Contributions from Science Education Research 8

Marianne Achiam
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Addressing Wicked Problems through Science Education

The Role of Out-of-School Experiences

Springer

Contributions from Science Education Research

Volume 8

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ISSN 2213-3623 ISSN 2213-3631 (electronic)
Contributions from Science Education Research
ISBN 978-3-030-74265-2 ISBN 978-3-030-74266-9 (eBook)
https://doi.org/10.1007/978-3-030-74266-9

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Addressing Wicked Problems through Science Education: The role of out-of-school experiences

Foreword

"Obviously, we are against it!" This confident assertion emerged during an informal meeting of science communication professionals I attended. For quite a while, we had been debating if we all should – and could – agree on a common position regarding scientific issues that are currently regarded as controversial. Vaccination and climate change had already been discussed, and things were going smoothly, perhaps too smoothly. Then someone threw the topic of GMOs onto the table. At which point another colleague exclaimed: "*Obviously*, we are against it". Tumultuous discussion ensued.

This is neither the time nor the place to debate all the matters related to the science, policy-making, consumer awareness, economy and ethics of GMOs. The relations between all these factors are … well, it's complicated. I was not bothered by the fact that someone with a scientific background was against GMOs; what really troubled me was the use of the word "obviously".

A common and accepted feature, in contemporary debates, is that any affirmation is immediately met with either complete agreement or complete disagreement, with little nuance evident. Interpretations of the same evidence often differ wildly. More disturbing is that whether the issue has been debated for many years (such as race or immigration) or is more recent (such as the use of face-masks to prevent the spreading of the virus responsible for the COVID-19 pandemic), opinion wars in social media are fuelling lethal physical clashes on the streets. If there is something obvious, it is that nothing is obvious anymore. But the problem is that, for each faction, for each person or group of people with an opinion about anything, their own position is *absolutely obvious*. So obvious that it becomes impossible to debate it or to discuss it sensibly.

In fact, the world around us is not obvious at all, and it never was. It only seemed so because, for a long time, systems of beliefs, ranging from political models to religions, were accepted as the basis for interpretations of the world and for determining *obvious* explanations and courses of action. Challenging these systems was usually achieved by imposing an alternative belief system, based on the same type of validation by authority. The processes of authority-based challenging of belief systems are, at present, enormously accelerated and fragmented, with a daily dose of new gurus, new authorities and new beliefs increasingly resorting to very primitive forms of validation: shouting louder or using plain aggression. The result is that everything seems to become senseless.

Two factors can be identified as the main triggers for this situation: previously unthinkable levels of access to information, and platforms that provide rapid, large-scale sharing of opinions. These two elements are, in themselves, very positive and it is good that they are almost universal. But most of the media, from print newspapers to the internet, are inundated with an enormous array of unsubstantiated affirmations and opinions that are taken as *evidence,* when they are very far from being anything of the kind.

We live in an era where access to information and the capacity to spread opinions have become problematic unless we are able to identify just what is trustworthy (which is very different from trying to determine what is true). And it is essential to be willing to spread information in a way that allows it to be tested and contradicted, which might easily be achieved by pointing out the source of information, how it was obtained, and how certain we are of its validity. However, this is seldom done.

Science education was never so essential if we are to be able to make sense of all of this knowledge, information and opinion. However, in this context, the main contribution of science is not so much the knowledge it produces (though that knowledge constitutes an enormous wealth), but rather the development of a scientific frame of mind: the willingness and the capacity to challenge the "obvious" *in a structured way*. Expertise, knowledge, and ideas should be constantly put to the test. But *testing* is not equivalent to *mistrusting* expertise or *disregarding* current knowledge. Nor does it allow a superficial *dismissal* of facts. There is a rational scientific way of challenging the obvious, and this is what science education needs to focus on.

This is a complex exercise, requiring an ability to analyse and identify the multiple layers of a problem, the opportunity and capacity to *use* science (and not only to *learn* science), and the capacity to understand the limits of science as an instrument to determine possible actions. In this book, a series of cases and arguments are presented that show the importance of out-of-school science education. Indeed, the out-of-school context brings a sense of reality to the issues under analysis, making it easier – even necessary – to identify the multiple aspects to be considered, and to develop the capacity to embrace and understand the complexity and the ever-evolving nature of some problems. We find here excellent examples and analysis of how we can improve science education and how out-of-school activities may result in the capacity to understand and accept that science alone cannot provide the answers to some problems; and, at the same time, lead to a realization that this affirmation does not imply a dismissal of science as an essential and powerful tool to address those same problems, quite the contrary.

Which brings us to the central notion of wicked problems, the role of science, and why I was so disturbed to hear a science communicator using the word "obviously" in relation to GMOs. Science can provide us with precious information, ascertain the validity of facts, and help us to reason logically, based on the evidence.

But it also provides us with new questions and allows us to identify multiple factors in a problem. Being "obviously against" something complex is far from the scientific attitude we all seek to promote.

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Chapter 1
The Role of Out-of-School Science Education in Addressing Wicked Problems: An Introduction

Justin Dillon, Marianne Achiam, and Melissa Glackin

On Genealogy

This book is part of the European Science Education Research Association (ESERA) Science Education Research Series. The aim of the series and the way in which the aim is realised is outlined on the ESERA website, as follows:

> The aim of the series is to enhance the quality and impact of research in science education in Europe. To achieve this, books present and discuss, for the benefit of the scholarly community and other users of research, the findings of high-quality research in the domain of science education and in-depth explorations of specific methodological strands in science education research. The series aims to publish books that are innovative in the issues they explore, or the methods they use, or the ways in which emergent knowledge in the field is represented. It includes edited collections of chapters on a specific theme, monographs and handbooks. (ESERA, n.d.)

ESERA has a number of Special Interest Groups (SIGs). This book emerges from the work of one of them – 'Science Education in Out-of-School contexts'. The SIG members carry out research in a range of contexts including museums, science centres, aquaria, zoos, botanical gardens, natural open or green spaces and science fairs and competitions. The three editors of this volume were the first coordinators of the SIG. When we were planning this book, all SIG members were invited to contribute. Several years later, here it is.

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M. Achiam et al. (eds.), *Addressing Wicked Problems through Science Education*, Contributions from Science Education Research 8,
https://doi.org/10.1007/978-3-030-74266-9_1

On Science, the Environment and the Public

Public understanding of, and interest in, the environment appears to be at an all-time high. However, it was not that long ago that the situation was quite different. For most of the twentieth century, the Earth was seen as a provider of resources almost without limit. However, in the 1960s, public awareness of the impact of human activity on the atmosphere, the oceans and the countryside began to develop.

> We can still feel the impact of those changes more than 50 years later. However, our understanding of the complexity of the environmental challenges that we face has developed substantially. Helping the public to make sense of this complexity in an era when science, facts and trust are taking on new meanings is a challenge to which the science education and engagement communities must rise. (Dillon, 2017)

Key events that changed how society understood the growing levels of environmental degradation include the publication of *Silent Spring* (Carson, 1962). Rachel Carson was a scientist who became an award-winning author. In a series of articles in the *New Yorker*, she detailed the catastrophic impact of pesticide spraying in the USA. The series was published as a book in 1962. The columns and the book were highly controversial, and Carson was both lauded and viciously attacked. Nevertheless, in 1963, President John F. Kennedy tasked his Presidential Science Advisory Committee to look at pesticide use in the USA. Carson's apocalyptic style of science communication had hit a nerve.

The Scottish writer and poet, John Burnside, has commented that the publication of *Silent Spring* and the subsequent public debate provided a learning opportunity for business and industry:

> In 1962, the field where battles were fought, in public at least, was scientific debate; the trick then was to have control over the nature, terms and extent of the debate. An unexpected bonus, in recent years, has come from public awareness of that control; now when the scientific organisation speaks, the voice we hear is too often that of [the industry concerned]. We do not know who to trust, and in such cases, we tend to hope that our leaders and elected representatives are still as well meaning as they seemed when we elected them. (Burnside, 2002, p. 1)

The fossil fuel industry has had to adapt its approach to the environment in the last 50 years. If *Silent Spring* provided a wake-up call for the US public, then the Liberian registered LR2 Suezmax Class oil tanker, ss *Torrey Canyon* changed UK and French public opinion in a matter of days in 1967. The Torrey Canyon was capable of carrying 120,000 tonnes of crude oil and left Kuwait in mid-April chartered by British Petroleum. Four weeks later, it ran aground on a reef between the Isles of Scilly and the coast of England. Being so close to the coast, media access was relatively easy, and pictures of oil-covered seabirds and oil-slicks filled the newspapers. This was the first major supertanker shipwreck, and it opened the public's eyes to the possibility of environmental catastrophe on their doorstep.

Fifty years on, and we now see the Torrey Canyon as a relatively straightforward environmental problem. The combined might of the UK's armed forces eventually managed to condemn the vessel to a watery grave 30 m below the waves, where it still resides. The slicks were dispersed naturally and through a clean-up operation. Now we realise that there are far more complex problems facing society whether they be poverty, climate change, biodiversity loss, water security or pandemics.

On Wicked Problems

In times of crisis, scientists are seen as providing reassurance – a high level of educated objectivity coupled with access to reliable knowledge and independence from political bias which together afford substantial public trust.

> Truth and trust seem to have achieved almost totemic status in modern discourse and scientists, in general, are still seen as far more trustworthy than journalists and politicians. *Silent Spring* has 42 pages primarily consisting of papers in scientific journals and correspondence with scientists. On such a base lies Carson's credibility. (Dillon, 2017, p. 2)

Writing in June 2020, with millions of people unable to work, travel, attend sporting events or go to restaurants because of restrictions brought in by 'our leaders and elected representatives' in response to the COVID-19 pandemic, it is clear that science now has a unique role in society. Medical and life scientists stand alongside politicians often acquiring almost hero status:

> Dr Ashley Bloomfield is the director-general of health and the public face of [New Zealand's] battle against the disease, alongside prime minister Jacinda Ardern. Since March, Bloomfield has been fronting near-daily televised press conferences and has swiftly become a figure of fascination in a nation that has enjoyed early success in the global fight against coronavirus. Quietly spoken and always impeccably prepared, Bloomfield has impressed with his depth of knowledge and quick recall of statistics and unflappable demeanour. (Roy, 2020)

Powerful though science is, it cannot, in itself, solve many of the major challenges facing society. This point was recognised in the 1970s by two academics from the University of California, Berkeley – Horst Rittel and Melvin Webber. They argued that 'the search for scientific bases for confronting problems of social policy is bound to fail' (Rittel & Webber, 1973, p. 155). In their opinion, science could deal with 'tame' problems (such as oil tanker spills) but not with a range of social policy problems, which they termed as 'wicked'.

