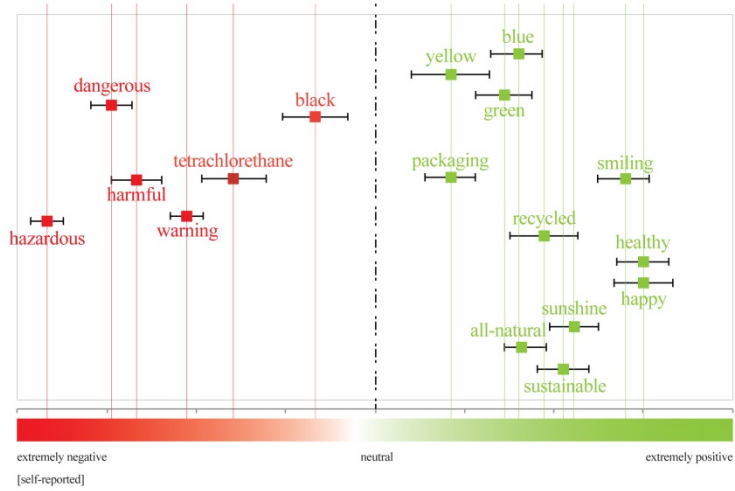


Figure 9: Reported Valence of Design Keywords

Valence of Package Stimuli

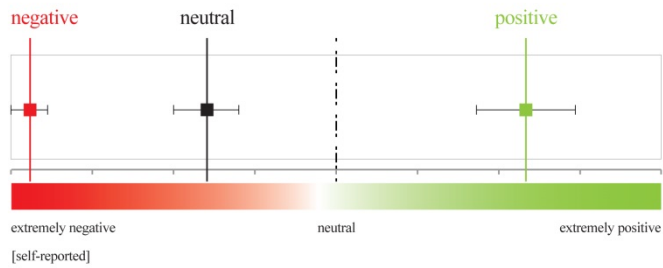


Figure 10: Reported Valence of Package Stimuli

S.A.M. Self-Report Valence of Individual Stimuli

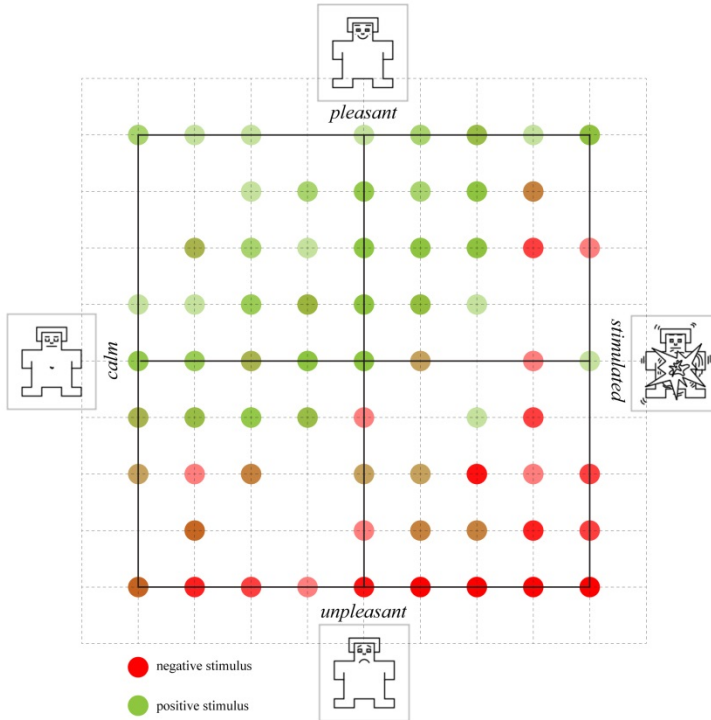


Figure 11: Self-Assessment Manikin Survey of Positive and Negative Stimuli

Three eye-tracking metrics were analyzed with the packaging stimuli outlined as an AOI (Area of Interest): Time to First Fixation, Total Fixation Duration, and Fixation Count. The eye tracking metric most likely to provide significance would be the Fixation Count of the “negative + context” package stimulus (figures 12-13). The “negative + context” package design, in this stimuli layout, did not loudly contrast with its surroundings as did the other stimuli layouts. An increase in fixations could suggest an increase in EDA or increase in mean peak height per stimulus. Total Fixation Duration (figure 14), in addition to Fixation Count (figure 12), represent the emotional power of the “negative” package design. At the critical time of the purchase decision, the negative package (both in neutral and realistic contexts) was the result of increased visual attention, confirming the third hypothesis. This could be attributed to confusion and surprise towards the odd claims found on the “negative” design.

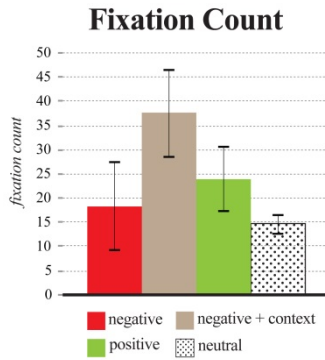


Figure 12: Fixation Count

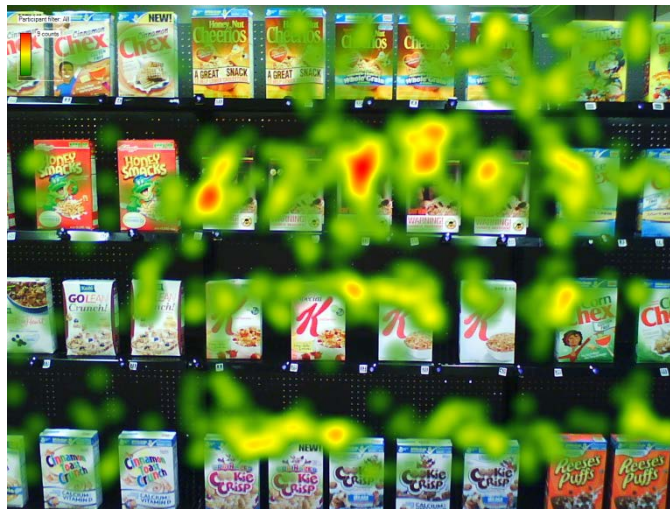


Figure 13: Aggregate Heat Map, Negative in Context

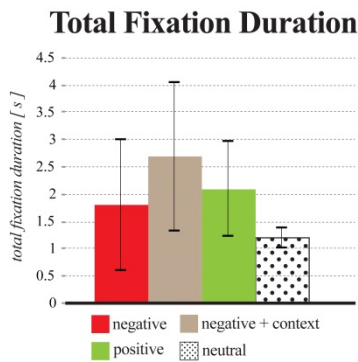


Figure 14: Total Fixation Duration

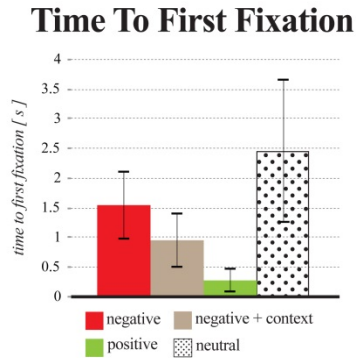


Figure 15: Time to First Fixation

The additional eye tracking metric of Time to First Fixation (figure 15) represents the importance of positive packaging design. The “positive” package was the first design to grab the visual attention of the consumer. Conversely, the “neutral” design, the package with the least amount of design influence, was discovered last among the shelf. The extreme increase in TTFF with the neutral package supports the importance of packaging design. Consumer shopping lists of the study provided interesting reactions where the “positive” design was the only package stimulus to be purchased (2 purchased, n=5). Aggregate heat maps (figures 16-18) illustrate the importance of emotional design influence in packaging. The red “hot” areas envelope the packaging stimuli, the only packages with designed graphics. Conclusions can already be made with eye tracking and self-reporting as to the importance of emotion in design at the moment of purchase. However, in order for the degree and accuracy of this emotional influence to be measured, EDA techniques should be implemented.

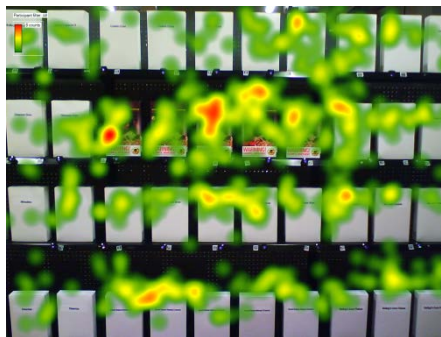


Figure 16: Negative

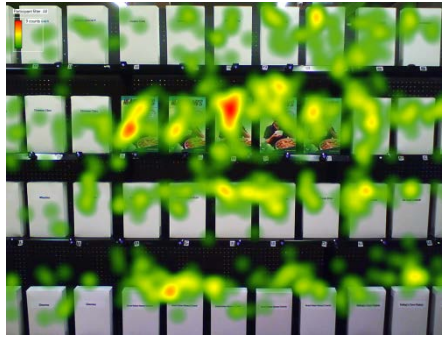


Figure 17: Positive

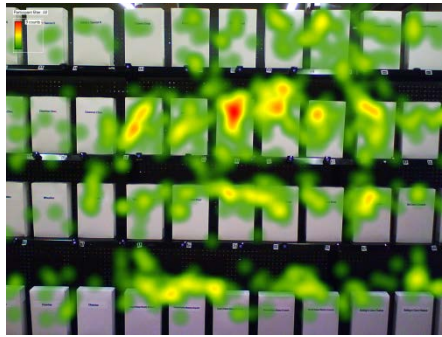


Figure 18: Neutral

Peaks per Stimulus Interval

[all participants]

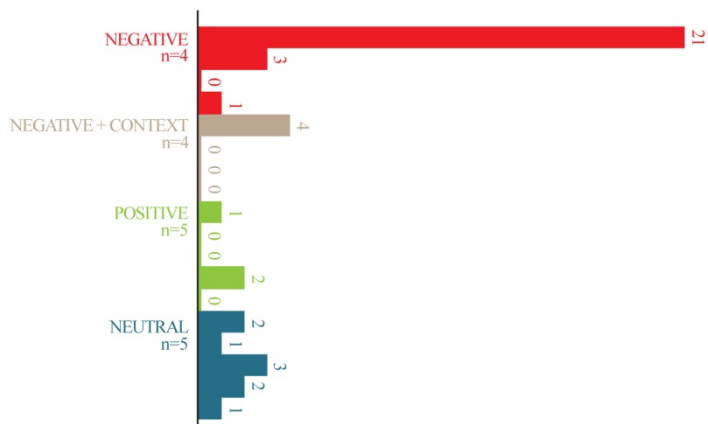


Figure 19: Peaks per Stimulus Interval (experiences of each participant)

The above chart represents the peaks per stimulus interval experienced by the participants, all of which are represented by a horizontal bar (figure 19). Through viewing the different experiences by each participant, it is evident that there is no obvious pattern developed in peaks per stimulus. The variances between the different stimulus groups are very large, showing an unpredictable pattern. The peaks per participant experienced during the neutral group is the most surprising, this is the only group where all of the participants experienced at least one peak. The neutral group is the only stimulus group highlighting a physiological response from each of the neutral stimulus participants. This could be evidence to suggest that the experimental layout of many white, neutral boxes caused a higher arousal than the positive and negative packaging stimuli. From this we can learn that experimental layout is highly important in recording EDA measurements.

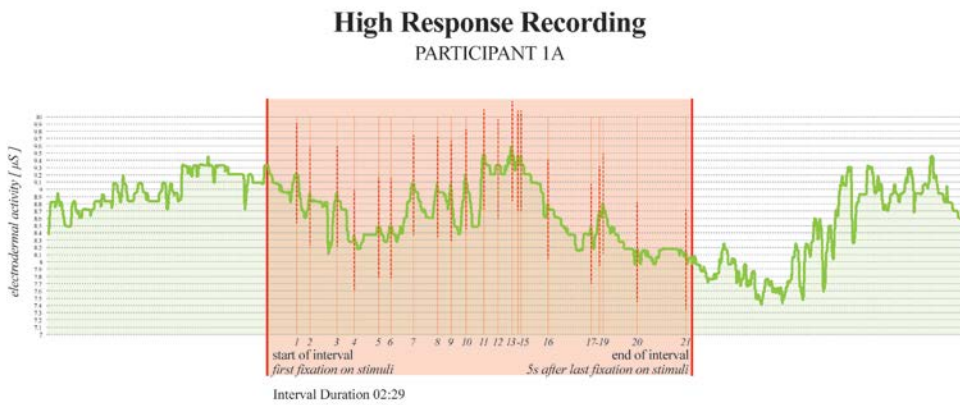


Figure 20: High Response EDA Example

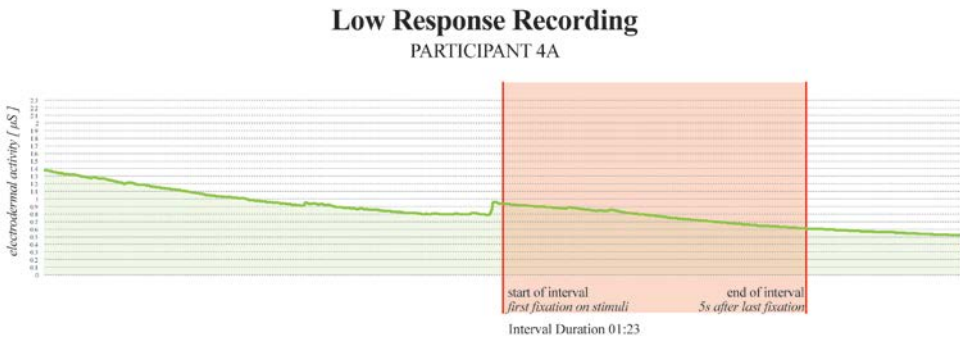


Figure 21: Low Response EDA Example

Figure 7 provides an example of a participant’s EDA throughout the entire experimental procedure (parts 1-4). Figures 20 and 21 represent the variability of the EDA recordings experienced across different participants (both participants experienced the same stimuli, the negative package design). Participant 1A is an illustrated example of a participant, whose EDA reading is highly active. Participant 1A experienced a total of 21 peaks, the largest out of the entire study. To an opposite effect, participant 4A showed a very low response in EDA. During the interval of stimulus viewing time, this participant experienced absolutely no peaks, and

relatively few throughout the entire duration of the study. In addition to differences in body types, the variability of EDA responses could be attributable to the person’s general arousal levels and personal character. Personal character by the definition of introversion and extroversion can also be linked to a person’s EDA levels where some have very stable EDA (Bullock and Gilliland 1993, 113).

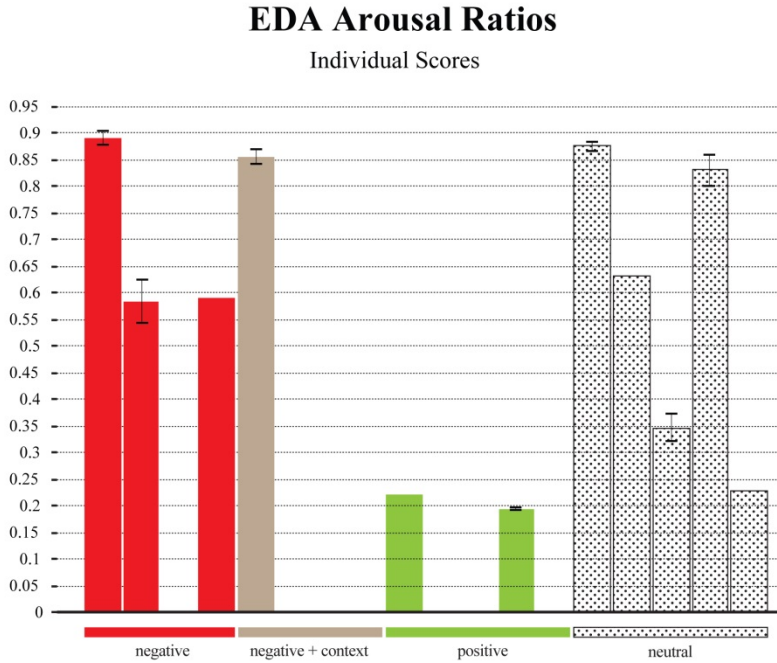


Figure 22: Mean EDA Arousal Ratios (Experiences of Each Participant)

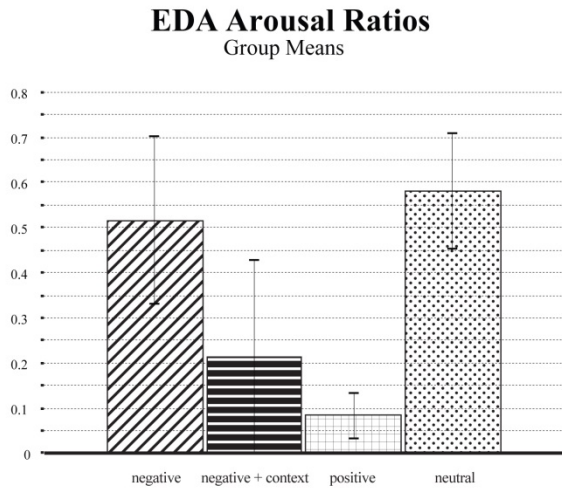


Figure 23: Mean EDA Arousal Ratios per Stimulus

EDA Arousal Ratios

Group Means

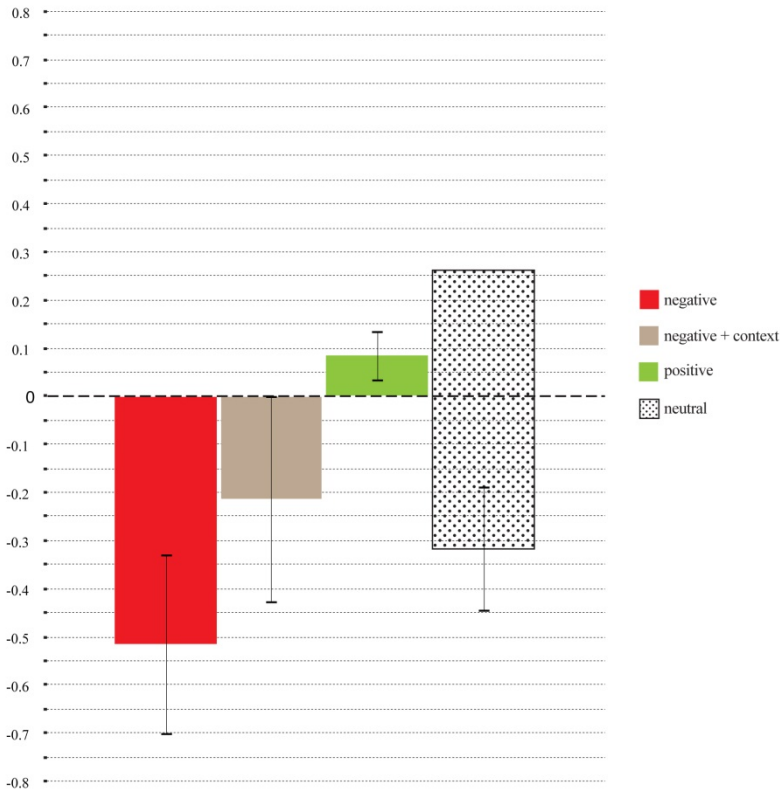


Figure 24: Mean EDA Arousal Ratios with Valence

Careful calculations of the interval size for each participant was recorded to highlight the peaks experienced per interval. Some of the EDA peaks could have resulted from anticipatory or congratulatory emotions experienced by the participant before or after completing a task. This can be seen with almost every participant at the conclusion of each study where large peaks frame the end of the shopping task. Peak interpretation can sometimes be difficult and time intensive because post-experiment interviews and questionnaires are necessary to clarify the meaning behind peaks. The video provided from the eye tracking glasses is helpful in aiding participants recall the experience.

Figures 22-24 are used to show the EDA arousal ratios calculated per stimulus. Figure 22 illustrates the individual EDA ratios per person, while also highlighting the variability of peaks experienced per person. Figure 23 summarizes the EDA ratios through the group means of each stimulus. In other words, figure 23 shows the degree of arousal experienced per stimulus. To combine the efforts of figures 9-11 and 23, figure 24 is drawn to show the degree and valence of the arousal experienced with each stimulus. With the combined data, this last graph represents the emotional reaction towards the contrasting packaging designs. As hypothesized (hypothesis 2) an increase in EDA when the arousal is termed positive results in higher purchase intent. The negative package shows the largest increase in EDA, confirming the assumptions that a negative design will cause the largest arousal among the consumer—due to its strange and alarming

uniqueness. The neutral design is found floating in the middle between negative and positive. As found through the EDA, eye tracking, and self-report measures, a successful design can be found in the positive y range of figure 24. In other words, consumers are more likely to purchase positively designed packages (hypothesis 2) where negative packages are the most alarming and eye-catching (hypotheses 1 and 3).

To clarify the valence of the reaction to the stimuli, electroencephalography (EEG), would be beneficial with EDA used as paired biometric devices. Through studying left and right hemisphere dominance of the brain it is possible to add arousal degree and valence factors to the previously used EDA measures (Davidson and Tomarkin 1989, 419).