It has taken some time for the phrase to catch on and be widely understood, but it is a powerful way of looking at our modern world. So, what are wicked problems? According to Rittel and Webber (*ibid*., pp. 161–7), wicked problems have at least ten distinguishing features:

1. There is no definite formulation of a wicked problem;
2. Wicked problems have no stopping rule;
3. Solutions to wicked problems are not true-or-false, but good or bad;
4. There is no immediate and no ultimate test of a solution to a wicked problem;
5. Every solution to a wicked problem is a "one-shot operation"; because there is no opportunity to learn by trial-and-error, every attempt counts significantly;

6. Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan;
7. Every wicked problem is essentially unique;
8. Every wicked problem can be considered to be a symptom of another problem;
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution;
10. The planner has no right to be wrong.

(*ibid*., pp. 161–167)

The reference to 'the planner' in number 10 is because the idea of wicked problems was first applied to social planning; now it is used much more widely.

> According to Rittel and Webber, such problems are never solved; 'at best they are only re-solved – over and over again' (*ibid*., p. 160). What is even more sobering is that while climate change had been happening for some time, the true nature of the problem only emerged relatively recently. That suggests that there may well be other major environmental issues of which we are still unaware but which will become known in the years to come. (Dillon, 2017, p. 2)

The list of wicked problems continues to grow. The University of Southern California (USC) identified: 'poverty; food and water security; obesity; social justice issues; cancer; sustainability and climate change; terrorism; cyber security; aging and dementia; among others' (USC, n.d.). To that we can probably add pandemics such as COVID-19. Although it might be too early to say, COVID-19 is a symptom of a range of other problems such as under-investment in health services, food production and transportation methods, and the public's lack of understanding of molecular mechanisms and their potential impact on health issues.

> Many of those issues might reasonably be expected to be addressed by museums, science centres, etc., through their public programmes. For example, one might expect to see a lunch-time talk by museum-based scientists on cancer research or see an exhibit on cyber security in a science centre. Almost 20 years ago, Einsiedel and Einsiedel argued that museum-sponsored public forums could be boring but that 'they could be made into more enjoyable learning experiences by integrating the relevant issues that affect the public, who appreciate finding solutions to important and urgent "wicked" problems' (Einsiedel & Einsiedel, 2004, p. 83). (Dillon, 2017, p. 3)

Wicked problems pose major challenges for society at large. They pose particular challenges for people who design curricula and for teachers faced with classes asking questions that do not have straightforward answers. So, this book focuses, to some extent, on how wicked problems can be addressed in school science lessons. However, given how slowly school science evolves, another focus of this volume is on that part of the education sector that depends on being topical and relevant and which has as its audience, the public. That part of the sector includes museums, science centres, zoos, aquaria, botanic gardens and science cafés.

On Purpose

When we set out to curate this volume, we could not find any books that addressed wicked problems in the field of science education. The idea of focusing the book on this issue was refined through interactions with the contributors. The authors of the chapters discuss the different ways in which out-of-school science education can critically and uniquely engage learners with wicked problems in ways that go beyond what is possible in classroom-based settings alone.

Research about out-of-school science education recognises its potential to promote interest and create motivation for engaging with science and nature. However, in professional circles, there have been a number of complementary discussions about the role of institutions, such as natural history museums and science centres, in addressing problems such as biodiversity loss and climate change. Therefore, in this book, we focus specifically on how out-of-school settings can prompt important disciplinary and cross-disciplinary engagement among learners. We hope that this collection of chapters will open up a new dimension in the field, bringing together the concerns of practitioners and the outcomes of research, synthesizing the educational priorities with the sustainability goals.

On the Challenge to Science Educators and Their Institutions

So, what does the challenge to science education involve? In 2007, the Australian Public Service Commission published *Tackling Wicked Problems*. Their report asserted the need for a radical change in society based on the assumption that traditional ways of policy-making had failed:

> Achieving sustained behavioural change is usually a key component of tackling wicked problems because it has become increasingly clear that government cannot simply 'deliver' key policy outcomes to a disengaged and passive public. In the areas of welfare, health, crime, employment, education and the environment it is clear that achieving significant progress requires the active involvement and cooperation of citizens. Agencies may have more impact on key policy outcomes by using their limited resources to engage, involve and change the behaviour of users and other parties, than by concentrating on traditional policy tools and service delivery. (Australian Public Service, 2007, section 9)

The state of our planet and our civilisation suggests that our existing methods of governance are failing to protect either of them sustainably. Why, then, should we worry about our failure to influence policy-makers, many of whom are thoroughly distrusted by the public. Thus, science education needs to prepare people, of all ages, for a world where neither the media nor politicians, generally, are trusted a priori. It should also help students to appreciate that science does not always deliver certainty nor does it have a single, simple scientific method.

If the public are to engage in the 'sustained behavioural change' advocated in the Australian report mentioned above, they need the best possible education delivered by the most effective educators. In the current circumstances, it is likely that education out of school, due to its flexibility and its efficacy to address topical issues, will be more able to deliver such an education than the traditional science classroom. That is not to deny the role of science teachers, indeed, they also have an obligation to prepare their students for a world where problems such as climate change and biodiversity loss will evolve but never disappear. Educational goals such as 'scientific literacy', 'problem-solving' and 'creativity', which have come to be, often, at best, meaningless slogans, will need to be rethought and integrated into a new vision of science education.

The issue facing the out of school sector is well summed up by Antonio Gomes da Costa, Director of Science Mediation and Education at Universcience, in Paris:

> We need to look at our public in a different light: it's no longer simply about those who are scientifically literate vs. the scientifically illiterate, it's no longer a matter of "preaching to the converted" vs. engaging new people with science. It is, rather, a matter of addressing different worldviews. In this regard, it is essential to notice that the same group of people may host factually sustainable and unsustainable views: for instance, it is common for people who are anti-vaccine (an anti-scientific stance) to be very much concerned with climate change (a very scientifically sound attitude). Can we develop instruments to work with the scientific and unscientific attitude of the same individuals in a productive way? (da Costa, 2017, p. 10)

The challenge for science communicators, who share many of the goals of science educators, is well articulated by Rod Lamberts (2017) when he argues that:

> science is steadily being relegated to the kids' table at the wedding, and countering this will take much more than repackaging science facts into more universally digestible forms […] it will require disruption, reconfiguration and action' (p. 6).

Lamberts' challenge is applicable across the whole of the science education sector:

> …the substance of your communication doesn't stop at translating complex or technical concepts into language intelligible beyond academia / the lab. It requires situating communications in social, political and cultural contexts. And it involves having, and expressing, opinions. Going beyond straightforward translation, the public intellectual will interpret, question, and challenge the ideas they communicate […] Translation of science into plain language alone has not, and will not, accomplish this. (*ibid*., p. 7)

Scientists themselves need to be more proactive in challenging falsehoods and misunderstanding according to the editors of *Nature*:

> The science [of genome sequencing] is moving rapidly. All the more need, therefore, for researchers to engage, and for those who see results being misrepresented to respond publicly, whether or not they choose to discuss research regulation and potential applications. ("Editorial: Why researchers should resolve to engage in 2017," 2017)

So, we have reached a point in the history of civilisation when things have to change. The role of museums, science centres, botanical gardens, zoos and aquaria has to change from being, primarily, a place that people visit to a place that facilitates changes in society, systematically, for the better. We hope that this book provides some support for people who see a new vision emerging.

On Structure and Content

The rest of the book contains chapters that look at *designing* experiences to address wicked problems and at the challenges of *teaching* and *learning* about wicked problems. The chapters are arranged thematically, by the type of out-of-school environment they take place in (natural history museums, science centres, botanical gardens, geological localities, and local communities) as well as by the nature of the wicked problem they address (health, biodiversity loss, sustainable energy production, and climate change). We finish the book with a chapter that synthesises the findings from the preceding contributions and points to the messages for teachers, educators/facilitators, teacher educators, and curriculum developers. Finally, we outline a forward-looking research agenda to build knowledge of education addressing wicked problems.

On Process

The idea to put together this book occurred to us in 2016, at the ESERA summer school in the Czech Republic. As coordinators of the newly emerged Science Education in Out-of-School Contexts special interest group of ESERA, we were keen that the SIG produced a book as well as organised symposia and panel discussions. It seemed obvious that a natural home for the book would be in the ESERA Science Education Research Series published by Springer. We invited potential authors to submit their ideas for chapters. Our original table of contents included 10 chapters from several different countries. That was the easy bit.

Once the proposal had been accepted, we invited chapter authors to submit drafts to us as editors. At this stage we lost one author but were able to invite another colleague whose work was well-known to us to fill the gap. We were then required by the process setup by Springer and ESERA to send out each chapter to two independent reviewers (who had to be approved by the Editorial Board). The reviewers provided insightful comments and advice to all the authors. With one exception, the chapters were revised. The other chapter authors decided enough was enough and dropped out.

Edited works succeed if they offer new insights and if the chapters provide different lenses through which to take fresh looks at the field. We believe these chapters do both of those jobs. Finally, we believe that the book will raise the status of researchers working on science education in out-of-school contexts and will activate cross-disciplinary debate in science education research.

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Chapter 2
Co-Designing a Controversy-Based Educational Programme in a Science Centre

Ingrid Eikeland and Dagny Stuedahl

Introduction

One of the most urgent challenges for the science communication sector is to find ways to engage the public with major challenges with no clear solutions, such as climate change, biodiversity loss, the use of GMOs and food security, so-called wicked problems. Engaging the public with these problems requires a changed focus in the science communication sector regarding both the content and pedagogical approaches in educational design. It is no longer adequate to 'deliver' scientific content to a passive and unknowledgeable public, which has been the traditional communicative approach in, for example, museums and science centres (Beetlestone et al., 1998). Rather, the public should have the opportunity to interpret, question and challenge ideas, and museums and science centres should empower visitors to engage in dealing with current issues (e.g. Allen & Crowley, 2014; Navas-Iannini & Pedretti, 2017; Quistgaard & Kahr-Højland, 2010).

As with other changes in educational thinking, these processes do not automatically become part of an institution's practice (Tal, 2012). Dillon et al. (2016) recommended a collaborative research agenda for researchers and practitioners to jointly deal with practice-based challenges in regard to addressing wicked problems. This effort aims at practitioners developing insight on, awareness of, and agency around key learning challenges, and researchers developing a theoretically informed understanding of learning activities within the museum and science centre sector (ibid.).

This chapter gives an example of how such collaborations may be realized by implementing techniques and principles from co-design (Sanders & Stappers,

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M. Achiam et al. (eds.), *Addressing Wicked Problems through Science Education*, Contributions from Science Education Research 8,
https://doi.org/10.1007/978-3-030-74266-9_2

2008). Co-design principles and techniques were used to support the practitioners and researchers in jointly developing an understanding of how to address controversial issues in a science centre learning programme and to design an educational programme as a result of this understanding. More specific, we were four science centre educators and one researcher (first author) co-designed a controversy-based educational programme for upper secondary school at their centre. The concept ‘controversial issues’ was selected by the researchers before initiating the co-design as a response to the call for science centres to address contemporary issues. The research was connected to the national research project EXPAND which aimed to develop an understanding of learning in science centres in close collaboration with practice (Stuedahl et al., 2014). The second author was a researcher in the project EXPAND and provided support in planning and analysing the co-design work.

In our study, the co-design process did lead to important insights in addressing controversial issues for both the educators and researchers. However, it is also widely acknowledged that co-design processes are demanding, conflicting and time-consuming (Sanders & Stappers, 2008). For example, neither the researcher nor the educators had a fixed solution as to how the educational programme would be structured, and dealing with the complexity of controversial issues, was a challenge. In addition, we had to deal with different expectations concerning the research outcomes as well as the resulting learning programme, the time span, workload, roles and responsibilities. Therefore, the research questions we explore in this chapter are as follows: What possibilities and challenges arise when educators and researchers co-design a controversy-based educational programme in a science centre?

Literature Review

Controversial Issues and Wicked Problems

In this study, we define controversial issues as having no right or wrong answers where both the scientific and social dimensions are questioned. Furthermore, we see the addressing of controversial issues as a means to engage visitors in discussion and decision-making processes related to contemporary issues. However, as experienced in Eikeland and Frøyland (2020), the understanding of the concept ‘controversial issues’ could also be related to conflict and dispute within or between particular fields or group, but not being disputed in other areas. For example, by seeing controversial issues as being either ‘internal’ or ‘external’ to science, understood as whether the controversy exists within science or elsewhere, like social, political, economic, cultural or religious areas (Hodson, 2013). In contrast, wicked problems are issues that are both internal and external to science, where the uncertainty and controversy exist in a number of areas. Wicked problems could be characterized by ‘incomplete, uncertain or contested expert knowledge, conflicting values and objectives, a lack of unambiguous problem formulations and the impossibility to find uncontested definitive solutions' (Block et al., 2019, p. 30). In the co-design process, we were looking to deal with the wicked problems of a controversial issue. For example, as we decided that bacterial resistance would be our final topic, in the programme, we focused on addressing the wicked problem of how to deal with this issue.

Science Centres and Controversial Issues

Science centres are learning institutions where people can learn science through hands-on and interactive experiences with scientific phenomena. Science centres were built with the intention of raising interest and engaging the public in STEM (science, technology, engineering and mathematics) subjects (Beetlestone et al., 1998). To achieve these aims, science centres have traditionally focused on addressing basic scientific phenomena to make the subjects easily accessible for the visitors, in addition to presenting the 'wonders of science' to amuse and engage (Beetlestone et al., 1998).

There has been criticism of this initial focus on basic facts and wonders of science (Pedretti, 2002). As an alternative, Quistgaard and Kahr-Højland (2010) have proposed that future science centres might create educational settings and exhibitions 'that would prepare the next generation to participate fully in society as critical and informed citizens' (p. 424). However, this transition raises challenges and tensions in science centres.

A focus on controversial issues differs from the science centre pedagogy that is traditionally based on addressing scientific facts and the 'wonders of science'. In studies that explore museum and science centre staff perceptions about addressing controversial issues in their practice (Delicado, 2009; Henriksen & Frøyland, 2000; Pedretti, 2002), the staff reported concerns with controversial issues creating scepticism and confusion towards science. Controversial issues were understood as being easily outdated and include subject matter that is too complicated and difficult for visitors to handle or that visitors might be lacking sufficient background knowledge and would need a significant amount of information to engage in.

Conversely, other studies have investigated how wicked problems could be addressed in museums and science centres (Allen & Crowley, 2014; Eikeland & Frøyland, 2020; Navas-Iannini & Pedretti, 2017; Quistgaard & Kahr-Højland, 2010). For example, Pedretti (2004) investigated how critical issues-based exhibitions could enhance learning through a case study in which students engaged in two cases. She found that critical issue-based exhibitions could enhance student learning by personalising subject matter, evoking emotion, stimulating dialogue and debate and promoting reflexivity. So, although there exist doubts and tensions about addressing controversial issues, studies also suggest that it can be done resulting in deep and valuable learning outcomes.

Collaborative Research

Recently, an increased interest in methods and techniques of collaborative research has resulted in a number of projects in museums and science centres and other out-of-school settings. The focus has been on collaborative processes among different expertise to develop new educational practices and in some projects to promote professional development and reflective practice (Ash et al., 2012; Mygind et al., 2015; Stuedahl 2019; Tzibazi, 2013). In the following sections, we give a short overview of established collaborative research approaches that may have elements that the collaborative activities of co-design build on. In addition, we provide an overview of challenges that come when people with different expertise come together to collaborate and the special challenges that come when there is a focus on designing something novel together.

Action Research in Science Education Co-design may be related to action research methodologies in that both engage researchers and practitioners in collaborative processes to narrow the gap between theory and practice. Action research has been used to develop new teaching practices that are informed by both research and practice – as well as to promote professional development where researchers support and empower practitioners in the process of changing their practice (Ash et al., 2012; Bjønness, 2017). Ash and Lombana (2012), for example, established a collaborative relationship with a group of museum educators in a community of practice to introduce and empower the educators to move from content-oriented teaching towards learner-oriented teaching. In this process, the researchers facilitated the museum educators in a process in which the educators critically examined and reflected on their own practices. The authors argued that with an action research approach, the researchers and staff were able to dig deeply into complex dimensions of learning. A research project by Tal (2012) implemented action research methods to empower science teachers to integrate outdoor teaching into their practices. The teachers participated in a process of practising outdoor teaching as part of an action research project and reflected on their experiences with a group of other teachers and researchers. Tal (2012) argued that the action research design was a valuable approach for developing teachers' practices, as it blends theory and practice.

Action research approaches are often longitudinal as establishing collaboration and to be able to bring about change take times. For example, Bjønness (2017) worked with a group of science teachers in an action research process over a period of 3 years. The aim was to both empower the teachers to implement inquiry teaching in their practice, at the same time to develop new teaching practices related to inquiry learning. In this process, they found solutions to challenges and obstacles for inquiry-based teaching and tried to overcome them together.

Overall, action research has been found to be especially effective in introducing major changes in beliefs, dispositions and practices particularly where new learning approaches are introduced. Tal (2012) argued that unrealistic expectations exist of practitioners being able to carry out a reform when it is implemented, such as outdoor teaching, inquiry-based learning, ICT-based activities or addressing controversial issues as approaches in science education. Tal (2012) further argues that teachers and educators need to be given support to be able to carry out a reform, where professional development through action research facilitates opportunities to learn by and from actions in practice.

Co-Design in Museums and Science Centres Collaborative research facilitated through the process of designing a concrete product is at the core of two approaches to design, participatory design and co-design. Co-design and participatory design include the active involvement of researchers, staff, visitors and/or external participants in exhibition development and curation (Mygind et al., 2015). They share a focus on the design aspect in collaborative research but derive from different disciplinary traditions of design (Stuedahl, 2019). Co-design has relatively recently been used as a concept to neutralize the political aspects that are linked to participatory design, in the focus on supporting collaborative creative processes when designing a product, more than the focus on empowerment and change of practices which is at the core of participatory design. Nevertheless, the two approaches are increasingly moving towards each other in shared intentions and aims. Co-design has frequently been used in the field of museum and science centre research (see, e.g. Bønnelycke et al., 2018; Stuedahl, 2019), and we will focus on this approach in the following.

In museums and science centres, co-design has mainly been carried out with the intention of including the visitors or external participants so as to enhance the relevance and accessibility of the museum. These strategies aim to empower visitors to engage in and influence the museum setting. For example, Bønnelycke et al. (2018) and Sandholdt (2018) carried out a co-design process in which they engaged science centre staff and families in designing an exhibition about health promotion. Through this process, they identified valuable contributions from the different participants and found that the visitors were empowered to share their thoughts on health promotion.

Meanwhile, co-design has also been used to develop new curatorial and educational practices, for example, in the Norwegian project EXPAND (Stuedahl et al., 2014). In a continuing professional development (CPD) course, participants joined a longitudinal collaboration with science centre educators supporting their re-design of an exhibition installation. The overall intention was to develop a shared language and practice among science centre educators in terms of learning with exhibition objects by working creatively with re-design of installations. With this approach, the educators were facilitated through collaboration and contributions by educators from other science centres with ideas and suggestions related to the re-design of installations (Stuedahl, 2017).

Identified Challenges with Collaborative Research and Co-Design Many tensions and conflicts occur when researchers and practitioners engage in collaborative processes. The tensions come from negotiating common aims and intentions, level of participation, diverging expectations of the research process and outcomes as well as confusion in different roles. These tensions are well-known within collaborative research, such as action research, co-design and participatory design even though the methods differ to some extent. Furthermore, there is an expressed need for studies that highlight tensions and conflicts related to collaborative research approaches (Bjønness, 2017; Bønnelycke et al. 2018; Mygind et al. 2015). For example, Mygind et al. (2015) concluded that 'more research concerning obstacles and facilitating factors to participatory practice as well as good and bad examples of participatory exhibition development projects in museums […] would be both useful and much needed' (p.18). In this section, we will elaborate on some of these tensions.

In collaborative research, the roles may get confused as the researcher is no longer the only expert; the participants are also experts in their own fields. This meeting between different expertise causes dynamics in the research process and could be confusing to the participants in the group. Stuedahl (2004) highlighted within co-design the challenge of participants who are used to being defined as passive informants suddenly being given active and participatory roles. Stuedahl (2004) argued that this change led to confusion, as the participants did not know what their new roles included and what was expected of them. In a collaborative process, therefore, there is a more expressed need to clarify different roles and expectations and to introduce the participants to the ideas and principles underlying the research approach (Bjønness, 2017; Bønnelycke et al., 2018; Mygind et al., 2015).

The role of the researcher in collaborative research is also a challenge in itself (Bjønness, 2017; Pedretti, 1996a). Often, the researcher will experience tensions when trying to find a balance between these roles. For example, one of the issues experienced by the researcher is the balance between giving support to the participants in some situations and holding back in others. Pedretti (1996a) reported that she often worried that she had provided too little structure and guidance to the group of teachers she collaborated with on developing an STS practice. However, one of the characteristics of co-design is that the research path is unknown and changes with practice as the process evolves. As a result, the researcher needs to be open and adaptive to the research process where decisions often need to be made in practice.

The level of participation from different actors (e.g. researchers, designers, educators, visitors) in collaborative research may vary. An example of a study where there was a high level of participation could be found in Bevan, Gutwill, Petrich and Wilkinson (2015). In this study, researchers and practitioners collaborated on developing the knowledge 'tinkering' learning in museums, and where the practitioners were involved in both deciding the research focus and questions, methods, collecting and analysing data. However, negotiating the level of participation in collaborative research may lead to tensions. More specifically within collaborative design, Mygind et al. (2015) found that, in many cases, the researcher expected the participants to engage more in the design process than was realistically possible. It is therefore argued that the initiators of the collaborative process should be aware of which kind of participation they anticipated and, consequently, what they must ask participants to do to help reach that goal (Mygind et al., 2015). The authors further found that in several cases, the participants were more involved in the beginning of the design process but that the initiator was the one putting the design together in the end (Mygind et al., 2015).