Eye tracking metrics provide sufficient evidence to support the claim that package design plays a large role in emoting consumer reaction and increasing purchase intent. In eye tracking, the negative package was significant in increasing total fixation count over all packages due to its highly negative emotions. The neutral package has a significant difference in time to first fixation when compared against the positive package design. Positive designs (and designed packages alone) gain the consumers visual attention the quickest (TTFF). EDA and self-report measures represent the degree of arousal and high purchase intent of positive package designs. EDA and self-report measures also show high negative arousal to negative package designs with no purchase intent. The consumer's purchase intent was recorded during the simple shopping task where each participant was able to "purchase" the stimuli presented (positive, negative, or neutral) or a competing package design. While some chose to purchase the positive stimuli, none of the participants purchased the negative stimuli. Data from this study provide sufficient evidence that biometric devices are useful in measuring emotion in packaging design studies. Through measuring and understanding emotion in consumer purchasing decisions, designers can start to apply strategies to create an increasingly transparent design process. The methodology of this study is provided as a foundation for a new direction in the design process. Previous research combining packaging and biometrics has not revealed a less opaque design process. Strategies similar to those in this study must be implemented such as: using a realistic retail environment, combining multiple measures (eye tracking, EDA, and EEG), and data acquisition safety checks (post experimental video interviews and Witmer-Singer Presence Questionnaires). By using these realistic settings and interviewing the participant, interpreters of the data can confidently report the findings of the consumer studies. A future in biometric research will provide closer connections to consumers as evidenced through their physiological responses, a recordable influence of resulting purchasing decisions.

To further validate this model of physiological research in packaging design, several areas are being planned for future experimentation. The following variables are advised for future studies: increased sample sizes, varying product categories, varying design elements (e.g., shape, color, and size), and the implementation of additional biometric devices (e.g., EEG, fMRI, and facial EMG).

Conclusion

Through studying physiological means, designers are provided with more accurate methods of measuring consumer emotional response to designs when compared to self-report measures. Increased use of biometric devices and realistic experimental settings in the design process will help designers employ a transparent design process and strategy. Eye tracking provides valuable eye movement metrics that explain the location and duration of a fixation. Electrodermal activity is a sensitive measure of arousal within a consumer. Self-report measures such as interviews and/or surveys are required to describe the valence of EDA reactions to stimuli. The mobility of these devices, paired with a realistic retail setting enable researchers to collect definite data. By listening to the quiet conversations that consumers have with packaging, we can better understand how people make decisions affecting their health and well-being. This study of our

daily interactions inside the shopping environment brings light to the audibly tacit, but visually loud conversations that consumers have with packaging. Eye tracking and electrodermal activity are two noninvasive biometric devices that can document what draws attention, causing emotion to lead to action.

As the quality of these devices rapidly advance, it would be beneficial to add biometric sensors into the real shopping environment to allow packages to globally adapt in real time to consumer reactions. A process of alteration could occur in real time in front of the shopper, highlighting and encouraging discourse between the consumer and the product. *Tesco's* virtual grocery shopping advertisements are close predictors of a future where consumers can shop in front of biometrically adaptive packaging (Simpson 2012). This example not only represents technology's place in the packaging design process but also in our society as a facilitator between humans and the products that enable us to live our lives.

The exploratory results in this study combine accurate, physiological measures of eye tracking and electrodermal activity with self-report measures (a checking device) to provide a process by which to measure emotion in the consumer. This emotional reaction is occurring during the critical instance of the purchasing decision where emotion is the key to action, not conscious and rational thought. With a better understanding of measuring consumer emotion, designers are provided with a process by which to design better interactions for people. With a powerful understanding of emotion shown here, designers can help target the claims that draw consumer emotional engagement. Theorized dangers such as "the buy button," in the brain have been criticized by neuromarketing journalists in the wake of physiological research in advertising (Witchalls 2004, 50). While a better understanding of a consumer's emotion could result in a negative direction, safeguards should be implemented to encourage designers to use these tools for the benefit of humankind. While we cannot expect consumers to make rational decisions in the retail environment, we [designers] can help people make healthy emotional decisions. With the knowledge of a consumer's physiological responses we can be inspired to provide people with positive influences at the point of purchase. This quick time interval, but large influence, will be brought to the home to positively drive a more healthy and happy lifestyle. The merging of this scientific field in packaging design represents the major influence of packaging within our society.

Acknowledgements

Special thanks are extended to Harris A. Smith and the *Sonoco Institute of Packaging Design + Graphics* for providing exceptional facilities to prototype and analyze packaging.

REFERENCES

- Blakeslee, Sandra. 2004. "Is There a 'Buy Button' in the Brain?" *International Herald Tribune* 10.
- Boucsein, W., and G. Hoffmann. 1979. "A Direct Comparison of the Skin Conductance and Skin Resistance Methods." *Psychophysiology* 16: 66-70.
- Bradley, M. and P. J. Lang. 1994. "Measuring Emotion: The Self-Assessment Manikin and the Semantic Differential." *Journal of Behavior and Experimental Psychiatry* 25: 49-54.
- Bullock, Wesley A. and Kirby Gilliland. 1993. "Eysenck's Arousal Theory of Introversion Extraversion: A Converging Measures Investigation." *Journal of Personality and Social Psychology* 64: 113-123.
- Chamberlain, Laura and Amanda J. Broderick. 2007. "The Application of Physiological Observation Methods to Emotion Research." *Qualitative Market Research: An International Journal* 10: 199-216.
- Chandon, P. 2002. "Do We Know What We Look At? An Eye-Tracking Study of Visual Attention and Memory for Brands at the Point of Purchase." *Insead* 1: 2-41.
- Ciprian-Marcel, Pop, Radomir Lâcrâmioara, Maniu Andreea Ioana, and Zaharie Monica Maria. 2004. "Neuromarketing-Getting Inside the Customer's Mind." *Journal of Economic Literature* 1: 804-807.
- Critchley, H. D. 2002. "Electrodermal Responses: What Happens in the Brain." *Neuroscientist* 8: 132-142.
- Davidson, Richard J., and Andrew J. Tomarken. 1989. "Laterality and Emotion: An Electrophysiological Approach." *Handbook of Neuropsychology* 3: 419-441.
- Dawson, Michael E., Anne M. Schell, and Dianne L. Filion. 1990. "The Electrodermal System." In *Principles of Psychophysiology: Physical, Social, and Inferential Elements*, edited by John T. Cacioppo and Louis G. Tassinari, 159-181. Cambridge: Cambridge University Press.
- Duchowski, Andrew T. 2007. *Eye Tracking Methodology: Theory and Practice*. London: Springer.
- Folch-Lyon, Evelyn, and John F. Trost. 1981. "Conducting Focus Group Sessions." *Studies in Family Planning* 12: 443-449.
- Girling, Rob. 2012. "21st Century Design: Shaping Behavior for Preferable Outcomes." *Artefact* 1: 1-12.
- Hurley, Rupert Andrew. 2011. "Persuasive Packaging: An Eye-Tracking Approach to Design." PhD diss., Clemson University.
- Hurley, R. A., Galvarino, J., Thackston, E., Ouzts, A., and Pham, A. 2012. "The Effect of Modifying Structure to Display Product Versus Graphical Representation on Packaging." *Packaging Technology and Science* 10: 1-8. Accessed November 1, 2012. doi: 10.1002.
- Liao, Lewis. 2012. "Can Packaging Elements Elicit Consumers' Emotional Responses?" Paper presented at the annual meeting for the European Marketing Academy, Lisbon, Portugal, May 22-25.
- Landwehr, J., A. McGill, and A. Herrman. 2011. "It's Got the Look: The Effect of Friendly and Aggressive 'Facial' Expressions on Product Liking and Sales." *Journal of Marketing* 75: 132-146.
- Latulipe, Celine, Erin A. Carroll, and Danielle Lottridge. 2011. "Love, Hate, Arousal and Engagement: Exploring Audience Responses to Performing Arts." Paper presented at Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Vancouver, BC, Canada, May 7-12.
- Lindstrom, Martin. 2010. *Buyology: Truth and Lies about Why We Buy*. New York: Broadway Books.

- Pawle, J., and P. Cooper. 2006. "Measuring Emotion: Lovemarks, the Future Beyond Brands." *Journal of Advertising Research* 46: 38-48.
- Picard, R. W., and S. B. Daily. 2005. "Evaluating Affective Interactions: Alternatives to Asking What Users Feel." Paper presented at CHI Workshop on Evaluating Affective Interfaces: Innovative Approaches, Portland, Oregon, USA, April 2-7.
- Poh, Ming-Zher, Nicholas C. Swenson, and Rosalind W. Picard. 2010. "A Wearable Sensor for Unobtrusive, Long-Term Assessment of Electrodermal Activity." *Transactions on Biomedical Engineering* 57: 1243-1252.
- Raghubir, P. and E. Greenleaf. 2006. "Ratios in Proportion: What Should the Shape of the Package Be?" *Journal of Marketing* 70: 95-107.
- Reimann, Martin, Judith Zaichkowsky, Carolin Neuhaus, Thomas Bender, and Bernd Weber. 2010. "Aesthetic Package Design: A Behavioral, Neural, and Psychological Investigation." *Journal of Consumer Psychology* 20: 431-441.
- Rettie, R. and C. Brewer. 2000. "The Verbal and Visual Components of Package Design." *Journal of Product & Brand Management* 9: 56-70.
- Rundh, B. 2009. "Packaging Design: Creating Competitive Advantage with Product Packaging." *British Food Journal* 111: 988-1002.
- Silayoi, P. and M. Speece. 2004. "Packaging and Purchase Decisions: An Exploratory Study on the Impact of Involvement Level and Time Pressure." *British Food Journal* 106: 607-628.
- Simpson, Emma. 2012. "Tesco Try Out Virtual Grocery Shopping at Gatwick Airport." BBC News, August 6. Accessed September 12, 2012. <http://www.bbc.co.uk/news/technology-19148154>.
- Stewart, David W., David H. Furse. 1982. "Applying Psychophysiological Measures to Marketing and Advertising Research Problems." *Current Issues and Research in Advertising* 5: 1-38.
- Sukhvinder, Obhi. 2011. "Book Review." Review of *The Buying Brain: Secrets to Selling to the Unconscious Mind*, by A.K. Pradeep. *Journal of Consumer Marketing* 28:162-164.
- Thaler, Richard H., and Cass R. Sustein. 2009. *Nudge: Improving Decisions about Health, Wealth, and Happiness*. New York: Penguin Group.
- Tonkin, Charles. 2011. "CUshop: A Simulated Shopping Environment Fostering Consumer-Centric Packaging Design & Testing." PhD diss., Clemson University.
- Valentino DeVries, Jennifer. 2010. "MIT Researchers Read Consumers' Faces to Make a Better Taste Test." *The Wall Street Journal*, January 19. Accessed August 20, 2012. <http://blogs.wsj.com/digits/2010/01/19/mit-researchers-read-consumers-faces-to-make-a-better-taste-test/>.
- Van der Laan, Laura N., Denis T. D. De Ridder, Max A. Viergever, Paul A. M. Smeets. 2012. "Appearance Matters: Neural Correlates of Food Choice and Packaging Aesthetics." *PLoS ONE* 7: 1-11. Accessed December 17, 2012. doi: 10.1371/journal.pone.0041738.
- Westerman, S. J., E. Sutherland, P. Gardner, N. Baig, C. Critchley, C. Hickey, and S. Mehigan. 2013. "The Design of Consumer Packaging: Effects of Manipulations of Shape, Orientation, and Alignment of Graphical Forms on Consumers' Assessments." *Food Quality and Preference* 27: 8-17.
- Witchalls, Clint. 2004. "Pushing the Buy Button: Companies Are Starting to Turn to Powerful Brain-Scan Technology in Order to Figure Out How We Choose Which Products to Purchase." *Newsweek* 1: 50.
- Witmer, B.G., and M.J. Singer. 1998. "Measuring Presence in Virtual Environments: A Presence Questionnaire." *Presence-Teleoperators and Virtual Environments* 7: 225-240.
- Zaccai, Gianfranco. 2012. "Why Focus Groups Kill Innovation, From the Designer Behind Swiffer." *Fast Co. Design*. Fast Company, October 18. Accessed November 1, 2012.

<http://www.fastcodesign.com/1671033/why-focus-groups-kill-innovation-from-the-designer-behind-swiffer>.

ABOUT THE AUTHORS

Daniel E. Hutcherson: Daniel Hutcherson is an architectural designer at tvsdesign and has just recently completed a M.S. in Packaging Science at Clemson University. His research merges the fields of packaging and architecture to better understand the connection between design and people's happiness. As the 2011-2013 Harris A. Smith Fellow at the Sonoco Institute of Packaging Design and Graphics, Hutcherson's M.S. research focused on measuring consumer arousal within the shopping environment. Hutcherson studied under the direction of Dr. R. Andrew Hurley to design and fabricate an internationally recognized consumer experience lab named CUshop, where studies integrated eye tracking, electrodermal activity, and electroencephalography. Hutcherson looks forward to applying to PhD programs in hopes to further study how we interact with architectural and packaging systems.

Dr. R. Andrew Hurley: Andrew Hurley is an assistant professor of Packaging Science as well as a research associate at the Sonoco Institute of Packaging Design and Graphics at Clemson University. His M.S. focused on transport and distribution methods in the packaging supply chain and Ph.D. focused on optimizing the packaging design and development process along with an eye-tracking integration. His research and teaching interests include entrepreneurial development and support efforts, eye tracking, consumer experience and research in design optimization and aesthetics. Andrew joined the College of Agriculture, Forestry and Life Sciences in 2008 and is currently teaching in the department of Food, Nutrition and Packaging Sciences. He is a noted research leader in the field of packaging design, having a variety of peer-reviewed papers, author of seven electronic training programs used by hundreds of industry professionals and has presented at international conferences. Andrew was the first faculty member at the Sonoco Institute and aided in developing and maintaining many of its laboratories at Clemson University, and teaches three regular courses on packaging design methods attracting students from a variety of disciplines across campus.

Dr. Shaundra B. Daily: Shaundra Daily is an Assistant Professor in the School of Computing at Clemson University. She received her doctorate from the Massachusetts Institute of Technology where her doctoral work involved designing and implementing technology-infused collaborative learning environments. Prior to her doctoral studies, she received a B.S. and M.S. in Electrical Engineering from the Florida Agricultural and Mechanical University - Florida State University College of Engineering as well as a S.M. from the Massachusetts Institute of Technology. Currently, her group is designing and implementing a system to support teachers in understanding classroom engagement from a physiological perspective. Dr. Daily has authored/co-authored articles in the field of affective computing as well as the learning sciences in venues such as American Education Research Association and Conference on Human Computer Interaction.

Andrew D. Ouzts: Andrew Ouzts is a computer analyst at Dynetics, Inc., having recently received a M.S. in Computer Science at Clemson University, where he studied eye tracking algorithms. Ouzts has been involved with eye tracking research since 2008 and has published a variety of papers on his eye tracking research and its applications. As a research assistant at the Sonoco Institute of Packaging Design and Graphics at Clemson University, Ouzts worked in a multidisciplinary environment collaborating with professionals in industry and other academics in the fields of packaging science, graphics, and computer science.

Promoting Environmental Justice through University-Community Research Collaborations: The Case Study of Farm Worker Communities in Oxnard, California

Haco Hoang, California Lutheran University, USA
Grady Hanrahan, California Lutheran University, USA
Kaitlyn Noli, University of California, Santa Barbara, USA

Abstract: The focus of this study is to demonstrate how university-community research collaborations can lead to enhancement of civic discourse and action on health issues in environmental justice communities. We developed a seasonal water, soil and urine sampling/monitoring approach to assess pesticide risk and exposure in agricultural communities, thereby establishing an empirical baseline to examine potential health effects. Data from community surveys and content analysis of Spanish radio facilitated the identification of resources, structures and processes that could inform and engage the public. Monitoring results showed that pesticide exposure is related to direct contact in agricultural fields or secondary exposure by family members residing in the same household, depending on the amount of accumulation on clothes and skin. Findings also revealed the importance of enhancing the civic capacity of low-income and minority populations to promote healthy, sustainable communities. How can affected stakeholders build the capacity to promote environmental justice in their communities?

Keywords: Environmental Justice, Civic Engagement, Low-income Populations, Minorities

Introduction

Studies indicate that “urban areas, where a large percentage of racial minorities reside, are prone to have higher levels of ambient pollution due to heavy traffic...(and) poorer communities are more likely than affluent communities to be located close to environmental hazards such as landfills, medical waste incinerators, diesel bus depots and Superfund sites” (Bullard et al.; 2000; Gwynn and Thurston 2001; Bevc et al. 2007; Van Roosbroeck et al. 2008). In 1994 President Bill Clinton issued Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*. The directive calls for the “the collection of data on low-income and minority populations who may be disproportionately at risk...(and) it also encourages participation of the affected communities in the various phases of assessing impact” (Clinton 1994).

Government resources like The National Environmental Justice Advisory Council (NEJAC) provide counsel and recommendations about expansive issues related to environmental justice, from all stakeholders involved in the environmental justice discourse. Moreover, the NEJAC provides a much needed forum for discussions about integrating environmental justice with other EPA priorities (NEJAC 2002). Despite this support, environmental justice efforts are undercut because they are often based on weak empirical assessments like proximity to locally unwanted land uses (LULUs) rather than actual measurements of risk and exposure to pollution (Bowen and Wells 2002). Therefore, it is essential for environmental justice communities—those at higher risk for disease and stressed by poverty, unemployment, and inadequate access to health care—to produce or utilize empirical data that can be integrated into civic engagement strategies. Not surprisingly, environmental justice communities often lack the technical expertise to produce or the resources to acquire empirical data to support their environmental health concerns.

The purpose of this article is to explain how university-community research collaborations can help affected populations promote environmental justice in their communities. Funded by a two-year grant from the California Wellness Foundation, researchers from California Lutheran

University established relationships with key stakeholders in Oxnard, a large agricultural community in California, to do the following:

- Measure environmental pollution and exposure in potentially impacted communities;
- Assess barriers to civic engagement faced by stakeholders in environmental justice communities; and
- Provide recommendations for enhancing the civic capacity of environmental justice communities.

The empirical data generated by the collaboration were used to help populations identify environmental health concerns, and empower them to advocate for healthy, sustainable communities.

Oxnard is a significant case study because the majority of the population consists of Latinos (73.5%) with higher poverty rates and lower median income levels, English language proficiency and educational attainment compared to the rest of Ventura County (U.S. Census Bureau 2010). The California Institute of Rural Studies estimates that there are “25,000 farm workers, another 25,000 family members and many other farm workers concentrated in Oxnard and in the surrounding farm worker towns” (Schroeder et al. 2003). In addition, three times as many Oxnard residents work in occupations related to farming, fishing and forestry compared to the rest of Ventura County (U.S. Census Bureau, 2010). Further, Ventura County used nearly 5.8 million pounds of pesticides in 2009, ranking eighth in the state for pesticide use (California Department of Pesticide Regulation 2010). Given the aforementioned statistics, Oxnard farm workers, their families and other residents are potentially exposed to environmental pollution from the agricultural industry and may also lack access to environmental health information due to their limited education levels and low socioeconomic status.

Background

When marginalized populations suffer from environmental injustice, they can encounter three obstacles: monitoring the impact of environmental pollution/exposure, overcoming barriers to civic engagement, and building the capacity to influence decision-making. By partnering with organizations that have established trusting relationships with farm workers, we were able to identify study participants and gain access to a community that can be cautious about collaborating with university researchers.

Measuring Environmental Pollution and Exposure

The targeted populations for this study are farm workers, their families and other residents in Oxnard, Ventura County. Given their exposure to the agricultural industry and its byproducts, it is important for Oxnard community members to have an understanding of how pollution from farming affects their health and well-being. According to the National Resources Defense Council, 88% of agricultural workers in the United States are Latinos, and most reside in Western states including California. Given their regular exposure to pesticides and other chemicals, farm workers and their families are at greater risk for lymphoma, prostate cancer, childhood cancers and poisoning from arsenic and lead (Argo 2000; Feychting et al. 2001; Acurcy et al. 2002; Dodds et al. 2006; Tokar et al. 2013). More specifically, Latino farm workers in California were found to have a 59 to 69% greater risk of stomach, cervical, and uterine cancer, and different forms of leukemia compared with other Latinos in the state (Quintaro-Somaini and Quirindongo 2004).

A study by the California Institute of Rural Studies affirms the environmental health threats faced by Oxnard farm workers and other community members given that chemicals are widely and frequently used on farm lands which constitute one-third of Ventura County’s land mass. More specifically, fertilizer is used on 83% of crop land, 66% of the land is treated with insecticides, herbicides are used on 55% of the land to control for unwanted weeds, grass and brush, and 40% of the land is sprayed for disease control (Schroeder et al. 2003). Given the large

number and types of crops grown in Oxnard County, a variety of pesticides are commonly sprayed and subsequently detected in associated agricultural soils and waterways: the fumigants methyl bromide, carbamates, metam sodium/methyl isothiocyanate (MITC), and 1,3-dichloropropene (Telone); the insecticides bifenthrin and chlorpyrifos; the herbicides molinate and pendimethalin, and a variety of other organochlorine/organophosphorus class compounds. Complete listings of applied pesticides indexed by commodity in Ventura County can be found in more detailed sources (California Department of Pesticide Regulation 2008; Pesticide Action Network 2013). In addition, some of the more persistent pesticides from past use are commonly detected in deeper soil and sediment layers—these include: DDT and its derivatives, chlordane, and simazine (Reeves et al. 2002). Finally, we have detected a number of potential pesticide photodegradation products in soils as a result of hydroxylation, dehalogenation, oxoquinoline formation, and demethylation processes. However, we were not able to accurately trace this back to specific parent compounds. The rate of photolysis was likely dependent on the nature of the soil constituents and associated pH of the surrounding medium.