It is impossible to talk about collaborative research without mentioning time pressures. It is a time-consuming process to overcome the interdisciplinary, cultural and linguistic barriers that exist when people with different backgrounds collaborate (Mygind et al., 2015). Despite its time-consuming nature, this initial process should not be rushed. For the collaboration to function it is important to establish trust and good relationships between the participants (Pedretti, 1996a).

Case Description: Co-Designing a Controversy-Based Educational Programme

Our approach to collaborative research was based on overarching principles from action research using techniques from co-design, in which the collaborative process was driven by the design of a controversy-based educational programme. The co-design project was initiated by the researcher with the aim to jointly develop an understanding of how to address controversial issues in a science centre and to support and empower educators in addressing controversial issues. The science centre was relatively new, opened in 2011, located outside Oslo, Norway. The centre was a partner in the research project EXPAND. The science centre especially focused on school visits and had established a structured collaboration with all schools in the region. Over 30,000 students and teachers visit their centre each year.

In our research, one researcher (first author) and four science centre educators co-designed a controversy-based educational programme for upper secondary schools. The whole co-design project lasted for 21 months and included three steps:

1. A preliminary observation process in which the researcher became familiarised with the science centre context and recruited educators to the project (from August 2013 to May 2014).
2. A co-design process in which the controversy-based educational programme was designed in collaboration with a group of science centre educators (from May 2014 to January 2016).
3. A test process where two school classes were invited to participate in the final educational programme (February 2016).

In this study, we will focus on the second step, the co-design process. More findings of the outcome of the co-design project can be found in Eikeland and Frøyland (2020).

The Co-Design Process

The co-design process was mainly driven by eight workshops that were carried out at the science centre with approximately 2 months between each one. Each workshop lasted between 1 and 3 h where, usually, one researcher and four science centre educators participated. The researcher was a PhD student in science education with a background in school science teaching. The educators had varying backgrounds, spanning school teaching, nursing and health communication, science research and design and management. There were initially five educators in the main group, but one educator chose to leave the group after our first meeting due to the anticipated workload. The number of participants in the design process varied from meeting to meeting for different reasons. Two educators changed workplace midway through the design process, and one educator was more involved in the earlier stages of the process but less towards the end. One new educator was also introduced to the group towards the end of the process.

The workshops (WS) were further supplemented by two group interviews with the educators, one before WS1 and second after WS3. The first interview focused on educators' practice and perception of controversial issues and the second focused on educators' thoughts about the co-design process. In addition, the researcher also arranged three informal meetings with the educators (before WS4, WS6 and WS7). These meetings were carried out during a period in which the educators were prevented from engaging in workshops. The informal meetings were, therefore, held to keep each other updated on our current situation and to build continuity in the co-design process. In addition, the researcher arranged one meeting with high school students (before WS5) and two meetings with a bacterial resistance expert (before WS6 and WS7) to get feedback on the current educational design and to be able to design the final programme. After WS7, the final design was also presented at a staff meeting at the science centre. After WS8, the educators had one meeting alone where they planned the implementation of the educational programme. An overview of the co-design process is illustrated in Fig. 2.1.

The co-design process can further be divided into three main phases: a design criteria phase (GI1-WS2), an idea-generation phase (WS2-WS4) and a concretisation phase that started with a breakdown (WS5-WS8). These phases will be further elaborated on in the analysis. A detailed overview of the co-design process, when the different meetings were carried out, who participated and the focus of the meeting are illustrated in Table 2.1.

Data Collection and Analysis

The data from the co-design process consists of written field notes and audio-recordings from the eight workshops and additional meetings (group interviews, informal meetings, meeting with students and expert, presentation in staff-meeting

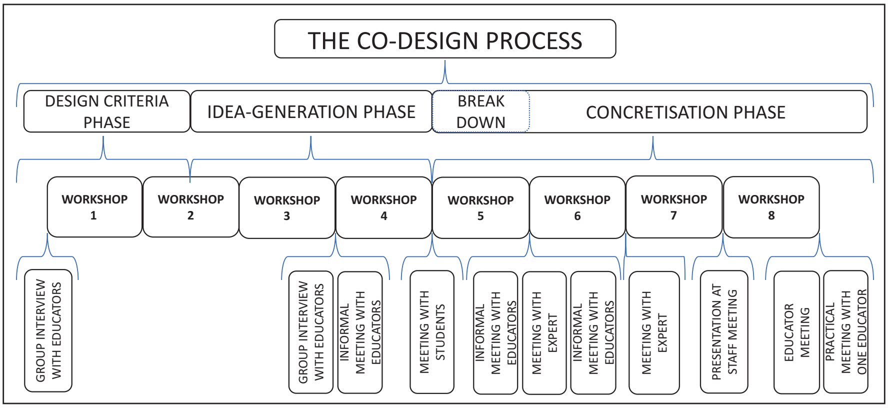

Fig. 2.1 An illustration of the design process

and educators' own meeting). Throughout the co-design process, the researcher also wrote a research diary, focusing on her thoughts as they emerged between the data collection episodes. The research diary was used to understand the co-design process and to plan for the next step of the process.

The different audio-recordings were transcribed, and the written material was organised in the qualitative analytical program NVivo. The data were analysed following thematic analysis (Braun & Clarke, 2006). The analytical process followed an iterative approach where the researchers switched between the empirical data and reading literature to make sense of the data. Overall, the researchers were interested in tensions and contradictions in the co-design process, and educators' reflection process that the empirical material shows. In addition, we were interested in documenting a trajectory in the co-design to illustrate how single episodes intertwined to inform the whole process (e.g. to illustrate our breakdown and how it related to what happened in the initial phase of the co-design process).

We have changed the names of the educators in the excerpts used in our analysis for anonymity purposes. In addition, the excerpts have also been edited to enhance readability when translating oral communication to written text.

Analysis

In our analysis, we found that the dynamics and tensions in the co-design process could be related to dealing with the multifaceted and complex nature of controversial issues, for example, by the many conversations on how to understand the concept and the overwhelming and time-consuming processes of mapping a controversy and dealing with ways to address the wickedness of an issue in the educational programme. In addition, we identified dynamics and tensions that could be more related to collaborative research in general, and co-design more specifically, such as

Table 2.1 A detailed overview of the different steps in the co-design process

When	What	Who	Focus
May 2014	Group interview 1	One researcher, five educators	Got an insight into educators' educational practice and perceptions of controversial issues
August 2014	Workshop 1	One researcher, Three educators	Discussed the outcome for students on a controversy-based educational program
October 2014	Workshop 2	Two researchers, Four educators	Landed a final set of design principles. Decided on the Ebola issue and discussed the specific content of the school programme
December 2014	Workshop 3	Two researchers, Three educators	Elaborated on the Ebola issue through a role play approach
December 2014	Group interview 2	One researcher, two educators	Got an insight into educators' thoughts on the co-design process
February 2015	Informal meeting 1	One researcher, two educators	Mapped the complexity of the Ebola issue and dealt with ways to address the wickedness of the issue
March 2015	Workshop 4	One researcher, Four educators	Elaborated on the Ebola issue through a role play approach, and dealt with ways to address the wickedness of the issue
March 2015	Student interview	One researcher, four students	Asked students on their thoughts on the current educational design
March 2015	Workshop 5	One researcher, Four educators	Changed the controversy to bacterial resistance. Elaborated on the bacterial resistance issue and pedagogical considerations for the school programme
June 2015	Informal meeting 2	One researcher, four educators	Kept the educators updated on the design process
June 2015	Meeting with expert 1	One researcher, bacterial resistance expert	Discussed the current educational design
June 2015	Informal meeting 3	One researcher, one educator	Elaborated on the current educational design
September 2015	Workshop 6	One researcher, two educators	The researcher provided a final design for the educational programme, discussed practical considerations
October 2015	Meeting with expert 2	One researcher, one bacterial resistance expert	Got input on our final educational design
October 2015	Workshop 7	One researcher, two educators	Discussed practical considerations related to the educational programme
January 2016	Workshop 8	One researcher, two educators	Finished up the programme by deciding on and carrying out practical matters
February 2016	Educators meeting	Two educators	Finalised the educational design
February 2016	Practical meeting	One researcher, one educator	Prepared for the school class visits by printing educational material, structuring the room, create a power point

confusion with different perceived roles, time-consuming issues and different expectations concerning responsibility and outcome. In our analysis we focus on these different dynamics and specific problems connected to the issue of handling controversial issues through a co-design process. The analysis is structured by the phases in the co-design process, following Sanders and Stappers (2008), with design criteria phase, idea-generation phase, and concretisation phase that started with a breakdown.

The Design Criteria Phase: Negotiating Our Understanding on Controversial Issues

In the design criteria phase, the aim was to establish a common language about how to understand controversial issues in the group by negotiating the aims and visions for the educational programme. This process was facilitated by the creation of a set of design principles, supported by visualisations that were created and introduced by the researcher.

Creating a Common Language on Controversial Issues Through Visualisations

The process of creating a common language involved defining controversial issues as well as creating a set of design principles in collaboration. The design principles developed throughout a continuing process going from the first group interview through to WS2. As the group consisted of participants with different expertise, the process of creating a common language was influenced by a multifaceted, and often contradicting, view on the concept 'controversial issues' and additional pedagogical approaches. For example, an initial understanding of controversial issues seemed to be more linked to provocations and sensitivity, rather than no right or wrong answer and discussion. Furthermore, there was disagreement as to whether to question science or to focus more on the uncertainty related to, e.g., ethics, politics and so on. To deal with these contradictions, we therefore had to negotiate a common understanding of controversial issues as well as educational intentions related to the educational programme. This negotiation process was facilitated through visualisations created and introduced by the researcher.

The first visualisation consisted of a list of understandings of controversial issues based on the initial group interview and was presented to the educators in WS1 (see Fig. 2.2). To create the list, the researcher carried out preliminary analysis of the interview and thematised what the educators emphasised with controversial issues. In addition, the researcher also created a list of elements that she found to be missing or that challenged the initial understandings of controversial issues.

What is a controversy?

- Conflict, disagreement, debate
- No right or wrong answer
- A challenging/sensitive topic
- The topic creates discussion
- The topic could engage as it concerns students

- *Not a too «hot» topic*
- *Leave the religious focus out*
- *A science-based controversy*
- *Training students' argumentation and decision-making skills*

Fig. 2.2 A visualisation of educators' initial understanding of controversial issues and additional elements from the researcher (in italics)

The visualisation worked as a tool to clarify and elaborate on the different understandings of controversial issues in the group. However, the added elements from the researcher on how to understand controversial issues created tensions and discussions in the group. For example, the researcher suggested to consider less 'hot' topics (understood as less provocative and ethically loaded), as she felt this focus outcompeted important elements like no right or wrong answer and promoted students' decision-making and argumentation skills.

This less 'hot' suggestion was met by the educators with resistance, especially from two of them being worried that a less 'hot' topic would be less engaging for the students. In addition, there was also a concern that the controversial element would be lost if we focused on less 'hot' topics. We therefore had to negotiate what elements of controversial issues we would emphasise in the group. As a result, we agreed that the issue had to emotionally move the students, an element the educators highly emphasised with a controversy-based focus. Nevertheless, we further discussed alternative ways to emotionally engage, for example, by creating a sense of ownership and relevance for the students related to a controversial issue. To highlight this and similar negotiations in WS1, the researcher created another visualisation that was presented to the educators in WS2 (see Fig. 2.3).

This visualisation aimed to illustrate our step-by-step process towards creating a common language for controversial issues, influenced by our different inputs and the outcomes of our negotiations. The result of the process was a final set of design principles that was presented to the educators in WS3 (see Fig. 2.4).

A Raised Awareness on Controversy-Based Learning

Overall, the process of creating a common language and final design principles both facilitated and challenged the group to express their aims and intentions with controversial issues. The process especially challenged the group to express their

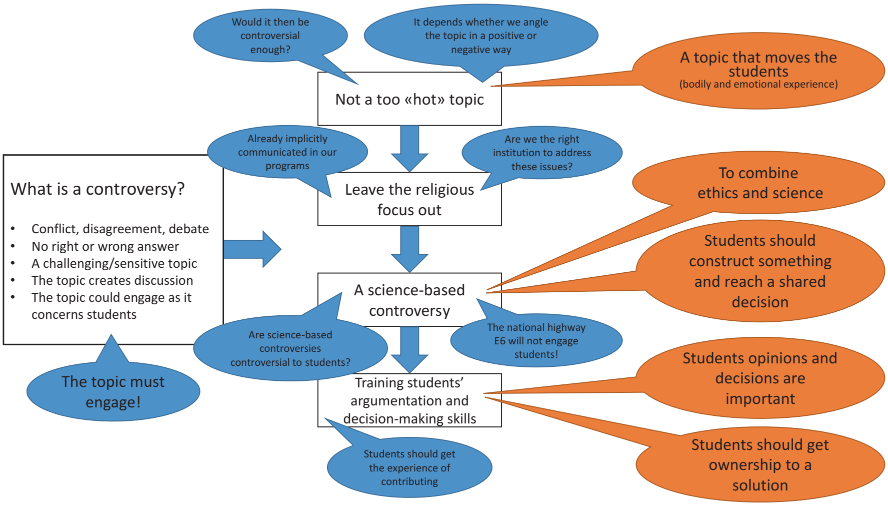

Fig. 2.3 A visualisation on negotiations on meaning of controversial issues presented in WS2: Researchers' suggestions (in squares), revised comments from the educators (in blue shapes) and the outcome of the negotiations (in orange shapes)

What is a controversy? Final design principles

- Conflict, disagreement, debate
- No right or wrong answer (?)
- A challenging/sensitive topic
- The topic creates discussion
- The topic must engage!

- A topic that moves the students (get a bodily experience, stimulate the students' emotions)
- A combination of ethics and science
- To construct something/decide on something together
- Students' own opinions and decisions are important
- The students get an ownership to one solution

Fig. 2.4 The final design principles for the controversy-based educational programme

educational intentions, values and priorities with controversial issues through the inputs from the researcher. When the researcher asked how they experienced dealing with controversy-based learning through the co-design process in the second group interview (between WS3 and WS4), the educators especially expressed appreciation of gaining a greater awareness of the pedagogical value of addressing controversial issues.

Sara: This has been an awareness-raising process for us. That we see how important [students'] dialogue and engagement in discussions is […] That we are now more aware of why we do what we do.

Martin: The pedagogical literature is also more highlighted here than in other design processes. Often, the design process becomes more practical.

Overall, the educators reported that they were not used to collaborative design processes where there was a focus on weighing different ideas against each other. Rather, they often created programmes alone, using their colleagues as consultants, and designed them with often a short deadline in mind.

Idea-Generation Phase: Dealing with the Wickedness of Ebola

The idea-generation phase focused on exploring different topics, content and pedagogical activities for the educational programme. This process was framed by a number of brainstorming sessions included, for example, structuring ideas in themes by using Post-it notes, using think-pair-share to generate new ideas and to prioritise ideas from generated lists (see Fig. 2.5). In addition, the final design principles further worked as a tool to guide our decisions in the design process based on our common aims and intentions.

In WS2, we decided on the Ebola epidemic as our final topic, as Ebola was a highly relevant issue at that time. We also decided to use role play as a pedagogical approach for the students to deal with the issue. As an initial step in the idea-generation phase, we therefore started to brainstorm on different wicked problem scenarios within the Ebola issue. For example, related to developing new vaccines, e.g. researchers needing money to develop new vaccines, distributing vaccines through medical companies that are looking to make money, who decides who get the vaccine, and who has the money to buy the vaccines? Furthermore, in WS4, we

Fig. 2.5 A brainstorming process in WS4

brainstormed potential roles and how they were affected by different wicked problems of Ebola by using Post-it notes (e.g. health-care professional, infected person, relatives of the infected person, doctor, microbiologist, ecologist and journalist).

However, as the idea-generation phase stretched out in time frustration started to surface for both the researcher and the educators. This frustration was especially related to dealing with a wicked problem being an overwhelming and time-consuming task. Thus, even though we had created a set of design principles we still had to deal with unwrapping the conflicts within a controversial issue and then deciding how to engage visitors in this complexity through role play. In addition, despite having used WS2-WS4 to brainstorm on the wicked problems of Ebola, the topic was changed to bacterial resistance in WS5. Bacterial resistance was chosen after presenting our ideas on our current design (Ebola and role play) to a group of students between WS4 and WS5. The students expressed more concern about bacterial resistance than Ebola. In addition, in WS5, the educators also experienced a greater relevance of bacterial resistance to the community surrounding the science centre (the centre being situated close to a hospital, students taking antibiotics and headlines in the newspapers). Thus, in WS5, we started unwrapping the complexity of bacterial resistance. As we started a new brainstorming process on bacterial resistance, frustration with the complexity of a controversy-based educational programme further surfaced:

> Sara: A part of the challenge here, because bacterial resistance is a very complex case, we are sitting here and fumbling in the dark because there are so many things. Can we manage to present such a complex case in a simple way where all students are involved? Will we be able to get the students to think about the complexity in the controversy? To really understand the controversy? To create a fruitful dialogue between the students? When I talk about it now, I wonder if we are at all capable of addressing the controversies within the bacterial resistance issue.

Thus, hesitation was expressed as to whether we would be able to create a controversy-based educational programme, focusing on the wicked problems of an issue and student-engagement.

The Magnified Complexity of Co-Design

The confusion coping with the complex nature of controversial issues seemed to be further magnified by the idea-generation phase of a co-design process. There was an experience of being stuck in a never-ending process of dealing with a number of ideas, but not getting closer to a final educational design, as expressed in the researchers' reflection notes:

> This takes so much time… Where is this ending? What do we get from the design process? This is such a complex process. (Researcher's reflection notes, WS4).

In addition, before initiating the co-design process, the researcher had envisioned a process in which the responsibility for designing the educational programme would be shared between the educators and herself. However, the reality was that the educators were often affected by their daily workload that prevented them from engaging at the level that the researcher had hoped for, as the workload at the science centre was already high.

To deal with the workload of unwrapping the Ebola issue, the researcher took on a supportive role. For example, she collected information on Ebola between the workshops that was further provided back to the group. This supportive strategy seemed to be well received by educators, making it possible to continue the co-design process despite the workload-issue. This could be illustrated in the researcher's reflection notes from an informal meeting with two of the educators between WS3 and WS4, in which the agenda was to come up with a suitable angle for the Ebola role play:

> It took quite some time before we managed to get focused in the meeting. The educators talked about all the other responsibilities they had that took their attention and time, and they expressed that they did not exactly feel that they were able to be creative and motivated in the design process […] I started to tell the educators about what we discussed in our previous workshop, and then the motivation and creativity gradually returned. Especially the fact that I had been reading about Ebola and epidemics before our meeting seemed to inspire them. This move probably led us further in the process, that the educators felt that they did not have to do it alone, that I actually had a supportive role. (Researcher's reflection notes, informal meeting between WS3 and WS4)

Thus, both the issue of making final decisions concerning topic, content and pedagogical activities was an overwhelming process that was linked to confusion concerning the roles in the co-design process as much as the time-consuming process of dealing with addressing controversial issues.

Concretization Phase: Landing a Final Controversy-Based Educational Design

The frustration that built up during the idea-generation phase eventually led to a breakdown in the collaboration, making it necessary to change the course of direction to be able to move from the idea-generation phase to the concretization phase. The frustration was especially related to a sense of not getting closer to a final educational design, and the overwhelming task that was related to dealing with ways to address wicked problems in an educational programme. In addition, there was confusion related to roles and responsibilities in the co-design process.

The Breakdown: Creating or Reflecting on Controversy-Based Learning

The breakdown made it clear that there existed different expectations related to the focus and outcome of the co-design process. Especially, there was an expressed confusion as to whether the creation of the controversy-based educational programme or exploring controversy-based learning through the process was the main priority of the research. One of the educators stayed after WS5 to elaborate on his thoughts on the research process:

> Steffen: I just feel that I am challenging the structure of the design process… You are not a regular chairperson, you want to carry out research on how we work […] My impression is that your aim is not to finalise the educational programme as soon as possible, or we could have been done two months ago. But that is not productive for you, I guess? I do not know what is useful for you. It is hard to know…

For this educator, there was a mismatch between the co-design process and how he normally designed new educational programmes in his daily practice, as he elaborated on after WS5:

> Steffen: For me, who has a busy workday, the aim is just to land something within a deadline […] But in this research project, we are, rather, testing different techniques? And that is okay, it is probably fruitful for you, since you get a lot of discussions that you can listen to and analyse afterwards. But for me, I am thinking 'should we not be done soon?' I just want to finish the educational programme. We just have different prerequisites.

Through the conversation with the educator, it became clear that we lacked a common understanding of the co-design process intending to arrive at a new understanding of how to address controversial issues. The educator was more focused on finalizing the programme, while the researcher was more focused on the reflections of controversy-based learning the creation of an educational programme sparked. These differences in expectations may have affected the educators' patience with the co-design process, and eventually leading to the breakdown.