There are two main pesticide exposure routes for farmworkers: inhalation (entry via the respiratory tract) and dermal contact (entry via the skin). Additionally, there is the possibility of entry via the gastrointestinal tract if farmworkers neglect to wash properly before eating during shifts. Moreover, the volatility of pesticides results in drift away from where they are applied, thus leading to the possibility of secondhand exposure. Pesticide toxicity can result from a number of adverse cellular, biochemical, or macromolecular changes including DNA modification/damage, impairment of neurological and enzymatic systems, and mimicking or blocking hormones if classified as endocrine disruptors (Hu and Kupfer 2002; Briviba et al. 2007; Starks et al. 2012). It is often the case that reactive intermediates or metabolites produced by the body's biotransformation process that produces the deleterious effects described above. Biotransformation can be classified as Phase I or Phase II—both contain an array of enzymatic reactions. The primary oxidative family of enzymes in Phase I is referred to as cytochrome P450 monooxygenases (Fasan 2012). Xenobiotic-metabolizing P450s serve as defense against the detrimental effects of foreign substances in our bodies. During Phase II metabolism (leading to bodily elimination) parent pesticides or their Phase I metabolites undergo additional transformation. Compounds are subsequently metabolized in the kidneys with derivatives being found in the urine upon excretion. Urinary metabolites excreted after a short-time exposure can be used as a reliable measure of individual pesticide uptake at varying exposure levels (Andersson et al. 1983).

Civic Engagement Barriers for Environmental Justice Communities

Populations grappling with severe environmental pollution often live and work in conditions that are not conducive to cultivating health literacy due to socioeconomic constraints, cultural and linguistic barriers, and immigration status. (McBride, Sherraden and Pritzker 2004). For example, “poor children were more likely to have routine and sick care in a neighborhood health center and hospital-based clinic and were less likely to receive care in a doctor’s office...(while) black children were twice as likely as white children to use the emergency room as their primary source of care” (Gwynn and Thurston 2001). Disparities in access to and knowledge about health care can affect a population’s ability to become aware of and treated for environmental health threats (Parker, Ratzan and Lurie 2003).

Linguistic and cultural barriers can also hinder public awareness and civic engagement. In Ventura County, Mixtecos and other indigenous populations from Mexico are an increasing segment of the Oxnard farm worker population but are culturally and linguistically distinct from Spanish-speaking Mexicans (Schroeder et al. 2003). There is a lack of trained and legally documented community organizers, labor contractors and health workers (promotoras) who can speak and translate indigenous languages to provide information about environmental health risks.

Immigration status can significantly limit opportunities for civic engagement (Flanagan and Levinson 2010). Many farm workers fear deportation and/or retribution by agricultural business owners; thereby, hindering their civic engagement on environmental issues. Undocumented workers and residents in farming communities like Oxnard are often reluctant to report, complain about or seek treatment for ailments related to poor working conditions in agricultural fields.

Enhancing Civic Capacity through University-Community Research Collaborations

Environmental injustices have led to efforts by affected populations, activists, scholars and policy makers to promote public awareness, community input and social change through advocacy. In their study of environmental justice in San Diego's Old Town district, researchers found that the Environmental Health Coalition (EHC) effectively used the skills of trained researchers, professional community organizers and community residents to foster community building, organizing and advocacy in a town that "has for decades been treated by planners as a dumping ground for polluting industry and warehouses" (Minkler et al. 2010). Community members were trained to be lay health promoters or promotoras de salud in order to raise public awareness about environmental health concerns, and to serve as a channel for voicing the concerns of the affected population. Like the EHC in San Diego, this study can serve as a successful example of professional researchers partnering with local organizations.

University-community research partnerships can enhance the civic capacity of environmental justice communities because academics are professionally trained researchers who have the expertise and resources to design, implement and produce research findings that support the advocacy efforts of affected communities.

University-Community Research Collaboration in Oxnard, California

Researchers from California Lutheran University established collaborations with key community organizations, public agencies and local residents in Oxnard who could assist with farm worker outreach efforts and the collection of data. The partnerships led to sampling and monitoring of water, soil and urine to establish a baseline for pollution risk and exposure. Data from community surveys and content analysis of Spanish radio were also collected to identify the resources, structures and processes that could inform and engage the public on environmental and health issues in Oxnard.

Assessment of Risk and Exposure to Environmental Pollution

Traditional approaches to monitoring pesticide and associated chemical levels in environmental systems are based primarily on discrete field sampling methods followed by laboratory analysis. Although common practice, "grab" or "judgmental" sampling is at best a cursory evaluation of a particular environmental compartment. While these approaches are appropriate for initial screening, they do not improve our understanding of the natural processes governing pesticide behavior and transport, nor do they assess direct human exposure and thus, acute and long-term health effects (Fitzhugh and Mackay 2001). For all soil and water sampling initiatives in this study, a stratified random sampling approach was employed. This technique involved dividing the sample population into homogeneous subgroups, with subsequent selection of a simple random sample from each. This allowed for representative samples to be drawn from the population; in addition, stratified random sampling generally allows for more statistical precision than simple random sampling alone. Representative agricultural soil samples were collected as follows: at the surface (1/2 inch of topsoil) and subsurface (up to 6 inches below the surface). For water sampling, samples were taken as follows: at the microlayer and halfway between the surface and sediment layer. Sediment samples were also collected and will be analyzed in the coming months. The sampling frequency varied monthly, during the growing seasons, and during dry and wet conditions. Moreover, in our approach, we included as much temporal and spatial variability as possible.

There is widespread belief that low-level chronic exposure may result in adverse health effects, especially in groups with inadequate access to health care and effective civic engagement opportunities. Unfortunately, it is usually not possible to measure pesticide exposures retrospectively and not cost effective to measure exposures prospectively; therefore, innovative techniques must be developed and utilized to assess pesticide exposure and risk. With the assistance of two well-established farm worker organizations, environmental agencies and local residents, researchers were able to collect urine samples from farm workers and residents in addition to soil and water samples from agricultural areas in Oxnard. A total of 38 soil and 20 water samples have been collected to date. Table 1 presents a snapshot of the pesticides screened in selected soil and water samples. An Agilent Technologies gas chromatography/mass spectrometry (GC/MS) instrument was utilized for all sample screening analyses after appropriate sample extraction procedures were performed. As shown in Table 1, the most significant sources of pesticides screened were located in soil and water samples on or near (within a 0.5 mile radius) farming locations. Such occurrences result from the entry and spread of contaminants into surface waters, sediments, and soil due to intense agricultural activity and weather events. We are currently working to purchase certified reference standards for quantitation purposes. The results will then be compared with established EPA drinking water standards, California Office of Environmental Health Hazard Assessment screening numbers, and California public health goals (PHGs). Analysis of heavy metal and nutrient levels revealed that all samples were near or below EPA regulated threshold levels, to date.

Urine samples were collected from a cohort of farm workers, individuals in close proximity (< 0.5 miles) to agricultural fields, and individuals residing > 0.5 mile from agricultural fields. Human biomonitoring, such as that utilized in this study, allows for the assessment of the types and concentrations of metabolites that result from the chemical breakdown of pesticides within the body. The detection and characterization of metabolites in urine reflect exposure (i.e., within a 1-2 week period) due to the short time these metabolites remain in the body. The first collection date was in March, 2012 at a Mixteco/Indigena Community organizing event in Oxnard. Samples were collected from 30 individuals, 25 of those being women, and transported to the laboratory for analysis. Of the 30 urine samples, five showed detectable levels of parent carbamate and endosulfan I compounds; two others showed detectable levels of possible pyrethroid and pendimethalin metabolites. Given this preliminary knowledge, we are confident that metabolic inferences will provide insight into the possible toxic and carcinogenic modes of action of pesticides and associated metabolites.

Initial results from the sampling campaign of water and soil suggest that Oxnard communities may be exposed to higher than normal levels of pesticides; therefore, more testing and the development of selective analytical methodology are needed to quantify and confirm and detect changes in endogenous metabolites in response to pesticide-related exposure. Equally important is the fact that university researchers may not have been able to collect vital data for the sampling campaign absent collaboration with community partners and stakeholders.

Assessment of Civic Capacity

A survey for Oxnard community members was developed to assess: 1) public perception of environmental exposure and risk; 2) opportunities for public engagement on environmental issues; and 3) obstacles to meaningful civic engagement by the affected populations. The survey respondents were asked questions based on five categories: demographics, employment history, environmental conditions in their communities, and community awareness and involvement. Surveys were collected from 101 Oxnard community members at three public events in collaboration with key community organizations: a weekly flea market at Oxnard College, job fair sponsored by a government agency, and cultural festival sponsored by a local farm worker organization. Researchers developed relationships with local farm worker families to identify appropriate venues for survey distribution, and two local Oxnard residents assisted in the distribution and collection of surveys.

The vast majority of 101 survey respondents were Latino (88%), 42% of the respondents reported that they lived or worked near an area where crops are grown and 43% lived in homes where only Spanish is spoken. More than one-third of the respondents (38%) worked in agriculture, primarily picking or harvesting crops (55%). 37% reported being exposed to chemicals used to protect crops while working in the fields but only 2 of the 101 respondents could specify the names of the products used. Despite their proximity to farms and their occupational exposure to farming pesticides, 78% of the respondents were not aware of any case when the government or a regulatory agency has tried to clean up pollution. Nonetheless, 71% expressed concern about the safety of water and air in their communities. More importantly, 61% of the participants believe that nearby industries like farms do negatively impact air and water quality.

The surveys revealed troubling findings about the level of community awareness of and involvement in environmental issues. 84% of respondents were not aware of events or meetings about water or air quality in their communities, and only 5% reported involvement in a community group, neighborhood association and/or civic organization, including churches. Only one participant had spoken to a public official about environmental conditions in the community even though 48% believe that poor water and air quality have negatively impacted their health. Of those who believe that environmental conditions have a negative impact on health, allergies (33%) and asthma (17%) were the most cited. Thus, the surveys indicate that Oxnard community members lack engagement, knowledge and opportunities for action despite their high levels of concern about environmental conditions in their communities.

Exploring Spanish Radio as a Channel for Civic Discourse

Based on the survey responses, researchers analyzed the potential for Spanish radio to enhance the civic capacity of the Oxnard community to promote environmental justice. Spanish radio was cited as the main source from which 44% of the survey respondents received information about community issues, and 47% stated that they prefer to receive information about community issues via radio. 60% of Spanish radio listeners from the surveys tune to Radio Lazer 102.9FM and 20% listen to La "M" 103.7FM. The preference for Spanish radio is logical because it eliminates language barriers, alleviates mistrust and reduces fear of retribution or deportation. Since Radio Lazer and La "M" are the primary radio stations consumed by Spanish-speaking residents in Oxnard, they were selected for content analysis. La Mexicana 910AM was also selected for content analysis due to its reputation for serving the local community.

Three specific programs were selected for qualitative content analysis for three hours (one hour per program) during a one week period from Monday through Sunday. The selected programs and times were: La "M's" *El Nuevo Show de la M* from 6:00 a.m. to 7:00 a.m., La Mexicana's *La Voz Poderosa* from 7:00am to 8:00am and Radio Lazer's program *Tribunal Lazer con Salvador Prieto* from 9:00am to 10:00 am. The qualitative content analysis was based on the following themes: 1) an evaluation of the topics and issues that the programs presented and discussed; 2) the quality of the information that the stations offered; 3) the type of speakers highlighted on the respective programs; and 4) the audience to which the programs were directed.

La "M"

La M's *El Nuevo Show de la M* is a fast paced morning talk show with minimal emphasis on discussions concerning important issues in the community. The program only airs three minutes of news per hour and the news broadcast is very fast paced. Local news is most often related to public safety and crime. International news focuses on Mexico and the violence experienced due to drug cartels. During the three minutes allocated to news, sports and media are also mentioned. The minimal time allocated to the news, combined with the numerous categories covered and the small range of topics that are emphasized makes the news broadcast on La "M" insufficient to educate the community about local issues.

Radio Lazer

Radio Lazer airs *Tribunal Lazer with Salvador Prieto*. Prieto, as he is popularly referred to, is comical and energetic, keeping the segment entertaining and fun for the audience. The topics presented range from fashion, vanity, traditions, relationships, family dynamics, and gender roles to more serious issues such as domestic violence, sexual problems and child abuse. Unfortunately, civic engagement and environmental issues are not regularly discussed on Radio Lazer because the bulk of airtime is divided evenly between light-hearted discussion and music.

La Mexicana

La Mexicana has a reputation as a community resource in Oxnard because it covers substantive local issues. *Voz Poderosa* is a bilingual show, broadcasted on La Mexicana in the morning from 6:00 to 9:00am. The focus of the program is on public discourse with 75% of the airtime allocated to discussion, and only about 18% to advertisements and 7% to music. While this show is an ideal example of how radio can be used to communicate community issues to the public, it is not as popular as other local shows which dedicate more air time to music.

The objective of *Voz Poderosa* is spelled out in its name, which translates to *Powerful Voice*. This can be confirmed by continuous inspirational exclamations made by the lively host, David Cruz, such as: “Knowledge is power!”; “Tell everyone to wake up! We are sleeping!”; “Express yourself!”; “Do you want to be part of the problem or part of the solution? ...the problem is ignorance.” Civic engagement is even present in the lyrics of the occasional songs that are played during the program, such as the song “Levantate,” which encourages people to stand up even if others turn their backs or criticize them. While water quality was the only topic talked about briefly in relation to the environment, issues of pesticide use and the health of fieldworkers would fit naturally into the show’s programming.

Content analysis of the three stations indicates that Spanish radio is under-utilized as a channel for public education and civic discourse in Oxnard, especially relating to environmental and other health related issues. Coupling the topics discussed by the hosts of *Voz Poderosa* with the popularity of the morning talk show on Radio Lazer would be immensely beneficial to educating the larger community in Oxnard.

Conclusions and Recommendations

Three sets of conclusions are generated from the study. First, initial findings from urine sampling suggest that farm workers are exposed to higher than normal levels of pesticides and the most significant sources of pesticides screened were located in soil and water samples on or near (within a 0.5 mile radius) farming locations. Second, the community surveys reveal that Oxnard community members lack knowledge and opportunities for action despite their high levels of concern about environmental conditions in their communities. There is a need to identify ways to increase public awareness and engagement, particularly by mitigating barriers posed by limited literacy, language, and fears about employer retaliation and immigration status. Third, local Spanish radio is a popular mechanism for engaging Oxnard residents on local issues but it is currently underutilized as a vehicle for disseminating information about health and environmental issues in the community. More importantly, local Spanish radio can mitigate the barriers to engagement because consumption in this medium does not require written literacy and allows listeners to retain their anonymity.

Given their exposure to pesticides and other farming-related chemicals, agricultural communities must have access to information and opportunities for engagement on environmental and health issues. These goals can be achieved by promoting two strategies. First, university-community collaborations should be identified and established in environmental justice communities as a way to promote *research in service of the community*. There is a mutually beneficial relationship between universities and communities: professionally trained

researchers can produce empirical data to inform the advocacy efforts of community-based organizations seeking positive social change, and academic researchers have the opportunity to apply their skills and knowledge to serve impacted communities by addressing real world problems. For example, meaningful partnerships with community organizations allowed for the collection of urine samples from farm workers and surveys from community members in Oxnard. Farm workers and residents in Oxnard were understandably hesitant to participate in the study due to concerns about confidentiality, potential retribution from growers, and fears about immigration status. However, collaborating with farm worker organizations and participating in or attending local events fostered trust and comfort between the research team and Oxnard community. Dissemination of the project's results will also be served by these partnerships because existing public forums sponsored by the community organizations will serve as venues for presenting the findings and conclusions. More importantly, Oxnard farm workers and community members will be more receptive to and trusting of the information provided if it is presented in a familiar setting and by researchers who have established a consistent presence in the community.

Second, Spanish radio and other non-English media outlets should be explored and utilized as a public venue for informing and engaging immigrant populations on environmental and other health related conditions. Radio is often considered the most democratic form of media due to its accessibility to a mass audience from a wide range of educational and income levels. In particular, Spanish radio can help farm workers and Spanish-speaking populations overcome or mitigate barriers to civic engagement such as limited literacy and immigration status. Enhancing civic discourse and action on environmental issues affecting farm workers and surrounding populations enhances civil society and contributes to healthy, sustainable communities.

Acknowledgement

The authors would like to thank the California Wellness Foundation for financially supporting this project. We also thank Antonio Flores, Maria Flores, Ivy Nguyen and Justina Cooney for their collaboration and valuable comments during this study.

Appendix

Table 1. A snapshot of pesticide types screened/detected in collected soil and water samples from Ventura County farms.

Sample Type/Sample #	Geographical Distance/Crop Type	Pesticides Screened/Detected
Soil/#3	Within the field/strawberries	Potassium N-methyldithiocarbamate; pyrethroids; endosulfan I; Chlorpyrifos
Water/#1	Waterway within the field/strawberries	Pyrethroids; endosulfan I; 1,3-dichloropropene
Soil/#5	>0.5 miles from a strawberry field	None screened/detected
Soil/#9	>0.5 miles from an onion field	None screened/detected
Soil/#12	Within the field/onions	Pendimethalin; Chlorpyrifos, DDT
Water/#4	<0.5 miles from an onion field	Pendimethalin
Soil/#19	Within the field/broccoli	Chlorpyrifos; menazon
Soil/#22	>0.5 miles from a broccoli field	None screened/detected
Water/#10	>0.5 miles from a broccoli field	None screened/detected
Soil/#29	Within an outdoor propagation nursery	Bifenazate; pendimethalin

REFERENCES

- Acuracy, Thomas A.; Quandt, Sara A. and Russell, Gregory B. 2002. Pesticide Safety among Farmworkers: Perceived Risk and Perceived Control as Factors Reflecting Environmental Justice. *Environmental Health Perspectives* 110(2): 233-240.
- Andersson, Rune; Carlsson, Anders; Nordqvist, Marianne B. and Sollenberg, Jan. 1983. Urinary Excretion of Hippuric Acid and o-Cresol after Laboratory Exposure of Humans to Toluene. *International Archives of Occupational and Environmental Health* 53: 101-108.
- Argo, James. 2000. Site-Specific A Priori Cancer Risk Estimator for Mixtures and Multiple Sources: Net Excess Relative Odds. *Environmental Science & Technology* 34(19): 4208-4213.
- Bevc, Christine A.; Marshall, Brent K. and Picou, J. Shaun. 2007. Environmental Justice and Toxic Exposure: Toward a Spatial Model of Physical Health and Psychological Well-being. *Social Science Research* 36: 48-67.
- Bowen, William M. and Wells, Michael V. 2002. The Politics and Reality of Environmental Justice: A History and Consideration for Public Administrators and Policy Makers. *Public Administration Review* 62(6), 688-698.
- Briviba, Karlis; Stracke, Berenke A.; Rufer, Corinna E.; Watzl, Bernhard; Weibel, Franco P. and Bub, Achim. 2007. Effect of Consumption of Organically and Conventionally Produced Apples on Antioxidant Activity and DNA Damage in Humans. *Journal of Agricultural and Food Chemistry* 55: 7716-7721.
- Bullard, Robert D. and Johnson, Glenn S. 2000. Environmental Justice: Grassroots Activism and its Impact on Public Policy Decision-making. *Journal of Social Issues* 56(3): 555-578.
- California Department of Pesticide Regulation. 2008. Annual Pesticide Use Report Indexed by Commodity Ventura County.
- Clinton, William J. Executive Order 12898 - Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations. February 11, 1994.
- Dodds, Linda; King, Will D.; Fell, Deshayne B.; Armson, Anthony; Allen, Alexander and Nimrod, Carl. 2006. Stillbirth Risk Factors According to Timing of Exposure. *Annals of Epidemiology* 16: 607-613.
- Fasan, Rudi. 2012. Tuning P450 Enzymes as Oxidation Catalysts. *ACS Catalysis* 2: 647-666.
- Feychting, Maria; Plato, Nils and Ahlbom, Anders. 2001. Paternal occupational exposures and childhood cancer. *Environmental Health Perspectives* 109 (2): 193-196.
- Fitzhugh, T.W. and Mackay, D.S. 2001. Impact of Subwatershed Partitioning on Modeled Source and Transport limited Sediment Yields in an Agricultural Nonpoint Source Pollution Model. *Journal of Soil and Water Conservation* 56: 137-143.
- Flanagan, Constance and Levine, Peter. 2010. Civic Engagement and the Transition to Adulthood. *The Future of Children* 20(1): 159-179.
- Gwynn, R.Charon; Thurston, George D. 2001. The Burden of Air Pollution: Impacts Among Racial Minorities. *Environmental Health Perspectives* 109: 501-506.
- Hu, Yiding and Kupfer, David. 2002. Metabolism of the Endocrine Disrupter Pesticide Methoxychlor by Human P450s: Pathways Involving a Novel Catechol Metabolite. *Drug Metabolism & Disposition* 30: 1035-1042.
- McBride, Amanda Moore; Sherraden, Margaret S.; Pritzker, Suzanne. 2004. Civic Engagement among Low-Income and Low-wealth Families: In their own Words. *Center for Social Development* 4(14): 1-21.
- Minkler, Meredith. 2000. Using Participatory Action Research to Build Healthy Communities *Public Health Reports, Focus on Healthy Communities* 191-197.
- Morello-Frosch, Rachel; Pastor Jr., Manuel; Porras, Carlos and Sadd, James. 2002. Environmental Justice and Regional Inequality in Southern California: Implications for Future Research. *Environmental Health Perspectives* 110(2): 149-154.