In addition, there was also confusion related to roles about who were the ones making the final decisions. This was especially a challenge when there was a number of decisions to be made related to, e.g., bacterial resistance (what information do the students need? What parts of the issue do we want the students to deal with?) and ways to engage the students (are they able to discuss and make decisions related to the issue? And are we able to make that happen within a time frame of 90 minutes?). As this was a collaborative process, the researcher was careful about making final decisions. However, this also led to confusion, as illustrated by the following excerpt in WS5:

> Steffen: I believe that you, Ingrid, in one way or the other need to just make some decisions, if you are the one who makes the decisions, or you need to give away a mandate to someone else to make some decisions. […] I do not know how easy it is in an open dialog with five people to agree on a final design. Someone needs to sit down and create a suggestion for the educational programme, and then we could continue the discussions from that suggestion.
>
> Martin: Do you think it is too much democracy? (Smiling)

To cope with the breakdown and maintaining the collaboration, the group decided that the researcher would take the responsibility for gathering the ideas and putting together a suggestion for a final controversy-based design before WS6.

Finalizing the Controversy-Based Design

For the researcher to be able to create the final educational design, she involved external resources on the topic of bacterial resistance and sought input on activities that could support our design principles. At the same time, she kept contact with the science centre educators through informal meetings in which she kept them updated on the design process. Through the finalizing of the controversy-based educational programme, the wickedness of bacterial resistance was reduced to a minimum, to be able to land a final design and for the wickedness to be illustrated within the time limits of an educational programme (90 min).

Thus, the final educational design addressed four dilemmas where the students were challenged on making decisions on what actions they were willing to carry in their daily life to reduce the amount of bacterial resistance. More specifically, they had to decide yes or no individually, and then in groups, related to the following dilemmas; if they wanted to travel less; eat less meat; take less antibiotics; and trust in researchers to come up with new antibiotics. To illustrate how these dilemmas are wicked problems, the students were provided with a counter-argument related to the decision they made in the group. For example, if the group had decided that they wanted to travel less as an action to reduce the spreading of bacterial resistance, they were provided with a counter-argument illustrating that the spreading of bacterial resistance still would be possible through imported products like fruit and vegetables.

The researcher worried that she would create a final programme that would not resonate with the ideas in the group. However, when the researcher presented the final educational design in WS6, the educators were both positive and relieved about being introduced to a product that followed the design principles developed earlier in the process:

> Steffen: My first impression is that the educational programme is good, that it finally looks like a programme that is possible to put into practice.

Even though the researcher took the step from ideation to concretisation, the collaboration seemed to be sustained in the concretisation phase by the fact that the group already had established a common language on controversial issues in the idea-generation phase. This statement could be illustrated by one of the educators who was not sure if parts of the suggested design represented the principles we had set for the programme:

> Sara: We need to show that there are no right or wrong answers here. We need to illustrate the complexity in the dialogues, so I have doubts about asking the students to make a stand on the question 'Are you worried about bacterial resistance?' […] Rather, we want the students to mobilise, to see that there are actually solutions to the issue. That is something that we have been discussing all the way, that we do not just want to give students knowledge, but also competencies!

The educators were able to engage at a detailed level in the concretisation phase and seemed to have regained confidence to engage in the process and expressing ownership towards the final design. In addition, the fact that the researcher took on the role of landing a final controversy-based design, this also led to a renewed motivation from the educators on wanting to continue the design process, while the researcher was now focused on landing the final design, illustrated in the researcher's reflection notes after WS7:

> In WS7, I was mainly focused on the practical considerations of the educational programme. Who can fix that, and how many exemplars do we need [for example, who could fix a set number of petri dishes] […] This seemed to stress the educators, and they wanted to include more people. So, we have changed. Now it seems as though they want to discuss and make the educational design better, while I just want to be done (Researcher's reflection notes, WS7).

Discussion

Through this study, we provide insight into the complexity of co-designing a controversy-based educational programme in a science centre. Our experience was that the longitudinal, collaborative and explorative aspects of co-design created a valuable platform for engaging in conversations about controversial issues and pedagogy with practitioners as contextualised to their practice. However, these aspects also created tensions in the collaboration due to different expectations about controversial issues, the complexity of dealing with wicked problems in an educational design and the co-design process.

Our research question has focused on the possibilities and challenges that arise when educators and researchers co-design a controversy-based educational programme in a science centre, and we will here structure our findings in relation to possibilities and challenges related to co-designing controversy-based learning activities, for example, the value of creating design principles, the challenging process of dealing with wicked problems through the idea-generation phase, the researcher taking on a supportive role and dealing with expected outcomes from the co-design process and negotiating responsibility in the design process.

Our analysis shows how the focus on creating a common language in the design criteria phase of the process supported the group in raised awareness and deeper understanding of the nuances of addressing controversial issues. Through the visualisations and creation of the design principles, both the researcher and educators were challenged to express their intentions, values and priorities with controversial issues. The educators also expressed that engaging in the co-design process made them more aware of both controversy-based learning and their own educational practice. This raised awareness reminds us of the experience Pedretti (1996b) had when using action research principles to create a model on how to understand STS education in collaboration with science teachers. The teachers reported that this process made them feel more confident and able to express their own opinions related to carrying out STS education.

Even though we had created a set of design principles to guide our design process, we still had to deal with unwrapping the wicked problems within an issue and then deciding how to engage visitors in dealing with the problem. This felt like quite an overwhelming and time-consuming task, especially combined with the open and explorative nature of co-design, where we struggled to move from ideation to a concrete design.

The complex nature of controversial issues may be one reason this transition was such a time and energy consuming process. For example, the complexity involved in unwrapping the conflicts within an issue such as bacterial resistance demands a broad overview of different subject areas as well as the ability to make its complexity accessible to visitors. The call for a learner-centred pedagogy focusing on engaging visitors in dialogue and decision-making processes adds yet another layer of complexity. On top of this, addressing controversial issues demands a process in which the concept and aims need to be clarified in the group. In addition, a focus on controversial issues differs from the science centre pedagogy that is traditionally based on addressing scientific facts and the 'wonders of science'. Thus, to focus on controversial issues could also be seen as challenging the educational practice at the science centre. These tensions related to the pedagogical considerations are elaborated on in Eikeland and Frøyland (2020), such as dealing with an issue without a right or wrong answer and to engage students in discussion and decision-making processes related to wicked problems.

However, we experienced the breakdown to be an important point in the collaborative process. This was the point where concretizing the design principles for controversial issues became an obstacle for the educators and where the researcher took an active role and designed an example of a controversy-based learning activity based on the discussions in the group. This was a pragmatic solution to the breakdown, which is not the ideal trajectory of a co-design process. Ideally the educators should have been active during the concretization phase. Meanwhile, the learning programme designed by the researcher materialised the discussions that had been during the co-design process and was recognized by the educators. The designed example gave the educators an idea of how their reflections and discussions about controversial issues and wicked problems could be linked to a concrete learning activity, and the educators were re-engaged to continue the design process.

In addition to dealing with controversy-based learning, the tensions experienced in the co-design process could also be related to confusion with the co-design process. For example, the main trend in our co-design process was that the educators were not able to engage at the level the researcher had anticipated and hoped for due to the general workload at the centre. This trend has also been the experience in other co-design projects where the expectations of participants engaged in the process often was higher than the engagement in practice (Mygind et al., 2015). More substantially, we are not sure whether the educators were aware of the workload and responsibilities that was expected of them upon engaging in the co-design process, something that created tensions through the co-design process.

Thus, we are not sure whether the educators saw the co-design as a learning process for both researchers and educators to create awareness and understanding on controversy-based learning, and how this affects the educational thinking and practice in the science centre. It could be suggested that they rather saw their role as working consultants to the researchers' suggestions. This was also how they normally interacted with colleagues when designing educational programmes in their daily practice.

We suggest that the confusion we experienced related to the outcome, responsibilities and roles in the co-design process could have been reduced by establishing an understanding of co-design as a research process from the beginning and to agree on roles and responsibilities. Especially when the participants are new to co-design, they need to be introduced to the research approach and to clarify what their roles include and what is expected of them (Stuedahl, 2004). From our experience we also suggest that to clarify different roles and expectations needs to be a continuing process, as the dynamics in our group constantly changed through the co-design process.

Furthermore, we believe that the researcher taking on a supportive and active role enabled the educators to participate in the co-design process. For example, one aspect that helped us through the co-design process was when the researcher took the step from ideation to concretisation on behalf of the group. This change of roles is a well-known situation in co-design processes (Mygind et al., 2015). This move enabled us to deal with the complexity of controversial issues again by departing from the concrete topic of bacterial resistance. Following this experience, the co-design process might have been less challenging if we had managed to move into the concretisation phase sooner. For example, Allen and Crowley (2014) recommend introducing successful cases after collaborating with a group of museum educators in developing the educators' practice related to addressing global warming. Thus, introducing cases to work with in the idea-generation phase might have been helpful in our co-design process to narrow the gap between ideation and concretisation. Nevertheless, we still want to highlight the importance of being in the explorative process and spending time on creating a common language on controversial issues, despite the tensions, as we experienced this process to be especially beneficial when moving into the concretisation phase, as we found the educators to be able to engage at a detailed level when presented with the final design because of the common language on controversial issues established in the initial stages.

In addition, we argue that the researcher was able to take on the active and supportive role due to her pedagogical competency related to science education and controversial issues. This competency became an important resource, especially while moving from ideation to concretisation in the co-design process. This step was something the researcher was able to do on behalf of the group, due to both her background and the discussions that arose in the idea-generation phase with the educators. In contrast, the researcher was a novice in carrying out co-design research. Thus, to facilitate the process was also a process of gaining experience with the research process through trial and error as the co-design process developed. The tensions experienced in the co-design process could therefore have been reduced had the researcher been more experienced with co-design. Within co-design literature, there exist a number of techniques on how to facilitate and to lead participants through different stages of the co-design process. One example of such a technique is `future workshop` which is an approach to leading the process of generating ideas and landing final decisions (see, e.g. Stuedahl, 2017). In addition, strategies from the ‘Research+Practice Collaboratory’ could also be used to facilitate the conversations in between the participants (Bevan 2017).

As a conclusion to this study, we argue that co-design was a suitable approach for raising both educators’ and researchers’ awareness of intentions and aims with addressing controversial issues in the science centre. The co-design process also provided insight into the complexity of addressing wicked problems. However, we also experienced that the complexity of focusing on controversial issues was magnified by the complex nature of a co-design promoting new ways of collaboration between researchers and practitioners and ways to learn through reflexivity. Thus, we recommend that special attention needs to be given to introducing the participants to the co-design approach, with a focus on their possible roles and responsibilities. In addition, as controversial issues were so complex in itself, we also saw the need for the researcher taking on more responsibility and support.