- NEJAC. 2002. Report on Integration of Environmental Justice in Federal Agency Programs, May 2002, Washington, DC.
- Parker, Ruth M.; Ratzan, Scott C. and Lurie, Nicole. 2003. Health Literacy: A Policy Challenge for Advancing High-Quality Health Care. *Health Affairs* 22(4): 147-153.
- Pesticide Action Network (PAN). California Pesticide Use Database-Ventura County. <http://www.pesticideinfo.org/>. Accessed June 18, 2013.
- Peterson, Jane W.; Lachance, Laurie L.; Betterfoss, Frances D. et al. 2006. Workshop Summary: Connecting Social and Environmental Factors to Measure and Track Environmental Health Disparities. *Environmental Research* 102: 146-153.
- Peterson, Jane W.; Lachance, Laurie L. and Betterfoss, Frances D. 2006. Engaging the Community in Coalition efforts to Address Childhood Asthma. *Health Promotion Practice* 7(2): 56-65.
- Reeves, M; Katten, A. and Guzman, M. 2002. *Fields of Poison 2002, California Farmworkers and Pesticides*. Pesticide Action Network, California Rural Legal Assistance Foundation, United Farm Workers of America. Pesticide Action Network North American Regional Center.
- Starks, Sarah E.; Gerr, Fred; Kamel, Freya; Lynch, Charles F.; Alavanja, Michael C.; Sandler, Dale P. and Hoppin, Jane A. 2012. *International Archives of Occupational and Environmental Health* 85: 505-515.
- Su, Jason G., Morello-Frosch, Rachel; Jesdale, Bill M.; Kyle, Amy D., Shamasunder, Bhavna. and Jerrett, Michael. 2009. An Index for Assessing Demographic Inequalities in Cumulative Environmental Hazards with Application to Los Angeles, California. *Environmental Science & Technology* 43: 7626-7634.
- Tokar, Erik J.; Person, Rachel J.; Yang, Sun; Perantoni, Alan O.; Waalkes, Michael P. 2013. Chronic Exposure of Renal Stem Cells to Inorganic Arsenic Induces a Cancer Phenotype. *Chemical Research in Toxicology* 26(1): 96-105.
- Van Roosbroeck, Sofie; Hoek, Gerard; Meliefste, Kees; A. H. Janssen, Nicole A.H.; Brunekreef, Bert. 2008. Validity of Residential Traffic Intensity as an Estimate of Long-Term Personal Exposure to Traffic-Related Air Pollution among Adults. *Environmental Science & Technology* 42(4): 1337-1344.

ABOUT THE AUTHORS

Dr. Haco Hoang: Dr. Haco Hoang has an extensive background as a practitioner and scholar of public policy, particularly in the areas of civic engagement, youth environmental activism, and community development. She has served as a policy consultant for public officials and agencies in Los Angeles, including Mayor Antonio Villaraigosa. She has worked on several projects related to civic engagement and community development. In collaboration with the Community Development Department in Los Angeles, she helped to design and implement capacity-building workshops for community-based organizations to improve their delivery of human and social services. She also worked with neighborhood councils in Los Angeles to improve their capacity to affect public policy and influence local decision-making through civic education and training programs. Most of Dr. Hoang's policy work has targeted underserved and underrepresented areas in Los Angeles including minority, immigrant and low-income communities. She has also worked with numerous environmental organizations that target youth environmentalism including TreePeople and Pacoima Beautiful. For three years, Dr. Hoang served as the youth and education policy consultant for Million Trees LA where she was responsible for developing policies and programs that fostered youth environmentalism and civic engagement, particularly in low-income areas.

Dr. Grady Hanrahan: Dr. Hanrahan has considerable experience in environmental sampling and analysis, particularly in areas of low-income populations, including East Los Angeles and the Oxnard region of Ventura County. He was a major participant in a National Institutes of Health (NIH) grant award studying the correlation between the chemical composition of air pollutants in the East Los Angeles region and the potential impact of long-term exposure to these chemicals on human health. He was instrumental in expanding upon established environmental monitoring techniques that are used universally to monitor pollution. Because these techniques are now widely used, they are easily incorporated into large-scale environmental monitoring studies designed to investigate the correlation between the exposure of populations to chemical pollutants and human health. One of his most important contributions to the NIH project was the generation of a database that included chemical pollutants and epidemiological data sorted by zip codes that reflected health disparities of residences in economically disadvantaged areas compared to more affluent neighborhoods.

Kaitlyn Noli: Kaitlyn Noli is a graduate student working on her Master's degree in Global and International Studies. She serves as a researcher on a project funded by a grant from the California Wellness Foundation titled "Integrating Science into Civic Engagement: Promoting Environmental Justice in Oxnard, California."

The Societal Importance of Embracing Counterintuitive Thought in Science: Assisted Exercise in Preterm Infants for Long-term Health Outcomes

Ellen Olshansky, University of California Irvine, USA
Jessica Vaughan, University of California Irvine, USA
Kelsi Sando, University of California Irvine, USA
Julia Rich, University of California Irvine, USA
Kimberley Lakes, University of California Irvine, USA
Daniel Cooper, University of California Irvine, USA

Abstract: For research to lead to progressive change, scientists and society must embrace what may seem counterintuitive. While there is often resistance to changing views of what we presume to already understand, we must be open to evolving knowledge and evidence. Our research is examining the effect of a novel intervention designed to increase physical activity of premature babies in their first year of life on: (1) body composition, (2) associated biochemical and cellular mechanisms of growth and inflammation, and (3) quality of maternal care. This study is novel because it is counterintuitive to prevailing knowledge of the care and treatment of infants born prematurely. Traditionally, we swaddle infants and restrict their movement in order to minimize energy expenditure. We are proposing the opposite: to increase energy expenditure in a systematic, controlled way in order to increase muscle mass and bone density, with the ultimate goal of preventing diseases associated with lack of muscle mass or bone density. Our research actively engages the mothers in the study by learning about their perceptions and their experiences of doing the exercise with their infants because the mothers, too, are aware of the prevailing views that are counter to what they are being asked to do. The mothers have taught us, however, that they are willing to participate in this exercise study, while paradoxically also viewing their infants as “fragile” and are fearful of hurting their infants. Our thesis in this research-based paper is that science and society must work in tandem to be effective.

Keywords: Clinical Translational Research, Society's Role in Research, Assisted Exercise in Preterm Infants, Counterintuitive Research Approach

Introduction

Research is conducted in order to make new scientific discoveries, develop new treatments for diseases, and generate new knowledge for the sake of progress. Progress is dependent upon being open to new ideas and new approaches. For research to lead to constructive and progressive change, scientists and society must embrace what may seem counter-intuitive. While there is often resistance to changing views of what we presume to already understand, we must be open to evolving knowledge and evidence. Thomas Kuhn wrote in 1962, his classic book on *The Structure of Scientific Revolutions*, in which he differentiated “normal science” from “revolutionary science,” that results from a “paradigm shift” in thinking. This process, in which prevailing scientific thinking undergoes a change, occurs as new knowledge accumulates and is tested through scientific means. Education and science are interrelated, as the goal of science is to generate new knowledge and the goal of education to impart such knowledge in such a way that both teachers and students think critically about the new knowledge, always seeking further knowledge. George Bernard Shaw noted that education is “a succession of eye-openers each involving the repudiation of some previously held belief” (Gold Eggs Quotations 2011). He also stated that “science becomes dangerous only when it imagines that it has reached its goal” (Shaw 1909).

In this paper we describe our research that is developing and implementing an assisted exercise program with preterm infants in order to test the effects of this exercise program on body composition, with the goal of enhancing long-term health. This approach is counter-intuitive to prevailing wisdom in which preterm infants are usually swaddled to prevent energy expenditure. Our paper emphasizes two important precursors to scientific progress: 1) the ability to embrace new ideas that initially appear to be counter-intuitive and 2) the ability to embrace society (research participants) in the journey of exploring and testing new paradigms.

Examples of Counter-Intuitive Thinking

Thinking in new and innovative ways and producing new ideas may appear to be counter-intuitive because sometimes these new ideas are, ostensibly, the antithesis of what has been commonly accepted as the norm. Numerous examples abound, however, of ideas that had been accepted and routinely followed, but were eventually replaced by newer ideas, grounded in the scientific evidence of the day. A classic example is Galileo's new idea that the earth revolved around the sun instead of the other way around, which was the prevailing view (Galilei and Scheiner 2010). Another example is the notion that Columbus could sail around the world if the prevailing view is that the earth is flat. Some scientists were considered heretics for their counter-intuitive views.

Over the last 40 years, numerous advances in neonatal care have been developed as a result of the ability of scientists and clinicians to question universally accepted treatment methods, and to be open to novel approaches to prevention, diagnosis and treatment of disease. An example of this is the advent of continuous positive airway pressure (CPAP) that was used in the treatment of infants suffering from respiratory distress syndrome (RDS) (Gregory et al. 1971). Through questioning their observations the scientists recognized that grunting was the infant's way of increasing air pressure in the lungs thus keeping their lungs partially open and decreasing the effort required to breathe. From an initial question about a grunting noise, CPAP was developed and is now the standard of care in all infants with RDS.

A second example is the "Safe to Sleep Campaign," formerly known as the "Back-To Sleep Campaign" (National Institute of Child Human Development [NICHD] 2012). The "Safe to Sleep Campaign" is an example of an advance in neonatal care, the success of which was dependent on societal implementation and acceptance to change. This campaign started in 1994 to combat Sudden Infant Death Syndrome (SIDS). The American Academy of Pediatrics recommended to parents that infants be placed on their backs during sleep. This recommendation was in direct contrast to the prevalent view that infants be placed on their stomachs to sleep (Willinger et al. 1994). Since the beginning of the campaign, the incidence of SIDS has decreased by over 50% and its success has resulted from caregivers' willingness to accept and implement this new approach. The "Safe-To Sleep Campaign" is an example of how evidence-based, caregiver-dependent changes in infant behavior can be successful.

Despite these advances and the increased rates of survival of infants born between 22 and 25 weeks, the proportion of survivors with major adverse health problems remains unchanged (Costeloe et al. 2012). These findings indicate that new approaches to treatment aimed at improving long term health outcomes are needed.

Current Work at the UC Irvine Pediatric Exercise Research Center

This brings us to the focus of the work at the Pediatric Exercise Research Center at UC Irvine. Premature birth is recognized as the single most important problem in maternal-child health in the United States (Behrman and Butler 2007). Health concerns associated with prematurity include lung disease, osteopenia, cardiovascular disease, failure to thrive, obesity, and abnormalities of muscle, bone, and fat ratios. (Casey 2008, Eliakim and Nemet 2005, Greenough 2008, and Greer

2005). Much attention has been paid to the nutritional intake side of energy balance in preterm babies (Singhal 2006) with less attention to energy output. In fact, the prevailing view is to swaddle premature infants, limiting their energy expenditure in order to maximize growth. (Langer 1990 and Long et al.1980) This model remains the dominate practice, contrary to the current knowledge that the third trimester of pregnancy is when infants are usually most active. Preterm infants miss out on the full third trimester. Determining a method to mitigate this loss is the basis of our current research. The implementation of an intervention aimed to increase physical activity is being tested as a possible simple and effective treatment for infants facing complications associated with prematurity.

In 2005 (see Figure 1 Study 1) we conducted a study in which the effect of four weeks of gentle range of motion exercises on body composition in premature infants was studied. The inpatient intervention was carried out by a nurse in the NICU. 95 subjects were randomized into one of two groups, either an active control group or the assisted exercise group. Although we are still in the process of analyzing the data, one important and encouraging finding is immediately evident: we did not have any serious adverse events related to the study, indicating that although often viewed as fragile, the preterm infant population can tolerate a physical activity intervention program. This prompted us to examine whether it would be feasible to continue promoting exercise in preterm infants with the mother carrying out the intervention in the home after discharge. To answer this question we conducted a pilot study of 10 subjects, over a four week period immediately after discharge from the hospital (see Figure 1 Study 3). From this pilot study we found that it was not only possible to teach parents how to perform exercises with their babies, but that the participants welcomed the interactions with their babies and the study staff. The pilot study has led us to our current project, Project Begin, “Impact of Exercise on Body Composition in Premature Infants; New Approaches” which is designed to look at augmented physical activity over the first year of life and its effect on body composition, associated biochemical and cellular mechanisms of growth, and inflammation. In order to demonstrate a positive relationship between physical activity and body composition in preterm infants we again have both an intervention group and an active control group. Both groups of caregivers are given social and emotional activities to complete at home every day, and in addition the intervention group performs daily physical activity exercises.

Embracing Society as Partners in Scientific Research

Achieving progress in the form of scientific advances involves rigorous and systematic research in order to generate evidence to support constructive change. A critical component in this process is involving society, as represented by people who are directly involved in the research. Our thesis is that science and society must work in tandem to be effective in making scientific progress. Therefore, it is important to understand the perceptions of the people directly affected by the research. In our study, we actively engage mothers of infants in the neonatal intensive care unit (NICU) by learning about their perceptions and their experiences of doing the exercises with their infants. Interviews with mothers were first conducted in the NICU in a study aimed to identify factors influencing mother’s perceptions of engaging in physical activity with premature infants (see Figure 1 Study 2). Mothers tended to express that they felt infant exercise was beneficial but they were concerned for the safety of their babies and were afraid of hurting them (Gravem et al. 2009). Through analysis of the qualitative data from these interviews, we constructed several conceptual categories that were used to create quantitative survey questions (see Figure 1 Study 4). 48 questions were compiled to create a survey tool, the Perceptions of Pediatric Physical Activity Scale (PPAS), in order to quantitatively measure a mother’s perception of infant physical activity (Olshansky et al. 2012). 68 PPAS surveys were distributed to mothers of infants in the NICU, and 75 were distributed to mothers of infants ages 8-14 months in childcare settings (see Figure 1 Study 5). The mothers were asked to anonymously

strongly agree, agree, disagree, or strongly disagree with various statements about infant physical activity. Preliminary results were used to shorten the survey, which is currently being used in the Project BEGIN study. In order to measure the mothers' perceptions of infant exercise, Project BEGIN participants are asked to complete the PPAS survey at the beginning of the program as well as at the completion of the yearlong intervention. In addition to using the PPAS as a quantitative tool, all participants are also given a qualitative interview at their 2 week home visit and at completion at the study.

A significant theme that emerged through our survey and interview process, is that mothers with infants participating in the intervention are aware that the prevailing views of neonatal care are counter to what they are being asked to do.

One mother, verbalizing some concern about performing the exercises with her infant, stated,

"I think most parents of infants don't understand exercise...because you need to leave them alone and sleep but then take them home and do this (exercise)...its unclear, when is the time they should still be bundled up and when they should start moving around."

Mothers are also keenly aware of the fragility of their babies, evidenced in the following quote:

"I think just being in the NICU, you're attached to your child because you know, you don't have them home with you for so long that when they are home, you want every minute (be)cause you know how fragile life is. It's scary, having a baby so premature."

The mothers have taught us that they are willing to participate in this exercise study, despite viewing their infants as "fragile" and feeling fearful of hurting their infants. (Gravem et al. 2009) A mother said:

"It's not hurting your baby spending one-on-one time with them, bonding with them, and exercising them to be healthier and have healthier joints or walk sooner or crawl sooner. They're already behind so what's it going to hurt to help them try to be on track. I would definitely encourage it."

We believe that it is critically important to involve research participants directly in studies not only by including them in the research protocol that has been designed, but as partners in the research by eliciting their views, concerns, fears, hopes. Our research is certainly not nearly as complex as describing the universe or the earth, but it is very complex to the mothers involved in the study. If we, as scientists who have reason to believe (to hypothesize) that we have developed an important intervention, we must involve society as partners in the testing of this new intervention, rather than simply imposing this new intervention as a new mandate. To be successful, we must recruit willing participants to implement our new ideas. We must understand and have empathy for any reticence on the part of the participants, recognizing that some of this reticence may be due to the sense that we are asking them to do something that is counter-intuitive to what we as a society think we know.

We also must be willing to provide an explanation for why we believe these new ideas make sense. Where is the evidence? What is the rationale? We need to thoroughly understand how the current prevailing view came about and carefully explain how we came to refute that prevailing view in favor of this newer approach.

By realizing that mothers have these conflicting views, being sensitive to their fears and understanding why mothers are still willing to participate, we believe that we are able to create partnerships with the mothers in our efforts to create an intervention that will be feasible to implement in the real world by these mothers. In developing our study design we have made

modifications, based on input from the mothers, in order to accommodate their needs and concerns.

We have taken steps to actively engage caregivers as partners during both the recruitment and implementation processes of the research. In the recruitment process we have worked to create open communication. The consenting process normally occurs over multiple meetings in which parents have the opportunity to communicate with physicians, physical or occupational therapists, nurses and study staff members about questions and concerns they have about participation. An informational video was created in order to facilitate a low pressure environment in which parents can make a decision about participation in the study.

Sensitivity toward the needs of our participants is maintained all through the duration of the study. Open communication is facilitated through use of monthly phone calls, which assess study adherence and give participants the opportunity to express questions or concerns to the study staff, nurses, therapists and physicians.

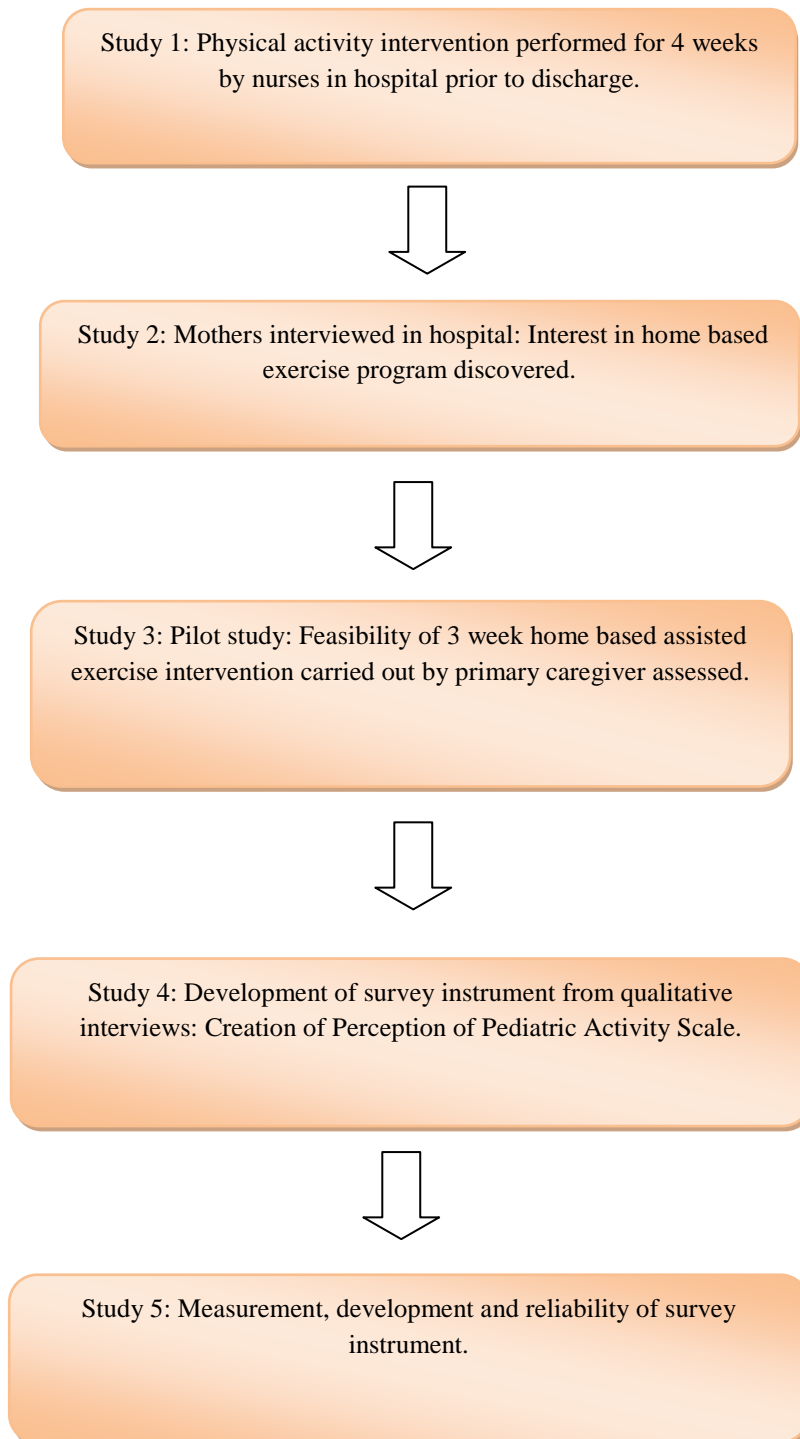
Both the daily control and intervention activities have been specifically designed to accommodate the needs and concerns of the preterm infant mother. Mothers are able to conveniently complete the study activities at any time throughout the day. Some mothers prefer to complete all activities at one time, which can take between 15 and 35 minutes. Many mothers have expressed that they prefer to break up the activities throughout the day, completing a few minutes at a time in order to give the infant breaks. In order to accommodate for these preferences, the activities have been designed so that they can be performed at the time of other daily activities. The therapist teaching the exercises to the mothers suggest which exercises are appropriate to perform either before or after changing their infant, or before putting the infant to sleep, etc.