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Chapter 3
Addressing Health in Out-of-School Science Experiences

Catharina Thiel Sandholdt

The challenges of the twenty-first century are multitudinous and complex, and there are no *right ways* of solving issues such as pollution, waste-handling or multi-resistant bacteria – so-called wicked problems (Dillon, 2017; Law, 2004). Our *business as usual* is questioned and the knowledge produced by science communities all over the world cannot stand alone or be approached in an objective manner. Instead, the generated knowledge can be interpreted politically and become the subject of social policy. Research from the field of environmental education relates these wicked problems to the world of science education. Environmental issues are used as examples because they are characterized by complexity and multiple scientific affiliations – for instance, through 'edible garden' projects educating youth(s) in the complex system of health, food and ecology and the various stakeholders involved (Wals et al., 2014).

Science educational researchers stress the necessity to approach these ambivalent and highly political problems through a participatory, interdisciplinary and contextual approach (Wals et al., 2014). Natural sciences can produce the knowledge and tools needed to work towards making the world a better, safer and more sustainable place. However, ambition to create societal impact challenges the classic mono-disciplinarity of most scientific communities by encouraging them to be explicit in demonstrating how their research adds value to society. Out-of-school science experiences have the potential to bridge the gap between people's everyday experiences and scientific research. The organised experiences offered in out-of-school science learning settings are important in that they are explicit in presenting how science is part of our every life whilst offering alternative ways to live. More broadly organised out-of-school science experiences can increase scientific literacy and thereby influence policy-making, ultimately shifting the direction of societies.

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M. Achiam et al. (eds.), *Addressing Wicked Problems through Science Education*, Contributions from Science Education Research 8,
https://doi.org/10.1007/978-3-030-74266-9_3

In this chapter, obesity and increased risk of lifestyle diseases related to an increasing sedentary behaviour on a global scale is investigated as an example of a wicked problem. I will use the development process of a health exhibition at a science centre as an example of an attempt to address sedentary behaviour through a participatory, interdisciplinary and contextual approach.

Sedentary behaviour is a health issue, embedded in our everyday life as well as at structural and policy levels (Tones & Green, 2004). In the West, the overall living conditions have improved since World War II, but paradoxically this improvement is one of the reasons for the dramatic rise of non-communicable diseases – such as diabetes and cardio-vascular diseases – which are creating public(s) with poor health (National Institute of Public Health, 2009). To reduce non-communicable diseases, the public are educated about health based on official recommendations derived from the natural sciences. The aim is to reduce for example sedentary behaviour on an individual level. Sedentary lifestyle is one facet of the obesity problem, but higher physical activity alone will not always result in normal body weight, because many other factors are involved. In this aspect it becomes an excellent example of a wicked problem, and this chapter will thus not thematise obesity, but rather physical activity as part of a healthy lifestyle woven into a complex web of entanglements.

Health education has historically been characterised by a moralistic, top-down approach, where health experts define right ways of behaving and what qualifies as a disease or illness (Grabowski et al., 2017; Jensen, 1997). In this traditional approach, people are informed about expedient behaviour and are expected to follow expert recommendations to prevent illness. However, the knowledge gap, where people know what to do, but do not act on it, is a well-known problem, and continuous attempts to inform the public of advisory health behaviour, primarily through campaigns, have not always had the desired impact (see, e.g. Cavill & Bauman, 2004; Halkier & Jensen, 2011). One of the main objections to the top-down approach to health education is that it ignores people's own perceptions of health and fails to mobilise or foster competences needed to change inexpedient health practices (Bønnelycke et al., 2019).

This approach also fails to acknowledge the role of social and structural mechanisms influencing the possibilities for living more active lives, for example, redistributive politics, working conditions and housing opportunities (Grabowski et al., 2017). This perspective on health illustrates how sedentary behaviour is an example of a wicked problem, where we as researchers, health practitioners or politicians have no clear-cut or true way of dealing with the issue but need to approach sedentary behaviour in the contexts it unfolds (Dillon et al., 2016). It also shows how wicked problems have a structural aspect and at the same time are part of everyday practices that are enacted within these societal structures.

An alternative to the top-down approach to health education – a more democratic approach – has been suggested, working with health promotion through participation and with health as a positive and open concept (Grabowski et al., 2017). This form of health promotion is aligned with the World Health Organisation (WHO) definitions of health from the Ottawa charter describing health as being 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' (WHO, 2014). The democratic approach guides resources towards keeping healthy people healthy (Kamper-Jørgensen et al., 2009). This approach is based on the fact that people are living longer, but at the same time non-communicable diseases pose a threat to the quality of these lived years. The pedagogical aim here is to build action competences, meaning resources to enable empowered citizens to act on knowledge acquired (Jensen, 1997). This can be done by encouraging target group participation, which increases sense of ownership over the educational process (Grabowski et al., 2017).

The basic assumption in health promotion, as it is understood in this chapter, is thus that health is influenced by both lifestyle and living conditions and that health interventions must aim at improving both (Jensen, 2009). This perspective draws on knowledge from the humanities and social sciences (Jensen, 1995), especially from the tradition of action research (Grabowski et al., 2017; Gustavsen, 2003). The overall approach is to create structural change and community-based incentives, which enable the individual to develop action competences that make her able to reflect and act on, for example, sedentary behaviour. This differs from moralistic health communication which frames sedentary behaviour as an individual problem that can be changed through fact-based information (Sandholdt & Achiam, 2018).

Within science education, Dillon argues that health and environment should receive the same amount of attention as traditional science (Dillon, 2012). He worries that by viewing health and environmental issues as cross-disciplinary, they become orphans that nobody wants to take in. This risks leaving the public with poor health or environmental literacy, which is just as important and integral to scientific literacy as the classic STEM disciplines (Dillon, 2012).

If we agree that health education is critical for achieving a broader scientific literacy, we are prompted to explore the potentials of out-of-school science experiences and here more specifically the role of science centres. Science centres have the opportunity to play a vital role in fostering action competence to deal with wicked problems such as sedentary behaviour. Science centres can approach the task of fostering action competences through the engagement of youth and families in science activities that can transcend mono-disciplinary barriers and lead the way in communicating health from different perspectives.

Museums and science centres are emerging as relevant learning environments for health education and health promotion (Chatterjee & Noble, 2013; Christensen et al., 2015; Flynn, 2016). One of the strengths of these learning environments is the opportunity to communicate health in a recreational rather than clinical setting (Chatterjee & Noble, 2013). In the context of the science centre, health is not an unfamiliar subject, as they have a tradition for exhibitions about the human body and its anatomy. However, science centres often take the aforementioned approach to health education where health behaviour becomes an imperative citizens are required and expected to follow (Sandholdt & Achiam, 2018).

Health exhibits typically deal with functions of the body in isolation from the contexts these bodies are part of and influenced by. In the example of sedentary behaviour, such a de-contextualised health communication could be exhibited showing a model of a clogged vein or an activity measuring your body fat providing the conclusion that you are obese and that this will shorten your life expectancy. This information poses no immediate possible actions or considerations of the context(s) in which imagined possible actions are to be performed. For the science centre, the subject of health, and in this chapter more specifically the subject of sedentary behaviour, can thus be an opportunity to break with a more objectivist approach to the investigation of scientific questions. In such approaches, the dominant scientific view is accepted and acts as starting point for further inquiries; the aim becomes to investigate and identify 'wrong' positions and locate truth, which is usually founded in the laws of nature (Meyer, 2010). Instead, sedentary behaviour can be a chance to engage with a wicked problem, or contentious topic, characterised by myriads of opinions and recommendations in the line of GM crops, stem cells, artificial intelligence, environmental issues, etc. (Cameron, 2005). In this sense, it is a hot topic in science education; a topic that is operationalised and made relevant through relationality rather than cold stabilised objects, such as laboratory apparatuses (Meyer, 2010). The open and negotiating nature of a democratic health approach offers a holistic (Jensen, 1997) and dialogic strategy to communicate health in the science centre, encompassing the contexts that co-form and co-define health – thereby not simply making sedentary behaviour a consequence of lifestyle, but something interwoven in structural and relational contexts. A science centre setting therefore offers an opportunity to increase health literacy (Nutbeam, 2000) and explore new futures for the communication of science.

The Science Centre as Setting for Out-of-School Health Education

A science centre is understood here as a physical learning space, exhibiting ideas from natural sciences and technology (McManus, 1992), through interaction and hands-on experiences (Amodio, 2013). The Exploratorium in San Francisco, which opened its doors to the public in 1969, marked the birth of the science centre as we know it today. The appearance of the Exploratorium and many of the similar institutions that opened in the West in the following years was in part a reaction to historic circumstances such as the success of the Soviet Sputnik space programme and the resulting perceived threat from the Soviet Union (Bradburne, 1998; Quistgaard & Kahr-Højland, 2010). Previous attempts to inform the public about science had failed, it was argued, because they lacked the props of science: 'Explaining science and technology without props can resemble an attempt to tell what it is like to swim without ever letting a person near the water' (Oppenheimer, 1968, p. 206). Thus, the rationale for the communicative approach that is still influential in science centre exhibitions today was the notion that providing visitors with the opportunity to manipulate and observe laboratory apparatus would lead them to discover answers to scientific questions, thereby promoting familiarity with science and ultimately, a scientifically informed citizenry (Bradburne, 1998).

However, the past decade science centres have been under increasing pressure to renew themselves to justify their continuing value to society (Black, 2012; Koster, 2016; Rodari & Merzagora, 2007; Semper, 2007). The particular constellation of social and political conditions in the Cold War era that prompted the emergence of the science centre at the end of the 1960s no longer exists (Ogawa et al., 2009). Instead, we are finding ourselves in an era of wicked problems. Museum director James Bradburne argues that mono-disciplinary exhibits, informing the visitors of the wonders of science in a top-down approach, are not sustainable (Bradburne, 1998). Instead, science centres are encouraged to (1) contextualise their exhibitions and make science part of society; (2) invite stakeholders, visitors and communities to be part of designing exhibitions and the daily run of the science centre; and (3) be bold and take on contentious topics such as GMO and environmental threats (Bandelli, et al., 2009; Cameron, 2005; Pedretti, 2004, 2002; Quistgaard & Kahr-Højland, 2010; Evans & Achiam, 2021). The time where science was seen as detached from society is over, and visitors expect science centres to discuss the role of science and technology in everyday life in a way that enables them to act (Schiele, 2014). This shift requires a change from doing science to reflection on science (Quistgaard & Kahr-Højland, 2010). This engagement should be facilitated through inquiry-based, contextualized exhibition milieus (Achiam & Marandino, 2014; Quistgaard & Ingemann, 2010), thus moving from an approach to science dominated by creating and nursing curiosity to an approach focused on finding solutions to societal challenges.