Because we are aware of many ethical concerns in conducting research with this vulnerable population, the study has been designed to include a program of best practices in structured social interaction that is provided to both the control and exercise intervention groups. This program enhances maternal child interaction which may aid in cognitive development. Throughout their yearlong participation, parents are shown videos and given handouts that address topics including infant communication, social and emotional needs, and emotional regulation. By incorporating these activities into the interventions of both arms of the study we ensure that all participants can benefit from their involvement in the research. Scrap books have been created to detail each infant's growth and development progress throughout their participation, in hopes that the book will reaffirm to parents the important role they and their infants play in the progress of scientific research.

Conclusion

We have found that by making these modifications, based on input from the research participants, we have built trust with them and increased recruitment and adherence. Our hope is that new ideas and evolving practices will be more readily accepted when they are discovered through a research process that is sensitive to the needs of participants. Our approach to research and to the design of our study has allowed us to learn from our participants and thus develop a caregiver-dependent intervention program that, if proven effective, we believe will be feasible to integrate into the standard of care treatment for premature infants. This design and approach to research allows for societal practices to be altered in response to scientific discovery. Similarly, scientific research is shaped by societal attitudes, perceptions and needs. By engaging society in the scientific process, new discoveries that are relative to societal needs can be made and implemented affectively.

Figure 1: Identifying Factors Influencing Mothers' Perceptions of Engaging in Physical Activity With Premature Infants



REFERENCES

- Behrman, R.E. and A.S. Butler. 2007. *Preterm Birth: Causes, Consequences, and Prevention*. Washington, D.C.: National Academies Press.
- Casey, P.H., 2008. "Growth of low birth weight preterm children." *Semin Perinatol* 32:20-27.
- Costeloe, K., Hennessy, E., Haider, S., Stacy, F., Marlow, N. and Draper, E. 2012. "Short term outcomes after extreme preterm birth in England: comparison of two birth cohorts in 1995 and 2006 (the EPICure studies)." *BMJ* 4:345.
- Eliakim, A. and D. Nemet. 2005. "Osteopenia of Prematurity- The role of exercise in prevention and treatment." *Pediatric Endocrinology Reviews* 2(4):675-82.
- Galilei, Galileo and Christoph Scheiner. 2010. *On Sunspots*. Translated and with an introduction by Eileen Reeves and Albert Van Helden. Chicago: University of Chicago Press.
- Gold Eggs Quotations. 2011. "George Bernard Shaw Quotations." Accessed December 8, 2012. <http://oaks.nvg.org/wm4ra12.html>.
- Gravem, D., Lakes, K., Teran, L., Rich, J., Cooper, D. and Olshansky, E. 2009. "Maternal perceptions of infant exercise in the neonatal intensive care unit." *J Obstet Gynecol Neonatal Nurs* 38: 527-533.
- Greenough, A. 2008. "Long-term pulmonary outcome in the preterm infant." *Neonatology* 93:324-327.
- Greer, F.R. 2007. "Long-term adverse outcomes of low birth weight, increased somatic growth rates, and alterations of body composition in the premature infant: review of the evidence." *J Pediatr Gastroenterol Nutr* 45(3): S147-S151.
- Gregory, George, Joseph Kitterman, Roderic Phibbs, William Tooley and William Hamilton. 1971. "Treatment of the idiopathic respiratory-distress syndrome with continuous positive airway pressure." *The New England Journal of Medicine* 284(24): 1333-1340.
- Harrison, V.C., Heese, V., and Klein, M. 1968. "The significance of grunting in hyaline membrane disease." *Pediatrics* 41:549-559.
- Kuhn, T.S. 1962. *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.
- Langer, V.S. 1990. "Minimal handling protocol for the intensive care nursery." *Neonatal Network* 9:23-27.
- Long, J.G., Philip, A.G., and Lucey, L.F. 1980. "Excessive handling as a cause of hypoxemia." *Pediatrics* 65:203-207.
- National Institute of Child Human Development (NICHD). 2012. "Safe to sleep public education campaign." Accessed Dec 09, 2012. <http://www.nichd.nih.gov/SIDS/Pages/sids.aspx>.
- Olshansky, E., Lakes, K., Vaughan, J., Gravem, D., Rich, J., David, M., Nguyen, H., and Cooper, D. 2012. "Enhancing the construct and content validity of rating scale for clinical research: Using qualitative methods to develop a rating scale to assess parental perceptions of their role in promoting infant exercise." *The International Journal of Education and Psychological Assessment* 10(1): 36-50.
- Shaw, George, B. 1909. *The Doctor's Dilemma: Preface on Doctors*.
- Singhal, A. 2006. "Early nutrition and long-term cardiovascular health." *Nutr Rev* 64:S44-S49
- Willinger, M., Hoffman, H.J., Hartford, R. B. 1994. "Infant sleep position and risk for sudden infant death syndrome: report of meeting held January 13 and 14, 1994, National Institutes of Health, Bethesda, MD." *Pediatrics* 93(5):814-9.

ABOUT THE AUTHORS

Dr. Ellen Olshansky: Dr. Olshansky is a professor and director of the Program in Nursing Science at the University of California, Irvine. She is part of the Leadership Team of the Community Engagement Unit of the Institute for Clinical Translational Science at UC Irvine. She also serves as co-chair of the Expert Panel on Women's Health of the American Academy of Nursing. Her research focus is on women's and family health, as well as women across the lifespan and qualitative research methods. She earned a B.A. in social welfare from the University of California, Berkeley and then went into nursing and earned a B.S., M.S., and PhD in nursing science from the University of California, San Francisco.

Jessica Vaughan: Ms. Vaughan is a medical student at the University of California Irvine School of Medicine. She completed her undergraduate degree in Biological Sciences at UC Irvine earning Phi Beta Kappa and Cum Laude honors. She served as a clinical research coordinator in the UC Irvine Department of Pediatrics for two years. Her research interests include exercise and preventative medicine. She hopes to pursue a career in pediatrics or obstetrics and gynecology.

Kelsi Sando: Ms. Sando began working with the Department of Pediatrics during her undergraduate education at the University of California, Irvine. After graduating with a Bachelor's of Science degree in Biological Sciences, she has been serving as an Assistant Clinical Research Coordinator in the Department of Pediatrics. She hopes to pursue a career in medicine. Her medical and research interests include integrative and alternative medicine.

Julia Rich: Julia Rich, RN, BSN, is a research coordinator and administrative nurse III in the Department of Pediatrics, School of Medicine, University of California, Irvine. She is interested in the mitigation of health problems associated with preterm birth. Under the vision of Dr. Dan M. Cooper, director of the Institute for Clinical and Translational Science, she is currently coordinating an NHLBI-funded research project, which has developed an intervention designed to increase physical activity of premature babies during their first year of life. She feels that this project is especially motivating because it is focusing on the whole family and the relationships between family members. It is rewarding to see how behavior change can be encouraged through development of a partnership with the family.

Dr. Kimberley Lakes: Dr. Lakes is an assistant professor in the Department of Pediatrics at the University of California, Irvine. Her research interests include the development of executive function and self-regulation, intervention to promote executive functions in children, and research methods. Her research translates cognitive neuroscience into novel intervention practices. Currently, she is studying exercise interventions that could optimize effects on executive function in children.

Dr. Daniel Cooper: Dr. Cooper is a professor of pediatrics, UC Irvine Chief, Pediatric Pulmonology Division, the founding director of the Institute for Clinical Translational Science and the program director of the UC Irvine Clinical Research Center. His research seeks to identify how exercise can best be used to prevent asthma and obesity in children, in particular, how brief bouts of exercise alter gene expression and functional responses of neutrophils. The neutrophil is a unique cell capable of instigating disease processes such as the common exercise-induced asthma. At the same time, conditioning of neutrophils by physical activity can play a role in how exercise prevents diseases such as atherosclerosis. He is particularly interested in new therapies involving both pharmacologic and lifestyle interventions.

The Red Day Star, the Women's Star and Venus: D(L/N)akota, Ojibwe and Other Indigenous Star Knowledge

Annette S. Lee, St. Cloud State University, USA

Jim Rock, Augsburg College, USA

William Wilson, St. Cloud State University, Fond du Lac Tribal & Community College, USA

Carl Gawboy, St. Cloud State University, Fond du Lac Tribal & Community College, USA

Abstract: In Ojibwe the Morning Star is called I'kwe Anung, which means the Women's Star. In D(L/N)akota the same planet Venus is called Anpetu D/Luta Wiçanłipi the Red Day Star. Both cultures have rich and interesting understandings of Venus that relate to other Indigenous cultures throughout the world. Venus is so often related to the feminine because native peoples carefully watched the movement of the 'star' and saw it in the east at sunrise for nine months and then in the west at sunset for the following nine months. Nine months is exactly the time for human gestation. Yet, tragically, the native star knowledge is disappearing as elders pass. The Native Skywatchers project focuses on understanding the Ojibwe and D(L/N)akota importance of this and other celestial connections. MN State Science Standards K-12 requires "Understanding that men and women throughout the history of all cultures, including Minnesota American Indian tribes and communities, have been involved in engineering design and scientific inquiry....For example Ojibwe and Dakota knowledge and use of patterns in the stars to predict and plan." And yet there is a complete lack of materials. Working closely with a team of culture teachers and language experts we are building community around the native star knowledge.

Keywords: Ojibwe Astronomy, Lakota Astronomy, Archaeoastronomy, Indigenous Astronomy, Astronomy and Native Culture, Science and Culture Curriculum, Science Education, Astronomy Education, Venus, Venus and the Feminine

Introduction and Purpose

In Ojibwe the Little Dipper is *Ojiig* – the Fisher (Morton and Gawboy 2000, 175-177; Gawboy 2005) and in D(L/N)akota star knowledge the same group of stars is seen as *To Win/Toy Wij*—Blue Woman/Birth Woman (Goodman 1992, 22). In each there are stories and teachings that help guide, teach and inspire native peoples. The *Native Skywatchers* Project focuses on understanding the Ojibwe and D(L/N)akota importance of these and other celestial connections. We seek to address the crisis of the loss of the indigenous star knowledge, specifically the native peoples of Minnesota, Dakota and Ojibwe. The purpose of this programming is to remember, rebuild and revitalize the native star knowledge.

There is urgency to this project for two reasons: the native star knowledge is disappearing as elders pass and state standards. One Ojibwe elder spoke of his vision of 'the star medicine returning through the native youth.' He specifically called them 'star readers' (P. Schultz, pers. comm.). In 2011 he passed away suddenly. At the same time, the new MN State Science Standards K-12 requires "Understanding that men and women throughout the history of all cultures, including Minnesota American Indian tribes and communities, have been involved in engineering design and scientific inquiry....For example Ojibwe and Dakota knowledge and use of patterns in the stars to predict and plan" (Minnesota Department of Education, 2010). And yet there is a complete lack of materials.

This research, *The Native Skywatchers Project*, seeks out elders, culture teachers and language experts to discuss the Ojibwe and D(L/N)akota star knowledge. From these sources and working with the elders we have created two astronomically accurate, culturally important star maps, *Ojibwe Giizhig Anung Masinaaigan – Ojibwe Sky Star Map* and *Makoçe Wiçanłipi Wowapi – D(L)akota Sky Star Map*. These valuable maps were disseminated to regional

educators at the *Native Skywatchers Middle School Teacher* workshop June 2012. In addition, hands-on curriculum that combines astronomy, culture, language and art has been developed. As with many North American tribes much cultural knowledge, especially cultural astronomy, has been lost. The goal of the *Native Skywatchers* programming is to build community around the native star knowledge.

Procedures and Methods

The *Native Skywatchers* programming is led by the author, Annette Lee, Professor of Astronomy and Planetarium Director at St. Cloud State University. Funding has been provided by: NASA-MN Space Grant, North Star STEM Alliance, St. Cloud State University and Fond du Lac Tribal and Community College. This project represents a unique collaboration between a large state university, a tribal and community college and federal agencies. The strategy of the project is to combine astronomical expertise, cultural knowledge and artistic talents to create programming such as star maps, constellation guides, and curriculum that currently does not exist. Regional teachers requesting information relating to the native star knowledge also motivated the creation of the map and related curriculum. This was clearly related to the new MN State Science Standards K-12, in particular benchmark 3.1.3.2.1 “*Understand that everybody can use evidence to learn about the natural world, identify patterns in nature, and develop tools*” (Minnesota Department of Education, 2010).

Travel and interviews were conducted to consult with various Ojibwe and D(L/N)akota cultural experts, such as Carl Gawboy (Boise Forte), Paul Schultz (White Earth), and William Wilson (Lake Nipigon), Jim Rock (Dakota), Charlene O'Rourke (Pine Ridge), Albert White Hat (Rosebud), Duane Hollow Horn Bear (Rosebud) and Arvol Lookinghorse (Green Grass) over a three-year period. Astronomical, language and cultural teachings were shared and recorded.

A culminating focus of the Native Skywatchers project was the creation of two star maps: *Ojibwe Giizhig Anung Masinaaigan* – Ojibwe Sky Star Map and *Makoçe Wiçañhpi Wowapi – D(L/N)akota Sky Star Map*. The maps are organized with Polaris –the North Star in the center. This is to emphasize the closeness of Polaris to our current north celestial pole (NCP) and circumpolar motion. Because of circumpolar motion, we appear to see all the stars in the night sky revolve around the North Star in a counter-clock wise motion as the hours pass each night into day. Because of this motion, in some native cultures the North Star is seen as one of the leaders of the star nation. The ‘Northern Stars’ referred to here by the Ojibwe and D(L/N)akota people are the circumpolar stars as seen from approximately 45-55° N latitude, 85-110° W longitude.

All stars not circumpolar, as seen from 45-55° N latitude, will rise in the east and set in the west at regular times throughout the year. They are seasonal stars. The *Ojibwe Giizhig Anung Masinaaigan* – Ojibwe Sky Star Map and *Makoçe Wiçañhpi Wowapi – D(L)akota Sky Star Map* are arranged in order to show the constellations that are best visible each season. This assumes a viewing time of about two to three hours after sunset. In the night sky stars of each season can be best seen overhead or in the south during that particular season. For example if you look at the stars in the early summertime, a few hours after sunset you will see Hercules overhead and Scorpio low on the southern horizon. These are early summer stars.

Results

Venus

Venus is the third brightest object in the sky after the Sun and the Moon. It is so bright that it is often mistaken for a UFO. This is because Venus is the closest planet to us at only about 25 million miles (compared to Mars at 47 million miles at closest approach). Its brightness is

completely due to light reflected from the Sun, like Earth and all terrestrial planets Venus does not generate any visible light. Venus' light is especially bright because it is covered in white, reflective clouds. For this reason, people had a fascination with 'life on Venus' in the early twentieth century, as we could not see what was underneath the clouds. In the 1960's the first missions used radar wavelengths to cut through the cloud layer and see the topography underneath. We found extensive volcanism (Head, J. et al. 1992).

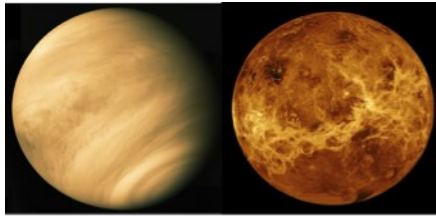


Fig. 1: Venus Visible wavelengths (left), Radar (right) (Photo courtesy of NASA)

Ojibwe Connection to Venus

In Ojibwe star knowledge, Venus is known as *I'kwe Anung* – Women's Star (C. Gawboy, unpublished data). This name has multiple layers of meaning. The first understanding is that native Ojibwe people carefully observed the motion of Venus each day/night and found patterns in the movement. The pattern of Venus' movement as seen from an observer on Earth is that Venus will appear in the east before sunrise (the Morning Star) and then in the west just after sunset (the Evening Star). The pattern repeats on a nine-month cycle. A person can watch Venus in the morning for about nine months; it disappears for a short time and then reappears in the opposite sky at sunset for about nine months. Then the cycle repeats. Remarkably this nine-month cycle is the same time as for human gestation. This is why Ojibwe and other indigenous cultures have associated Venus with the feminine.

Another connection between Venus and women is that traditional Ojibwe women were responsible for gathering the water. Very commonly women would rise very early before sunrise to gather water for the camp. (C. Gawboy, pers. comm.) It should also be noted that Venus is also called *Waabun'Anung* – East Star, which is translated 'Morning Star'. This is due to the fact that Venus is visible for about half of its cycle in the east just before sunrise.

D(L/N)akota Connection to Venus

In D(L/N)akota, the word for Venus is *Anpetu D/Luta Wiçanĥipi*, which translates 'Red Day Star' (A. Lookinghorse, pers. comm.). This idea has several layers. The first understanding is literal. The 'star-like' point of light that is the planet Venus, and the surrounding sky appear reddish in color. This is because Venus can only be seen low on the east or west horizon at sunrise or sunset. When celestial objects are positioned low in the sky (or just above the horizon), they appear reddish. This is due to Rayleigh scattering. The longer path of sunlight through the atmosphere at low elevations removes almost all of the blue and green light.



Fig. 2: Scattering of Sunlight at Sunset. (Photo by A. Lee.)

Another layer of meaning in *Anpetu D/Luta Wiçanłipi* – Red Day Star requires a cultural context. Red is a sacred color, to say a ‘red day’ is equivalent to ‘a sacred day’. For example, a traditional D(L/N)akota person wakes up gives thanks for life and the chance to live another day (A. Lookinghorse, pers. comm.). Recently, people refer to walking on the ‘red road’. It is a way of remembering our connection with all living beings, also stated *mitakuye oyasin/owasin*—all my relatives. *Anpetu D/Luta Wiçanłipi* – Red Day Star is considered one of the leaders of the star nation (A. Lookinghorse, pers. comm.). All families with the name *D/Luta* – Red were keepers of the star knowledge, for example: Red Eagle, Red Deer, Red Willow, Red Horse, Red Day and so on. These families traditionally protected and passed down the star knowledge from generation to generation (A. Lookinghorse, pers. comm., J. Rock, pers. comm.). Furthermore traditional star quilts were made with one large star in the center, this was in honor of *Anpetu D/Luta Wiçanłipi*– Red Day Star (A. Lookinghorse, pers. comm.).



Fig. 3: Star Quilt. (Photo by A. Lee.)

Much of the D(L/N)akota star knowledge rests on the framework of mirroring, which is said, “As it is above (in the sky), it is below (on the Earth).” *Kapemni*— can mean swinging around or mirroring in D(L/N)akota, which is drawn by two tipis/triangles connected at their apexes. When D(L/N)akota people on Earth mirror what is happening in the stars, a spiritual doorway opens up because of this connection. It is understood that the healing power of the star nation, ‘*the woniya of Wakaj Tanka*’, flows through (Goodman 1992, 31-34).

Another word for morning star is *Anpo Wiçanłipi* or *Anpao Wiçanłipi* (J. Rock, pers. comm.). This refers to dawn or ‘as the morning comes’ (Buechel and Manhart 2002, 21). In this context *Anpo Wiçanłipi* specifically refers to Venus as the Morning Star as opposed to *Wiçanłipi Hanjetu* or *Hanjetu Wiçanłipi* as Evening Star. Interestingly the star Arcturus in the Greek

constellation Bootes is called *Anpo Sunkaku Wiçanhipi*, which means Younger Brother of Morning Star (J. Rock, pers. comm.).

Other Cultural Connections to Venus

Various cultures throughout the world and spanning history have related connections to Venus. The Maya had entire codices devoted to the observational movements of Venus. They kept track of every astronomical event related to Venus: inferior conjunctions, superior conjunctions, transits, synodic orbit, etc. There are many Mayan words for Venus such as: *Noh Ek* (Big Star), *Chak Ek* (Red or Great Star), *Sastal Ek* (Bright Star) and *Xux Ek* (Wasp Star). Venus is associated with abundance, fertility, growth, death and rebirth (Milbrath 1999, 34-36). Dakota astronomer, Jim Rock, also associates Venus with related *Çekpa* Dakota and Maya traditions. (Rock 1997).

Another example of indigenous star knowledge relating to Venus comes from the Aboriginal Australian Yolngu people who know Venus as *Banumbirr*. They conduct a 'Morning Star Ceremony' that serves to help relatives communicate with those passed away. The ceremony goes from sunset to sunrise when Venus first re-appears as the Morning Star. On a really dark, clear night Venus can be seen with a faint band of light that stretches down towards Earth, zodiacal light. This is understood as *Banumbirr* and a rope that connects her to the island of Baralku. There is a strong component of mirroring in the ceremony with a Morning Star Pole that includes Venus and the rope (Norris 2009, 18-22).

Lastly, the Greeks associated the planet Venus with the goddess of love, Aphrodite. Later the Romans changed the planet's name to the goddess Venus (Krupp 1992, 177). Both of these have a strong, clear connection to the feminine. Venus is the only planet in our Solar System with a feminine name. In addition, all but three of the surface features on Venus were given feminine names as declared in 1919 by the International Astronomical Union.

Ojibwe Star Map

The Ojibwe map is a collaborative work between Annette Lee, William Wilson and Carl Gawboy. The Ojibwe constellations are a result of the research and work of Carl Gawboy over a forty-year period (C. Gawboy, unpublished data). Traditional Ojibwe x-ray style was used by William Wilson to paint the Ojibwe constellations. It is symbolic of seeing the unseen. It is an allegory for the material world and the spirit world. The brightly colored internal organs and anatomical shapes are a glimpse into the inner layers of our bodies. "We are seeing the picture as the spirits see us. They see right through. The strange looking animals and figures are portrayed as they come in ceremony. Sometimes they are half beaver, half eagle. Sometimes they are scary. Sometimes tempting.", explains William Wilson (W. Wilson, pers. comm.).

The border includes: strawberries, raspberries, blueberries and winterberries (traditional Ojibwe foods) illustrated in reference to Ojibwe style floral beadwork. Often the floral beadwork is done on black velvet or with a white beadwork background. Usually beadwork is done on items of importance spiritually or socially like pipe bags, moccasins, leggings, etc.



Fig. 4: Ojibwe Star Map created by A. Lee, W. Wilson, C. Gawboy (Photo by A. Lee.)

Ojibwe Fall Stars

Dagwaagin is the Ojibwe word for fall. On the right quadrant of the map are the constellations best seen in the fall. The four bright stars in the shape of a square indicate the Ojibwe *Mooz*—Moose constellation. In Greek mythology these are the brightest stars of Pegasus, the winged horse. The moose is complete with legs stretching into Pisces, the moose’s head pointing westward towards Cygnus, the swan and the moose’s horns overlap with the Greek constellation, Lacerta. Located inside the large square are three stars that mark the moose’s heart. This fall constellation can be seen in the Ojibwe pictographs at the Boundary Waters Canoe Area in northern Minnesota (Morton and Gawboy 2000, 189-191). High up on the cliffs at North Lake Hegman, the *Mooz* constellation is painted on the rock face, complete with heart line of stars indicated.



Fig. 5: Lake Hegman, Ojibwe Pictographs at Lake Hegman (Photo by A. Lee.)

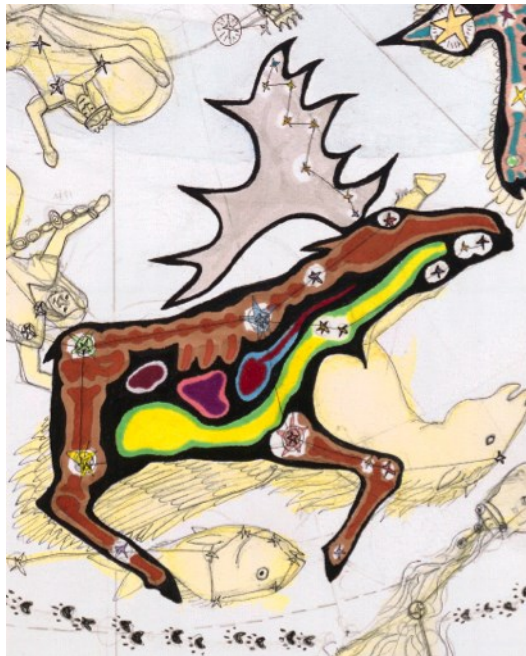


Fig. 6: *Mooz*– Moose Constellation (Photo by A. Lee.)

Ojibwe North Stars

Giwedín is the Ojibwe word for North. These important stars are found in the center of the map. The Ojibwe fisher, *Ojig* is found overlaying the Greek constellation Ursa Major (which includes the asterism Big Dipper). Here is an example of the keen observation skills of the Ojibwe people. The behavior of the fisher mirrors the motion of the stars. The fisher is known to be neither

nocturnal nor diurnal in its sleeping and hunting patterns (W. Wilson, pers. comm.). It hunts, sleeps, then hunts again, not returning to the same den; is it constantly on the move. Those that watch the stars know that most stars are seasonal, but only those found within 45-55° of the North Celestial Pole will be circumpolar. This set of stars is referred to here as ‘the North Stars’. They appear to rotate counterclockwise about Polaris in a regular 24-hour year-round pattern. In addition, the fisher is a small but ferocious fighter known for its ability to kill porcupines. This relates to some traditional Ojibwe stories that involve the heroic acts of the fisher. The only star that appears not to move in the northern hemisphere night sky, Polaris, is part of the Ojibwe constellation, *Maang* or loon. The loon constellation relates to the Ojibwe clan system. Loons are the leaders of the people (Benton-Banai 1988, 74-78).



Fig. 7: *Ojig*– Fisher and *Maang*– Loon constellations (Photo by A. Lee.)

D(L/N)akota Star Map

The D(L/N)akota map, *Makoče Wicahpi Wowapi* was painted by the author, Annette Lee and the Dakota astronomy and language consultant was Jim Rock. The map is based on the chart found in the book “Lakota Star Knowledge” by R. Goodman and his interviews with many Lakota elders (Goodman 1992, 65). The star map was painted in reference to D(L/N)akota beadwork. It is said that each bead is a prayer. Beads are traditionally used to beautify sacred items like medicine bags and pipe stems. Also beadwork is used to adorn clothing or accessories, like on an outfit to wear to a special occasion. Beaded items are worn with great pride, for example, pow-wow regalia. The pinpoint of colorful dots in beadwork are reminiscent of starlight. The process of doing beadwork is meticulous and disciplined; it requires stillness. This stillness is echoed in the night sky. Beadwork and stars both sparkle.

The four directions are seen as spiritual and physical guideposts. Often seven directions are used which includes the four cardinal directions plus above, below and center. Many ceremonies and everyday prayers use the directions to focus and send the prayers. Albert White Hat explains the four directions as *Tateuye ɔpa* - the four winds. The cardinal direction North in particular is associated with the wintertime and stillness. Trees and plants appear ‘dead’ on the outside in the winter, but they are still alive and growing on the inside, especially the roots. In wintertime people look to follow this example and practice stillness that will nurture inner growth. Each of the solstices and equinoxes mark the beginning of a season and are considered sacred days and good times to pray and have ceremony. Albert White Hat explains, “The seasons are described as births. Every season is a new birth” (White Hat Sr. 1999, 93-94).

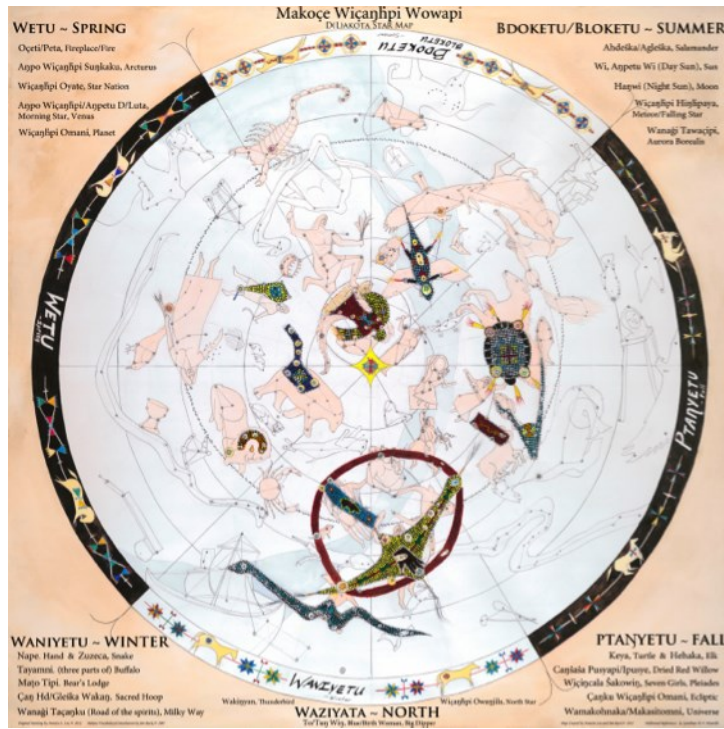


Fig. 8: D(L/N)akota Star Map created by A. Lee, J. Rock (Photo by A. Lee.)

D(L/N)akota Fall Stars

Ptanyetu is the D(L/N)akota word for fall. On the right quadrant of the map the D(L/N)akota constellations that are best seen in the fall are located as follows: *Keya* – Turtle, *Hehaka* – Elk and *Caņšaša Ipusye* – Dried Willow. The Turtle, *Keya* constellation refers to the medicine bag made for girls. The turtle’s attributes of long life, steadfastness and fortitude are connected with the feminine. (Goodman 1992, 37-41) *Hehaka* – elk is associated with love and romance. (J. Rock, pers. comm.) *Caņšaša Ipusye*– Dried Willow (Red Osier Dogwood) is plant medicine used for the sacred pipe and other ceremonies.

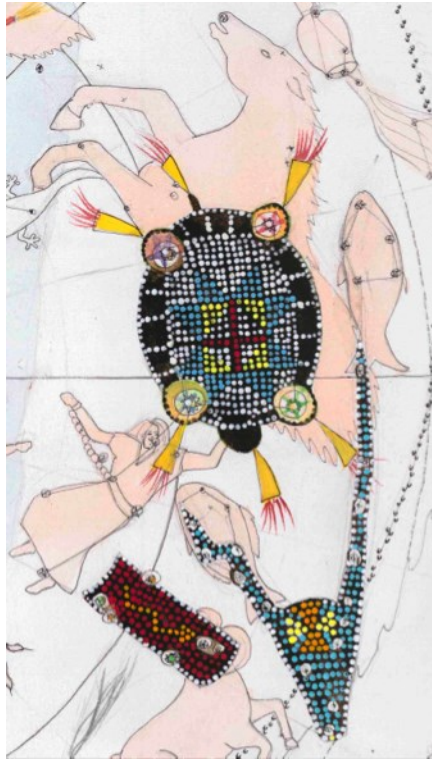


Fig. 9: *Keya*– Turtle, *Hehaka* – Elk and *Canšasa Ipusye*– Dried Willow constellations (Photo by A. Lee.)

D(L/N)akota North Stars

Waziyata is the D(L/N)akota word for North. Located in the center of the map are the circumpolar stars that are seen all seasons from the Northern Hemisphere. Over the north celestial pole is found *Wičanłipi Owanžila/Owanžina/Owanžida*, the North Star (the Star that Stands in One Place), *Wakiŋyaŋ* –Thunderbird, and *To Win/Tuŋ Wiŋ* - Blue Woman/Birth Woman overlaps with the Big Dipper/Ursa Major constellation. There is a depth of knowledge contained here in the northern night sky. Simply put, *To Win/Tuŋ Wiŋ* - Blue Woman/Birth Woman is a spirit that acts as a doorkeeper between the spirit world and the material world. She helps those crossing between the worlds; i.e. babies and recently deceased. The *Wakiŋyaŋ* – Thunderbird constellation overlaps with the Greek constellation Draco the dragon. *Wakiŋyaŋ* – Thunderbird constellation is also at the center of the precession circle. The Sun and Moon’s gravitational pull on the Earth cause a small wobble in the Earth’s axial tilt over a 26,000-year period. The heart of the Thunderbird, *Wakiŋyaŋ* constellation is at the center of this precession circle in the northern sky. This is an excellent example of the keen awareness and deep astronomical knowledge of the D(L/N)akota people. The word *Wakaŋ* means “the power to give life or to take it” (A. White Hat Sr., pers. comm.) and associating the thunder beings with both destructive and life giving powers is understood on several levels. On Earth, lightning and thunderstorms are often destructive forces causing forest and home fires. On the other hand, this same force can be a cleansing part of a natural cycle of growth, for example, prescribed burns. Astronomically there is another important connection, the stable axial tilt of the Earth over long periods of time is thought to be an important factor in the habitability of life on a planet, indeed

some theories suggest that life itself might have been sparked in the primordial soup by lightning (Cairns-Smith et al. 1992, 161-180).



Fig. 10: *Wiçajłipi Owaŋžila/Owaŋžina/Owaŋžida*, the North Star, *Wakinyan*–Thunderbird, *To Win/Tuŋ Wij* - Blue Woman/Birth Woman Constellations (Photo by A. Lee.)

Conclusion and Future Directions

The methods presented here are interdisciplinary. Astronomy, culture, art and language are all represented in this research. And yet the delivery of such an in-depth, interdisciplinary topic like indigenous astronomy can be overwhelming to students, adults or youth, that have grown up with light pollution, tall buildings, and computers. Unlike traditional native people, current members of society spend a lot of time indoors. Most people have some familiarity with the Big Dipper, Sun and Moon. The delivery of this culturally rich material must be simple and yet allow for complexity and abstraction. To achieve this goal we first use the cultural framework of the four directions. The current night sky is subdivided into: north, east, south/overhead, and west. From the beginning of the discussion the cultural context is intact. The four directions are considered important framework and guideposts in native culture. This instructional approach builds on a sense of place that often native peoples are aware of (Semken 2005) and allows participants to connect the current night sky to sense of place. This technique grounds the complexity of the current night sky in the tangible and the simple, and yet allows for a multi-layered, circular learning approach. Following this approach allows for the widest range of participants to take part in the learning experience.

Furthermore, the stars and constellations can be best understood in terms of the four seasons. The discussion is simplified again by fixing the time as a few hours after sunset. This is the observing time, and is referred to as ‘prime time’ for stargazing. Only in the northern direction will the circumpolar stars, or North Stars as seen from approximately 45-55° N latitude, 85-110° W longitude, be visible throughout the year. When an observer faces due south (azimuth 180° along the horizon) he/she will see the current season of stars. The previous season will be seen setting in the west and the following season will be seen rising in the east. The *Ojibwe Giizhig Anung Masinaaigan* – Ojibwe Sky Star Map and the *Makoçe Wiçajłipi Wowapi – D(L)akota Sky*

Star Map are best presented by transforming the discussion into an experiential, hands-on event. In addition, this highly visual, holistic and cooperative learning environment is more consistent with a traditional native learning style (Cleary and Peacock 1997).

Lastly, the *Native Skywatchers Project* is a collaborative approach. Native knowledge is sometimes a different way of knowing than Western science. There are strict cultural protocols that must be respected, such as some stories are to be told only when there is snow on the ground. We must be extremely careful not to introduce or propagate error into the written or oral records. Use caution and be hesitant. The orthography used here is 'D(L/N)' to represent the Siouan language spoken by the *Oceti Sakowin Oyate* – the People of the Seven Starfire/Campfire Nations - Dakota, Lakota, and Nakota nations. Also note that sometimes terms are now heard with the adjective preceding the noun, although traditionally the reverse was true. Users of these materials are urged to seek out elders and native community members to bring into the classroom. Materials represented here should be viewed as a beginning.

Acknowledgements

The *Native Skywatchers* project acknowledges the elders and others that have kept this star knowledge alive. We acknowledge Paul Schultz (White Earth) who passed away suddenly in 2011 and Albert White Hat Sr. (Rosebud) who passed away in June 2013. Both men were collaborators with this project.

REFERENCES

- Aveni, A. 2001. *Skywatchers of Ancient Mexico*. Austin: University of Texas Press.
- Benton-Banai, E. 1988, 2010. *The Mishomis Book: The Voice of the Ojibway*. Hayward: Indian Country Communications, Inc., Minneapolis: University of Minnesota Press, 74-78.
- Baraga, F. 1992. *A Dictionary of the Ojibway Language*. St. Paul: Minnesota Historical Society Press. First published 1878, 1880 as *A Dictionary of the Otchipwe Language* by Beauchemin and Valois.
- Buechel, E. and Manhart, P. 2002. *Lakota Dictionary*. Lincoln: University of Nebraska Press.
- Cairns-Smith, A. Graham, A. Hall, and M. Russell. 1992. "Mineral Theories of the Origin of Life and an Iron Sulfide Example." In *Marine Hydrothermal Systems and the Origin of Life*. Netherlands: Springer, 161-180.
- Cleary, L. Miller and Peacock, T. 1997. *Collected Wisdom: American Indian Education*. Boston: Allyn and Bacon.
- Furtman, M. 2000. *Magic on the Rocks*. Duluth: Birch Portage Press.
- Gawboy, C. 1992. "Ely Pictographs Linked to the Heavens," *Duluth News Tribune*, April 6.
- Gawboy, C. 2005. "Ojibway Stargazing – There's More Up There than a Greek Guy in a Tunic." *Lake Superior Magazine* 27, no. 1, March, 44-8.
- Gawboy, C. 2012. Personal Communication, Duluth, Minnesota, April.
- Goodman, R. 1992. *Lakota Star Knowledge: Studies in Lakota Stellar Theology*. Mission: Sinte Gleska University.
- Head, J., L. S. Crumpler, J. Aubele, J. Guest, and R. Saunders. 1992. "Venus Volcanism: Classification of Volcanic Features and Structures, Associations, and Global Distribution from Magellan Data." *Journal of Geophysical Research: Planets (1991–2012)* 97, no. E8: 13153-13197.
- Krupp, E. 1992. *Beyond the Blue Horizon: Myths and Legends of the Sun, Moon, Stars and Planets*. New York: Oxford University Press.
- Lankford, G. 2007. *Reachable Stars: Patterns in the Ethnoastronomy of Eastern North America*. Tuscaloosa: University of Alabama Press.
- Lookinghorse, A. 2012. Personal Communication, Green Grass, South Dakota, May.
- Minnesota Department of Education. 2010, "Minnesota Academic Standards – Science K-12." Retrieved from <http://education.state.mn.us/MDE/EdExc/StanCurri/K-12AcademicStandards/index.htm>.
- Milbrath, S. 1999. *Star Gods of the Maya: Astronomy in Art, Folklore, and Calendars*. Austin: University of Texas Press.
- Morton, R. and Gawboy, C. 2000, 2003. *Talking Rocks: Geology and 10,000 Years of Native American Tradition in the Lake Superior Region*. Minneapolis: Pfeifer-Hamilton Publishers), (Minneapolis: University of Minnesota Press.
- Nichols, J. and Nyholm, E. 1995. *A Concise Dictionary of Minnesota Ojibwe*. Minneapolis: University of Minnesota Press.
- Norris, R. and Norris, C. 2009. *Emu Dreaming: An Introduction to Australian Aboriginal Astronomy*. Sydney: Emu Dreaming.
- Riggs, S. 1992 (1890). *A Dakota-English Dictionary*. St. Paul: Minnesota Historical Society Press.
- Rock, J. 1997. *Multicultural Science and Math Synesthesia: Thinkin' Inkan and Applyin' Mayan as a Mni Sota Dakota*. Hamline University, MN.
- Rock, J. 2012. Personal Communication. Minneapolis, Minnesota, March.
- Semken, S. 2005. "Sense of Place and Place-Based Introductory Geoscience Teaching for American Indian and Alaska Native Undergraduates." *Journal of Geoscience Education* 53, 149-157.

Weltfish, G., 1977 (1965). *The Lost Universe: Pawnee Life and Culture*. Lincoln: University of Nebraska Press.

White Hat Sr., A. 1999. *Reading and Writing the Lakota Language*. Salt Lake City: University of Utah Press.

White Hat Sr., A. 2012. Personal Communication. Rosebud, South Dakota, May.

Wilson, W. 2012. Personal Communication. St. Cloud, Minnesota, January.

ABOUT THE AUTHORS

Annette S. Lee: Annette Lee (mixed-race Dakota-Sioux) is an assistant Professor of Astronomy and Physics and Director of the Planetarium at St. Cloud State University in central Minnesota. The crisis my work addresses is preventing the loss of Ojibwe and Dakota/Lakota star knowledge. Elders are passing. Otherwise knowledgeable native elders tell me that they "...just weren't listening when the star stories were being told." Others talk of new generations of 'star readers' and how the star medicine will be brought back by the younger generation. Interwoven in the star knowledge is the language, which holds keen insight and observation far beyond what people practice today. My goal is to help preserve indigenous astronomy and pass it on to present and future generations. The Native Skywatchers Program is about creating sustainable change by building community around the native star knowledge. Having graduate degrees in Astrophysics (Washington Univ. 2009) and Painting (Yale 2000) and a UC-Berkeley alumni in Applied Mathematics (1992) the Native Skywatchers project bridges many worlds—learning from elders; relating Native star knowledge to Western knowledge; inspiring youth in science; engaging audiences through culture, art and science.

Jim Rock: Jim Rock (Dakota) has a Master's degree in education and has taught astronomy, chemistry and physics for thirty years for thousands of students in universities and high schools from urban, suburban and reservation communities. He currently teaches a Native Skywatchers course at Augsburg College offering indigenous cosmology lessons to teachers throughout Minnesota in collaboration with Annette Lee at St. Cloud State University and Fond du Lac Tribal & Community College. Jim is currently a consultant with both NASA and NOAA using satellite visualization and storytelling, and he had an experiment on the last space shuttle STS-135. His Sisseton Dakota grandmother was a Red Day.

William Wilson: William Wilson (Lake Nipigon-Ojibwe) is from Ontario, Canada near Lake Nipigon (*Animbigon Zaaga'igan*-All You See Is Water). He was born and raised at his grandparent's house, speaking Ojibwe every day and living in a traditional way. Winter camp, snowshoeing, trapping, fishing, moose hunting and blueberry picking were a part of everyday life. William is a member of the Native Skywatchers team, a culture and language teacher, ceremonial/spiritual leader and a professional visual artist.

Carl Gawboy: Carl Gawboy (Boise Forte-Ojibwe) is from Ely, Minnesota, and is a prizewinning watercolorist. Recently, he has been a co-author with Ron Morton on the books, *Talking Rocks* and *Ancient Earth*. He retired from the College of St. Scholastica, where he taught in the Indian Studies Department.

What Students Know about Science

Chris Impey, University of Arizona, USA

Abstract: Science literacy is foundational in any society shaped by science and technology. Surveys of the U.S. general public by the National Science Foundation show an average score of less than 2/3 correct on a series of science knowledge questions, and fewer than half of the respondents show any significant understanding of the process of scientific inquiry. These measures are unchanged for two decades. At the University of Arizona, we have measured science knowledge and beliefs on scientific issues for 11,000 undergraduate students since 1989, using an instrument that overlaps with the NSF survey. This population of non-science majors is typical of ten million undergraduate students nationwide. There is a less than 10% gain in performance in the science knowledge score between the incoming freshmen and seniors who graduate having completed their requirement of three science classes. Variables such as the number of science courses and the level of pseudoscientific belief account for less than 10% of the variance in science knowledge scores. It is also clear in a related survey on where students get their information about science that the Internet is the dominant source, not the classroom, teacher, or textbook. This is the first study to track the evolution and progression of science literacy in the undergraduate population, and relate it to belief systems. If this situation is to be improved, scientists and policy makers need to decide what aspects of science knowledge and process are important for adults to know, and school and college science educators need to tailor their pedagogical approaches with those goals in mind.

Keywords: Science Literacy; Undergraduate Education, Knowledge, Belief Systems, Sources of Information, Pseudoscience

Introduction

Science and technology are pervasive influences on anyone living in the modern, industrialized world. Americans encounter science daily as citizens, workers, and consumers. They vote for political candidates with wide-ranging views on climate change, genetic engineering, nuclear power, and the space program. They compete for jobs in technology-driven sectors of the economy that didn't exist a generation ago. They are avid consumers of high-technology devices, and are mostly content to use these ubiquitous emblems of scientific ingenuity with no real knowledge of how they work. Science profoundly shapes human culture, but it's difficult to gain insights into the natural world without understanding how scientific knowledge is gained and how to distinguish scientific facts from other kinds of information. This collection of skills and basic knowledge is called "science literacy." The debate on science literacy has moved firmly the public arena, with both scientists (e.g. Hazen and Trefil 2009) and journalists (Mooney and Kirshenbaum 2010) marshalling their arguments and staking out positions. This is a topic where theory and rhetoric are abundant and practical solutions are elusive, though there is widespread agreement on the need to foster a lifelong engagement of the public in the ways that science impacts and informs their daily lives (Liu 2009, Feinstein 2010).

The concept of science literacy is based on lofty ideals; what is the reality? The National Science Foundation has carried out a survey of science knowledge and attitudes for over twenty years, and it is published biennially in the *Science and Engineering Indicators* series, a report presented to the National Science Board and the U.S. Congress that shapes research and education policy and also guides workforce development in the technical fields. From its inception, these report defined literacy criteria based on: (1) a vocabulary of basic scientific constructs, (2) an understanding of the process and nature of science inquiry, and (3) some understanding of the impact of science and technology on individuals, and on society. The threshold for declaring anyone to be "scientifically literate" is based on (1) the coding of open-ended responses to the question "What does it mean to study something scientifically?" (2) a recognition that astrology is not scientific, and (3) correct answers to six or more out of nine knowledge questions. Using these criteria just one in ten American adults was declared

scientifically literate, triggering vigorous debate on the issue (Miller 1987). The NSF studies do not claim to represent a consensus definition of science literacy, they give a useful baseline for the study presented in this paper. The motivation for the new study is to measure what undergraduates know and what they believe about science and scientific issues, at the beginning and end of their college careers.

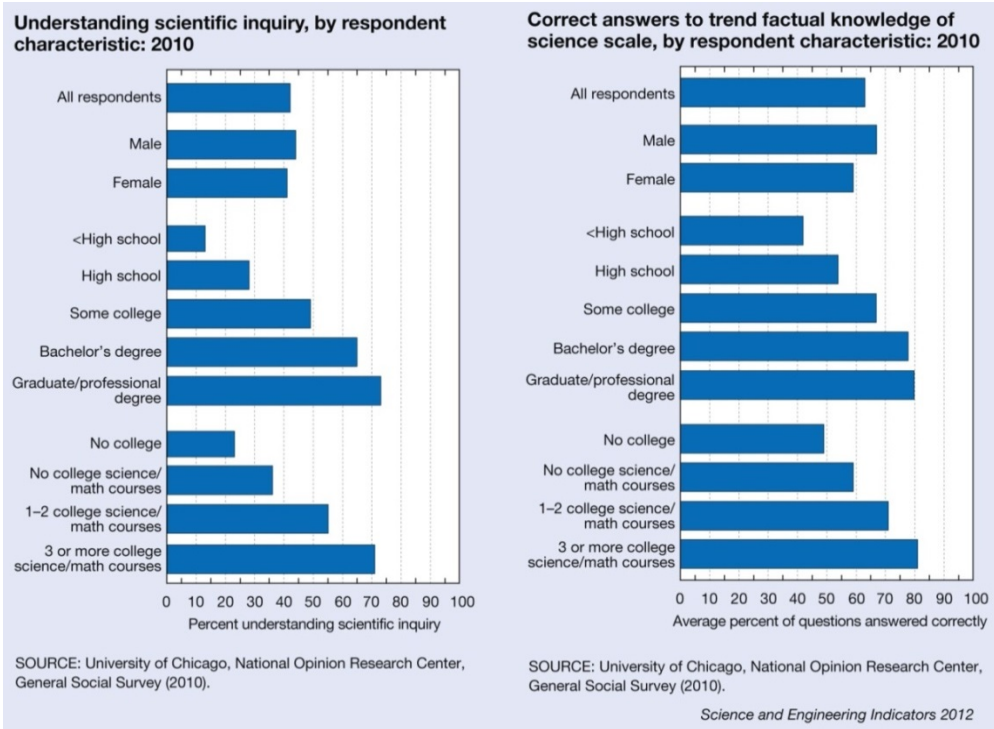


Figure 1: Percentage of the U.S. adult population able to recognize key attributes of scientific inquiry (left) and percentage of correct answers on a 9-question test of basic science knowledge (right). Details of the instruments and coding are given in the Science and Engineering Indicators 2012 report (NSB 2012).

The level of public science knowledge and familiarity with science as a method of inquiry depends strongly on level of education, and for those who attended college, on the number of science courses taken (Figure 1). Some science literacy models imply that the public has a “deficit” of knowledge or understanding compared to a benchmark that may be unrealistic, unattainable, or even irrelevant (Miller 2002). Recent discussion of science literacy has become more nuanced, deemphasizing the treatment of the public as proxy scientists and recognizing instead that citizens might only need to have an active role in the science policy process for topics of particular interest (Sturgis and Alum 2004). Workshops sponsored by the NSF have continued this debate, with conclusions exemplified by this quote: “The starting point for public knowledge of science is the need of the citizen or the information consumer, as opposed to a microcosm of what a scientist knows” (Tuomey 2011). However, the “consumer” framework makes many scientists uncomfortable, since awareness of the totality and interdependence of scientific knowledge is lost when literacy is based on particular topics or issues.

Science in School and College

Science and math courses are electives in a majority of high schools. Most students take biology, but fewer than half takes chemistry, a quarter takes physics, and just 5% take calculus (Blank, Langesen, and Petersen 2007). University marks the last formal exposure to science for most Americans. College students face a variety of choices, making it a challenge to create a coherent plan of study, and despite the emergence of General Education science requirements, science is being taken less frequently overall (Figure 2). The National Academy of Scholars surveyed science curricula used in B.A. degrees from the top fifty institutions in the U.S. News and World Report's rankings. The percentage with science requirements dropped from 90% in 1964 to 34% in 1993, and the percentage requiring both math and science dropped over the same period from 36% to 12% (Balch and Zircher 1996). When the Department of Education did a homogeneous analysis across what they called the "empirical curriculum," they found that science accounted for just 7 of the 100 course categories with the most undergraduates, while a third of all future school teachers do not take any college-level math (Adelman 2004).

The General Education or distribution requirement science course for non-science majors plays a pivotal role in science literacy. It often marks a final opportunity to promote and model evidence-based reasoning. For example, in the author's field of astronomy, introductory college classes for non-science majors enroll over 250,000 students per year. Nationwide, about 10% of all students take such a class (Fraknoi 2002). At the University of Arizona, this class provides a useful vehicle for testing and validating new approaches to improving science literacy (Brissenden, Prather, and Impey 2012). Most educators have goals that go beyond conveying scientific knowledge and instilling an appreciation for the subject but college undergraduate science education still struggles to be effective (Tobias 1992, Fairweather 2008). One problem is that students do not enter the classroom as "empty vessels," ready to be filled with science knowledge (Bransford, Brown, and Cocking 2000). They have a complex web of prior belief systems rooted in their upbringing, their social interactions, and the popular culture (Donovan and Bransford 2005). Some beliefs may align with scientific understanding, while others are superstitions. There are also pseudoscientific belief systems with a superficial resemblance to science that are not based on logic or evidence (Shermer 1997). Science educators often argue that non-scientific beliefs interfere with the learning of science and so with science literacy (Losh et al. 2003; Martin 1994). However, it is an open research question, addressed in the work described below, whether non-scientific belief systems do interfere with learning science or having a scientific worldview.

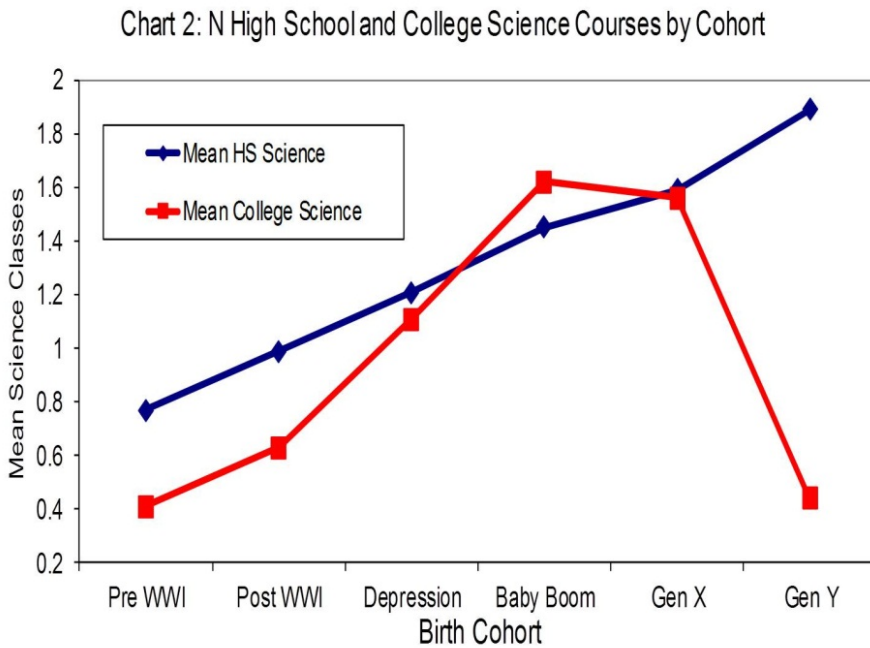
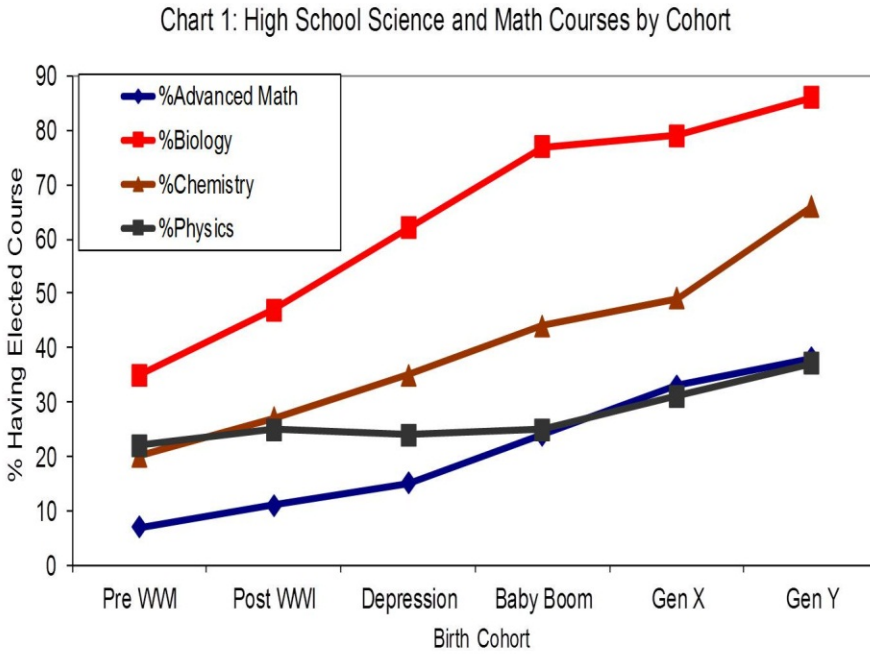


Figure 2. Percentage of high school students taking electives in science and math as a function of generational cohort (top), and average number of advanced high school and introductory science courses taken (bottom), also divided into the birth cohorts (Losh et al. 2003).

A Survey of Undergraduates

Initial results from our ongoing survey of science knowledge and beliefs have recently been published (Impey et al. 2011, 2012, 2013; Antonellis et al, 2012). The survey instrument has been stable since 1989 and it has two parts. The first has a substantial overlap with the instrument used by the NSF in the *Science Indicators* series. It measures general scientific knowledge with 21 questions; four are open-ended and ask for short written responses, the rest require true/false or multiple choice responses. The second part diagnoses attitudes to science and technology, perceptions of and susceptibility to pseudoscience, and some aspects of faith and religious belief. Details of the survey and its reliability, plus details of the data entry and coding, are in Impey et al. (2011). The survey has been administered primarily to freshman and sophomores with non-science majors taking a science requirement. The participation rate is 95%, the survey is anonymous, and data entry is by undergraduate research assistants. The freshmen have recently arrived at the university so their data reveals the knowledge and beliefs of students as they leave high school. There is a smaller, but still substantial sample size for students who are juniors and seniors and who have fulfilled their science requirements. In this way, the survey includes a “before and after” snapshot of undergraduates. With more than a half million individual responses and a twenty-year baseline the survey has great statistical power. In addition to continuing the survey, we have begun interviews aimed at diagnosing how students understand the defining attributes of science and where they get their science information.

Knowledge-based questions range from physics (“Which travels faster, light or sound?”) and astronomy (“Does the Earth go around the Sun or does the Sun go around the Earth”) to biology (“The oxygen we breathe comes from plants, true or false?”). In the survey instrument, 15 of the 17 questions overlap the NSF Science Indicators survey; a core set of 9 questions have consistently been part of the NSF survey, giving us a twenty year baseline of comparison (Figure 3). Open-ended questions ask for student explanations of the scientific method, DNA, radiation, and computer software. Students also respond to a set of 24 statements on a five-point Likert scale with choices: strongly agree, agree, no opinion, disagree, and strongly disagree. Items probe attitudes to science and technology (“Pure science should be funded regardless of its lack of immediate benefit to society”), ethical perspectives (“There are circumstances when medical science should not be used to prolong life”), superstitions and beliefs in pseudoscience (“Some numbers are especially lucky for some people”), and aspects of religious belief (“The Biblical story of creation should be taught alongside evolution in our schools”). Responses to selected items from the attitudinal survey are shown in Figure 4.

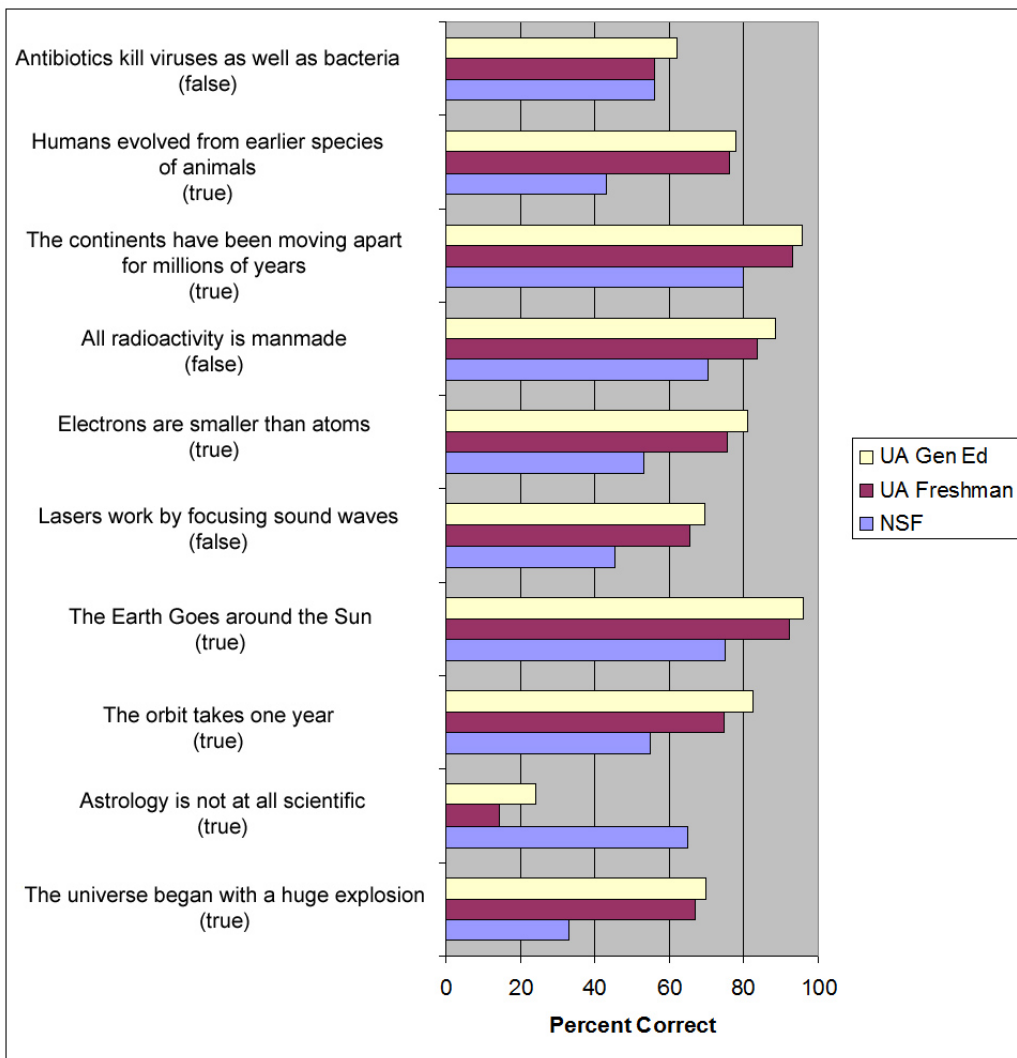


Figure 3. Responses to subset of items on the University of Arizona (UA) science literacy instrument. These items form the basis for a NSF knowledge-based metric of public science literacy. Freshmen have not taken any science classes, whereas Gen Ed category of students has taken 2 or 3 science classes.

What Students Know

Data are still being analyzed, and separate coding schemes had to be devised and validated for each of the open-ended question. The early results on the knowledge part of the survey are:

- Graduating high school seniors (as measured using incoming UA freshmen) perform slightly higher on knowledge questions than the general public. UA students scored 80% compared with 62% for the general public.

- At the high end of the distribution, slightly less than 3% of the sample got all 15 science knowledge questions correct, and that percentage was unchanged over the more than two decades of data.
- There is no measurable change in mean score on the knowledge questions over two decades, consistent with the most thorough analysis of NSF data, which showed no significant improvement for the general public.
- Improvement in score on any particular item averages less than 10%, where this measure is based on snapshots of different cohorts rather than following particular students through their college careers.
- The average net gain in score corresponds to a gain of only one additional correct item out of nine, despite students having taking nine credit hours of science classes by the time they graduate.
- While number of college science courses taken was the strongest predictor of overall score, it only accounted for 3% of the variance, and demographic variables overall only accounted for 7% of the variance.
- Women score slightly lower than men on knowledge questions. Among the different majors and fields of study, the Education majors (and so the future teachers in the sample) perform the worst.
- Among graduating seniors, one third think antibiotics kill viruses as well as bacteria, a quarter think lasers work by focusing sound, and 20% respond incorrectly to basic questions about evolution and the Solar System.

What Students Believe

Research on belief systems and attitudes about science is much less extensive than research on what people know about science, in part because it is difficult to design objective and validated instruments to measure belief. Among the results from the attitudinal part of the survey:

- Regardless of knowledge level, students have positive attitudes to science. Over 90% strongly agreed or agreed with a statement “Overall, the progress of science and technology has been beneficial to our civilization,”
- Similarly, students agreed by a ratio of 4:1 that “Pure science should be funded regardless of its lack of immediate benefit to society.” There was also support for the space program and the search for life in the universe.
- Belief in pseudoscience is high. About 40% believe that the positions of the planets affect everyday life; a similar percentage thinks some people have psychic powers, and about 1 in 6 think aliens visited ancient civilizations.
- Many students have a susceptibility to superstitious thinking. About one in four believe in lucky numbers. More generally 80% take the anti-rationalist stance that there are phenomena that science cannot explain.
- Among faith-based beliefs that impinge on scientific thinking: 1 in 4 think faith healing is a legitimate alternative to normal medicine, and more than a third think that biblical creation should be taught alongside evolution.
- Surprisingly, beliefs are only weakly correlated with scientific knowledge, accounting for 10% of the variance in the overall knowledge score. Taking college science courses has only a small effect on belief systems.
- Extending this conclusion, there is a less than 10% drop in overall science knowledge score between the high and low extremes of the spectrum of pseudoscience belief and faith-based belief.

- Overall, the data indicate that irrational and/or mutually conflicting beliefs can coexist with accurate science information in the minds of young adults. Belief systems are not substantially affected by college science classes.

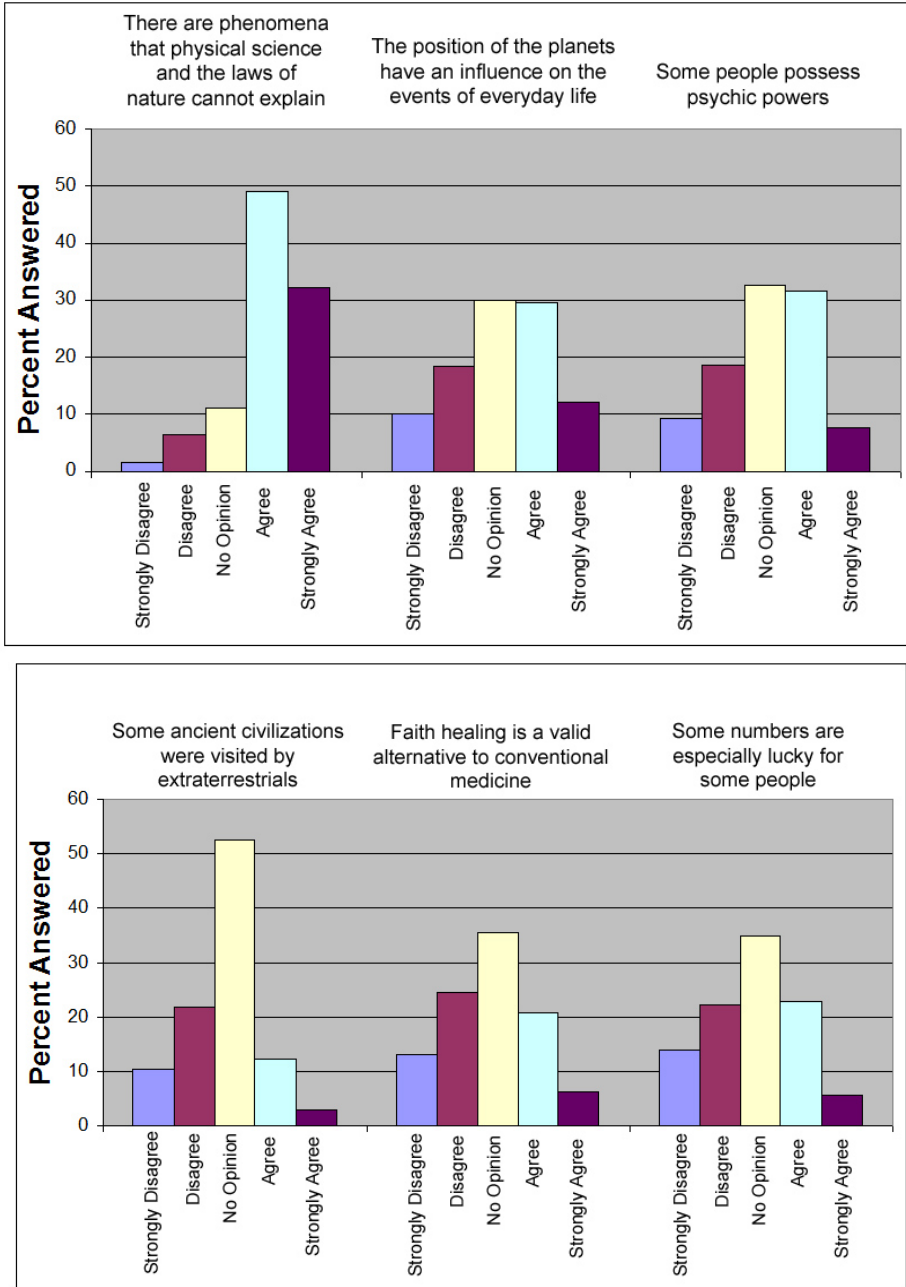


Figure 4. Overall responses, by nearly 10,000 undergraduates over a period of 20 years, to 6 out of 24 statements about science and technology, all items relating to pseudoscience or non-scientific belief systems.

Initial Conclusions

Science knowledge scores among non-science majors at the University of Arizona have not changed over 20 years, during which new a General Education program was implemented, which imposed a uniform requirement of three science classes for all undergraduates. Gains on most items, and in the overall score, are only 10% between incoming freshmen and graduating seniors. Some of the gaps in the basic science knowledge of people in the top quartile of U.S. educational attainment are particularly disconcerting. Very little of the variance in science knowledge score is accounted for by the number of college science classes taken, suggesting either that those classes are not effective in furthering science literacy, and/or that much of a student's science knowledge comes from outside the classroom. Regardless of the level of science knowledge, students have a strongly positive view of the scientific enterprise. Superstitions and beliefs in pseudoscience are pervasive and resistant to scientific instruction, and they are weakly correlated with science knowledge and account for only 10% of the variance in overall knowledge score.

Ongoing Work

Complete analysis of the survey will take another year or so. We have generated a coding schema for each of the open-ended questions: What does it mean to study something scientifically? What is DNA? What is radiation? What is the definition of computer software? Each of these presents a rich landscape of perceptions and understanding (Antonellis et al. 2012). DNA is the iconic molecule at the heart of the biological revolution of the past half century. Setting aside the responses that simply spell out the name of the molecule, students often show a hazy awareness of DNA, using metaphors such as “blueprint” and “code” and “building block.” However, some major erroneous beliefs are quite prevalent, such as the idea that DNA is found only in the blood or that it is only a component of humans. The word “radiation” typically triggers allusions to the idea of radioactivity, or to the fact that it is dangerous. Most responses are far from a scientific understanding of radiation. Computer software is ubiquitous in modern life, but most students have an imperfect understanding of what it is and how it works, often confusing it with hardware or with the operating system of a computer. Figure 5 shows just a partial map of coded responses on the nature of science.

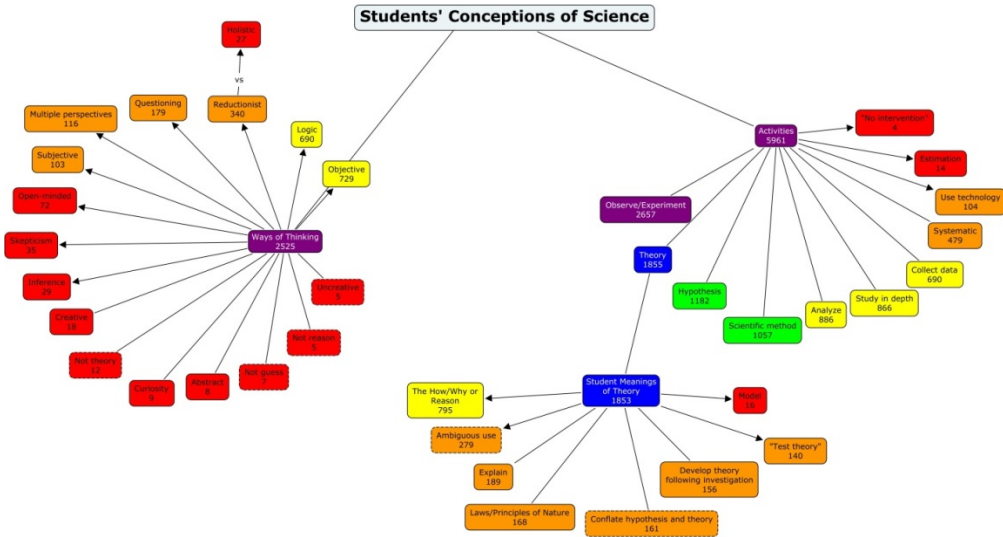


Figure 5. Partial map of the coding scheme for student responses to the question: What does it mean to study something scientifically? A complete version of the coding and a preliminary analysis is given by Antonellis et al. (2012).



Figure 6. Wordles where the text size indicates the relative frequency of terms used by scientists (top) and non-science students (bottom) when asked what they most associate with science and doing science.

Several follow-ups to the main survey have begun. In one, we administered an online survey to 150 scientists at the University of Arizona, mostly faculty and graduate students, plus a small percentage of postdocs. The respondents answered a subset of knowledge and attitudinal questions from the main survey and gave an opinion on how closely they associated 26 particular terms with science or with doing science, on a Likert scale: very strongly, moderately strongly, slightly, not very much, or not at all. There was also a keyword analysis of the answers to the open ended question: What does it mean to study something scientifically? This was compared to student responses to the same question in the large survey. Not surprisingly, scientists gave more detailed, thorough, and accurate answers to the question than students did but some of the differences in keyword frequency were striking. Both scientists and students gave strong emphasis to the terms evidence, experiment, hypothesis, and knowledge. However, scientists considered the terms creative, discovery, and imagination important and relevant to science,

while the students almost never used those terms. If students do not associate those attributes with science, they might naturally view it as a dry and unexciting enterprise. Figure 6 shows the relative keyword frequency of terms used by scientists and students.

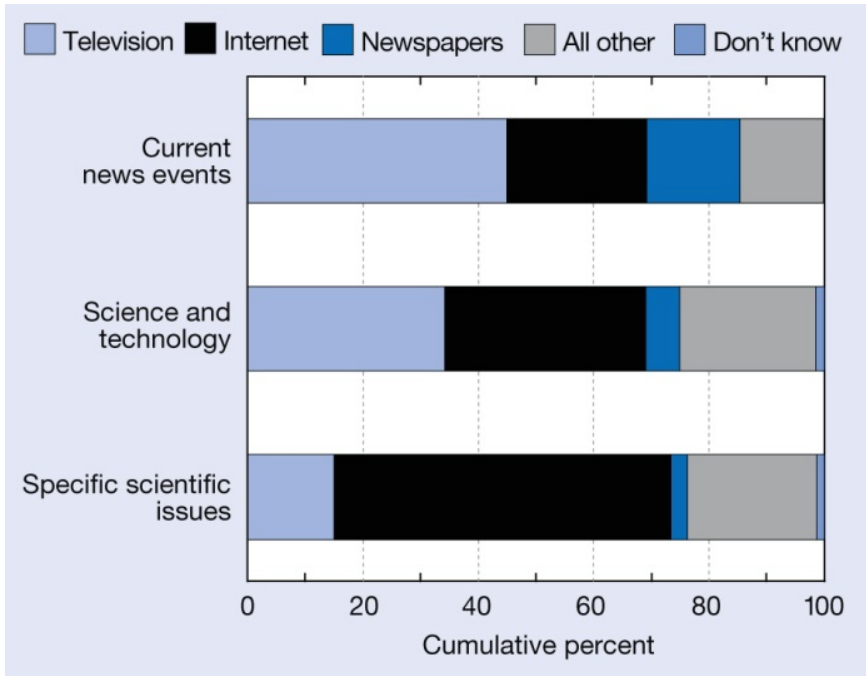


Figure 7. Where the American public gets its science information. The Internet has grown to rival television as a source of information, and is now the primary information source on specific issues in science and technology (NSB 2012).

Another issue that we have attempted to study is where students get information about science. Figure 7 shows the situation for the general public, where overall the primary information source is now the Internet. It is note that the Internet is twice as heavily used for information on a specific scientific topic as for news. Students tend to increase their science knowledge scores as they pass through the university, but since there is no strong correlation with number of science courses taken, a reasonable hypothesis is that they got most of their knowledge and their information outside class. We developed an online survey instrument to find out where students get their information about science. With a sample size of 660, a central result was the primacy of the Internet, and in particular Wikipedia, as an information source for science. In the past year, 70% had consulted Wikipedia, compared with 27% who had read a book or textbook about science. Teachers were admitted to be the most reliable information source, but they were rarely consulted. The influence of Wikipedia is not surprising, as it is the most visited information site on the Internet, used by most adult Internet users (Zickuhr and Rainey 2011). We have followed up this online survey with interview of thirty students from the same demographic, to get a more detail picture of where they look online for science information.

Implications for Science Literacy

This ongoing research has significant implications for science literacy and how we teach science to college students. While Miller (2007) analyzed the NSF data and concluded that the number of college science courses taken was the best predictor of civic science literacy (see also Hobson 2008), followed by formal educational attainment, we see no evidence in the University of Arizona data to attribute gains to the science classes that non-science majors take. Moreover, there has been no measurable improvement in undergraduate scientific literacy over the past twenty years. In the NSF data, even though the general public's scores on the knowledge questions have not improved over twenty years, overall public understanding of science has improved when cohorts are tracked, after controlling for the formal level of education (Bauer 2009). Unfortunately, this improvement coexists with strong, and in some cases growing, beliefs in pseudoscience and in non-scientific phenomena (Losh 2011). In NSF surveys, undergraduates have mean knowledge scores of 60% before they have taken any science or math courses, rising to 80% when they have taken three or more. But the gain from high school graduation to college graduation is even larger, from 54% up to 78%. The percent understanding the nature of scientific inquiry rises from 36% to 70% when three or more science courses are taken, but the rise from the time of high school graduation to college graduation is even larger, from 29% to 73%. Neither NSF nor UA data support attributing these gains primarily to science classes taken by non-science majors. Much of the improvement may be due to maturation and the overall educational experience, where much science information comes from outside the classroom.

Perhaps the most striking result so far is the weak relationship between science knowledge and level of belief in pseudoscience and the very modest change in those levels of belief after satisfying the standard science requirement for non-science majors (Impey et al. 2012). The pervasiveness of the web of beliefs in pseudoscience and supernatural phenomena among undergraduates suggests that their capacity for critical thinking is very unevenly applied (Lindeman and Aarnio 2007, Goode 2002). It might even mean that relatively high scores on knowledge items give an illusory sense of mastery, because they are unable to apply rational criteria to the subjects such as astrology, psychic powers, and lucky numbers that they meet in everyday life. Belief in pseudoscience is such a poor predictor of performance on the knowledge questions that it begs the question: do irrational beliefs matter? The ability of students (and the public) to distinguish between reliable and unreliable sources of science information is currently undocumented. However, it is clear that students graduate with sizeable holes in their knowledge and with a diverse array of non-scientific beliefs intact. These results present an interesting challenge for science educators. Suggestions for science educators are to directly engage and refute pseudoscience beliefs through examples in everyday life, to rebalance curricula to favor real world applications of scientific principles, and to move toward "unified" course sequences that don't leave substantial holes in coverage of the major theories and results of science.

Acknowledgements

I would like to thank my colleagues and collaborators in this work, particularly long-time collaborators Sanlyn Buxner and Jessie Antonellis, and undergraduate research assistants Elizabeth Johnson, Courtney King, Kitina Tijerino, and Jenna Llull. I'm grateful to Ed Prather and to Gina Brissenden for many conversations about science literacy and astronomy education over the years. This research has been generously supported by the National Science Foundation through a CCLI Phase 3 grant, and by the University of Arizona.

REFERENCES

- Adelman, C. 2004. *The Empirical Curriculum: Changes in Post-Secondary Course-Taking, 1972-2000*. U.S. Department of Education. Unpublished report, available online at <http://www.ed.gov/rschstat/research/pubs/empircurr/index.html>.
- Antonellis, J., Buxner, S., Impey, C. and Sugarman, H. 2012, "Surveying Science Literacy Among Undergraduates: Insights from Open-Ended Responses," *Journal of College Science Teaching*, Vol. 41, p. 82.
- Balch, S.H., and Zurcker, R.C. 1996. *The Dissolution of General Education: 1919-1993*. National Academy of Scholars. Unpublished report, available online at http://www.nas.org/polReports.cfm?Doc_Id=113.
- Bauer, M.W. 2009. "The Evolution of Public Understanding of Science—Discourse and Comparative Evidence." *Science, Technology and Society*, Vol. 14, p. 221.
- Blank, R., Langesen, D., and Petersen, A. 2007, *State Indicators of Science and Mathematics Education*. Council of Chief State School Officers.
- Bransford, J., Brown, A., and Cocking, R. 2000, *How People Learn: Brain, Mind, and Experience in School*, Washington, DC: National Academy Press.
- Brissenden, G., Prather, E.E., and Impey, C.D. 2012. "Astronomy Collaboration of Teaching Scholars," in *Organizations, People, and Strategies in Astronomy, Vol. 1*, edited by A. Heck. Duttlenheim: Vennggeist.
- Donovan, S., and Bransford, J. D. 2005, *How Students Learn: History, Mathematics, and Science in the Classroom*, Washington, DC: National Academies Press.
- Fairweather, J. 2008. "Linking Evidence and Promising Practices in Science, Technology, Engineering and Mathematics Undergraduate Education," Board of Science Education, National Research Council. Washington, DC: The National Academies.
- Feinstein, N. 2010. "Salvaging Science Literacy," *Science Education*, Vol. 95.1, p. 168.
- Fraknoi, A. 2002. "Enrollments in Astronomy 101 Courses," *Astronomy Education Review*, Vol. 1, p. 121.
- Goode, E. 2002, "Education, Scientific Knowledge, and Belief in the Paranormal," *Skeptical Inquirer*, Vol. 26, p. 24.
- Hazen, R.M., and Trefil, J. 2009. *Science Matters: Achieving Science Literacy*. New York: Anchor Books.
- Hobson, A. 2008, "The Surprising Effectiveness of College Science Literacy Courses," *The Physics Teacher*, Vol. 46, p. 404.
- Impey, C.D., Buxner, S., Antonellis, J., Johnson, E., and King, C. 2011, "A Twenty Year Survey of Science Literacy Among College Undergraduates," *Journal of College Science Teaching*, Vol. 40, p. 31.
- Impey, C, Buxner, S., and Antonellis, J. 2012, "Non-Scientific Beliefs Among Undergraduate Students." *Astronomy Education Review*. Vol. 11, 010111.
- Impey, C.D. 2013. "Astronomy Collaboration of Teaching Scholars," in *Organizations, People, and Strategies in Astronomy, Vol. 1*, edited by A. Heck. Duttlenheim: Vennggeist.
- Lindeman, M., and Aarnio, L. 2007, "Superstitious, Magical, and Paranormal Beliefs: An Integrative Model," *Journal of Research in Personality*, Vol. 41, p. 731.
- Liu, X. 2009, "Beyond Science Literacy: Science and the Public," *International Journal of Environmental and Science Education*, Vol. 4.3, p. 301.
- Losh, S.C., Tavani, C.M., Njoroge, R., Wilke, R., and Macauley, M. 2003, "What Does Education Really Do," *Skeptical Inquirer*, Vol. 27, p. 30.
- Losh, S.C. 2011. "Age, generational, and educational effects on American public understanding of science: 1979–2006," in M.W. Bauer, R. Shukla, and N. Allum, editors, *The Culture of Science: How the Public Relates to Science Across the Globe*. New York: Routledge.

- Martin, M. 1994, "Pseudoscience, the Paranormal, and Science Education," *Science and Education*, Vol. 3, p. 357.
- Miller, J.D. 1987. *Scientific Literacy in the United States*, in D. Evered and M. O'Connor (eds.) *Communicating Science to the Public*. London: Wiley.
- Miller, J.D. 2002, "Civic Science Literacy: A Necessity in the 21st Century," *Federation of American Scientists Public Interests Report*, Vol. 55, p. 3.
- Miller, J.D. 2007. Unpublished paper presented at the annual meeting of the American Association for the Advancement of Science, San Francisco, CA.
- Mooney, C., and Kirshenbaum, S. 2010. *Unscientific America: How Scientific Illiteracy Threatens Our Future*. New York: Basic Books.
- National Science Board 2012. *Science and Engineering Indicators 2012*. Arlington, VA: National Science Foundation.
- Shermer, M. 1997, *Why People Believe Weird Things*, New York: W. H. Freeman.
- Sturgis, P., and Allum, N. 2004. "Science in Society: Re-Evaluating the Deficit Model of Public Attitudes," *Public Understanding of Science*, Vol. 13, p. 55.
- Sugarman, H., Impey, C, Buxner, S. and Antonellis, J. 2011, "Astrology Beliefs among Undergraduate Students," *Astronomy Education Review*, Vol. 10, 010101.
- Tobias, S. 1992. "Revitalizing Undergraduate Education: Why Some Things Work and Most Don't. An Occasional Paper on Neglected Problems in Science Education. Tucson, AZ: Research Corporation.
- Tuomey, C. 2011. "Science in the Service of Citizens and Consumers." *Nature Nanotechnology*, Vol. 6, pp. 3-4.
- Zickuhr, K., and Rainey, L. 2011. "Wikipedia, Past and Present." Pew Internet and American Life Project. Unpublished report, available online at <http://www.pewinternet.org/Reports/2011/Wikipedia.aspx>.

ABOUT THE AUTHOR

Chris Impey: Chris Impey is a University Distinguished Professor and Deputy Head of the Department in charge of all academic programs. His research interests are observational cosmology, gravitational lensing, and the evolution and structure of galaxies. He has 160 refereed publications and 60 conference proceedings, and his work has been supported by \$18 million in grants from NASA and the NSF. He has won eleven teaching awards, and has been heavily involved in curriculum and instructional technology development. He is a past vice president of the American Astronomical Society. He has also been an NSF Distinguished Teaching Scholar, a Phi Beta Kappa Visiting Scholar, and the Carnegie Council on Teaching's Arizona Professor of the Year. He has written over thirty popular articles on cosmology and astrobology, and co-authored two introductory textbooks. He has had four popular science books published, *The Living Cosmos*, *How It Ends*, *How It Began*, and *Dreams of Other Worlds*. He was a co-chair of the Education and Public Outreach Study Group for the Astronomy Decadal Survey of the National Academy of Sciences. In 2009 he was elected a Fellow of the American Association for the Advancement of Science.

The International Journal of Science in Society

provides an interdisciplinary forum for the discussion of the past, present and future of the sciences and their relationships to society. Journal articles range from broad theoretical, philosophical, and policy explorations to detailed case studies of particular intellectual and practical activities at the intersection of science and society.

The International Journal of Science in Society is a peer-reviewed scholarly journal.

ISSN 1836-6236