The challenges discussed above move exhibition development processes into the spotlight, given that the exhibitions make out the 'public face' of the museum (Alberch, 1994). Museum exhibition design processes typically proceed through the phases of conceptualising the subject or theme, developing the exhibition (from physical and educational design to the building and installing of exhibits), various forms and degrees of evaluation and in some cases an assessment phase (Taxén, 2004). However, these phases are not linear or uniform processes (Achiam & Marandino, 2014; Macdonald, 2002; Mortensen, 2010). Rather, they are to a great extent formed by institutional and political agendas along with participating actors and project specific agendas such as an ambition of fostering participation in specific visitor groups (Davies, 2010; Morse et al., 2013). Exhibition development in science centres is therefore an interesting setting to explore and identify windows of opportunity where the science centre as an institution can find room to adjust to the challenges of the twenty-first century. In the rest of this chapter, I will use the development process of an exhibition on health at a Danish science centre as an example of an institutional attempt to address health in an out-of-school science experience.

The PULSE Project

PULSE was a collaborative project between two institutions: the Experimentarium Science Centre and Steno Diabetes Centre Copenhagen, both based in Copenhagen, Denmark. The project ran from 2012 to 2018 with a €4.4 m grant from the Novo Nordisk Foundation. The vision of PULSE was to 'create innovative research-based science exhibitions and community activities that motivate and support families to take action to develop and sustain a healthy lifestyle' (Experimentarium & Steno Diabetes Centre, 2012, p. 5). Families with children aged 6–12 years old were identified as the target group to the exhibition. The project was formulated through health promotion theory, which can be clearly traced in the projects four educational principles in the funding application:

1. Participation and action competences
2. A broad and positive health concept
3. Multiple approaches for multiple settings
4. Equity in health – reaching new target groups (Experimentarium & Steno Diabetes Centre, 2012, p. 6)

The combination of health promotion and a science centre setting, as well as the collaboration between the science centre and the research institution, offered opportunities for a new and interesting endeavour. It was stressed in the application that the project would have a user-involvement process, to engage families in health at the science centre and to use inputs from and knowledge about the target group in the exhibition development to create a relevant exhibition, dealing with challenges regarding health in everyday life. A cornerstone of the project was the collaboration between research and practice. To stay true to the four educational principles of the project – especially the first two – the exhibition development team (consisting of both researchers and exhibition designers) chose to work with a participatory design approach in the development process.

Participatory Design as an Approach to Generate Participation

Participatory design research aims at designing solutions to everyday problems in everyday settings – the home, office, school, etc. The approach is based on open inquiry and solving any problems in a collaborative process (Simonsen & Robertson, 2012). It is the focus on a mutual learning process between designers and end-users (visitors) that makes participatory design relevant for science centre contexts. In participatory design, end-users are involved in development processes and are viewed as legitimate and acknowledged participants in the design process, rather than merely informants or test-persons (Simonsen & Robertson, 2012, p. 5). The knowledge of the end-users is thus important and valued in the design process, and the users themselves are vital participants in imagining desirable future scenarios (Gunn et al., 2013; Kjærsgaard, 2011; Sanders, 2006; Smith et al., 2016).

Participatory design offers a relevant approach when taking on dialogues on wicked problems. Examples could be to involve the community in the science centre (Bandelli et al., 2009), work with youth as a resource and capacity (Stuedahl, 2015a), work actively with new communication strategies (Quistgaard & Kahr-Højland, 2010; Stuedahl, 2015b) and engage the visitors as users (Bradburne, 2001). A recent review concluded that the use of participatory exhibition development strategies is increasing (Mygind et al., 2015). However, the authors comment that 'more research concerning obstacles and facilitating factors to participatory practice as well as good and bad examples of participatory exhibition development projects in museums […] [is] much needed' (Mygind et al., 2015, p. 134). The PULSE project thus follows this line of inquiries and the research made in the project provides one such example. In the next section I will focus on the co-design process carried out in the exhibition development process and discuss the opportunities such a participatory approach offers for addressing wicked problems in out-of-school science educational designs.

Co-designing the PULSE Exhibition

The co-design process of the PULSE exhibition was intensive in the explorative design phase, where ideas of the main narrative and of specific exhibits in the exhibition were to be generated. This phase lasted approximately one year and consisted of a front-end study and three consecutive workshops (Fig. 3.1). At the end of this phase, the design of the exhibition was mostly finished. Afterwards, there was a long process of building the exhibition; finding technical solutions; acquiring all sorts of permissions, i.e. security checks; and working with the aesthetics of the exhibition. When the exhibition was ready to open, we arranged a special event for the families that had participated in the explorative design phase to thank them for their contributions and share the final result with them (bar five in Fig. 3.1). Here I will share the steps of the co-design process to provide a concrete example of an attempt to develop an out-of-school science design addressing a wicked problem.

The Front-End Study

In order to generate knowledge on the target group of PULSE, project researchers carried out an explorative ethnographic front-end study of families. Our aim was to generate knowledge of families' motivations and barriers concerning physical activity and sedentary behaviour in everyday life, as well as the family relations and dynamics that influenced them. We chose this approach with the intent to produce

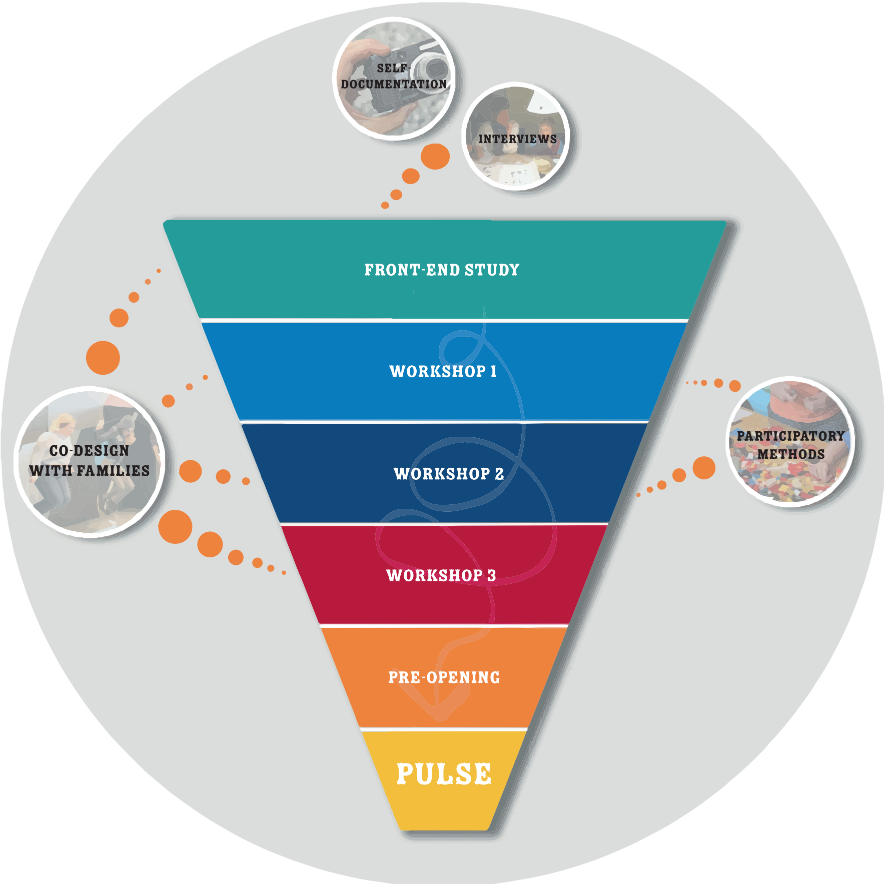

Fig. 3.1 The co-design process as a funnel

more contextualised and rich material than, for example, a focus group interview at the science centre would provide.

In the front-end study, we employed different qualitative methods: self-documentation via photos, as well as family group interviews and observations. We anticipated that the photos the families produced of their lives through the self-documentation method (Czarniawska-Joerges, 2007; Reeve & Bell, 2009) would be of great use to the designers in the exhibition development since such visual material can add and elaborate to textual material. But more importantly, we chose to work with self-documentation to give the children a medium that they could use to show us their everyday life (Rasmussen, 2013). We chose to carry out a family group interview with a point of departure in the photographs from the self-documentation process. The interviews used the photos taken by the family as guiding in the talk and questions, in combination with a semi-structured interview guide with overall interests of concern that we incorporated in the talk of the families' everyday health practices and perceptions of health (Halkier & Torhell, 2002; Staunæs & Søndergaard, 2005). The photos provided an especially useful tool for discussion when talking with the children in the family interview.

To recruit families, we put an advertisement in local newspapers. We stated that we were looking for families with one or more people who were willing to take photos of their life and share them with us in a two-hour follow-up interview in their home. We experienced a massive interest in the project, especially from families with a high level of socio-economic markers such as income and educational level. Generally, it seemed easier to mobilise more affluent families to the project. The inclusion of non-visitors and disadvantaged families proved to be a general challenge to the project. From the families that responded, we selected ten families that represented a broad spectrum of family constellations, including single parents and patchwork families.

All families were given a camera and asked to take photos of their everyday movement for 1 week. We chose the word movement rather than physical activity based on the assumption that movement would provide us with a richer data material, which is in accordance with health promotional guidelines (Grabowski et al., 2017, p. 3). Following the same guidelines, we chose movement to explore existing resources to be mobilized and opportunities for developing action competences, rather than asking specifically into inexpedient sedentary behaviour. When the cameras were returned, project researchers printed all the photos and brought them to the family interviews taking place in the homes of the families. Here we used the photos actively to ask questions concerning what, where and with whom. This lends some tangibility to the stories that unfolded (Hastrup, 2003).

As we had hoped, the photos illustrated a varied spectrum of everyday movement, from shovelling snow and carrying groceries to more traditional physical activity such as parents in training clothes and children at ballet practice. Lastly the photos were also full of images of children sleeping, children helping in the kitchen, parents at their desk, dad and children romping or sitting passively with a tablet (Bønnelycke et al., 2019). All the photos proved to be very useful in the interview sessions, where the *what*, *where* and *with whom* were exemplified and became concrete. The photos were also useful when talking with the children because they concretised questions, resulting in a lively dialogue.

The preliminary findings from the front-end study were presented to the exhibition designers in a seminar format. The ethnographic-field work formed a shared base of knowledge in the PULSE project. It challenged existing ideas of family life in the PULSE group and gave the exhibition designers new inspiration to work from.

Workshop 1: Design Game Set-up

In order for the findings from the front-end study and the participation of families to not only be something to inform the design, but actually be a part of the design process, the project team chose to do three iterative workshops to make the families part of the development. In the first workshop, we designed a design game set-up for the specific case (Halse, Brandt, Clark, & Binder, 2010). We chose to invite four families, because this provided a number of participants large enough to get discussions going, but small enough to give everyone a voice. We used the material generated in the front-end study; cutting up interviews to extract quotes to be used and printing a broad selection of participants' own photos in A6 size. The families then played the design game, which focuses on facilitating a shared imagination of desirable future scenarios – here being an exhibition on health. At the end the families had elaborated on a range of the exhibition designers' tentative ideas, prioritised favourites and discarded others (for more specifics, see Sandholdt, 2018). After the workshop, the PULSE team formulated a list of preliminary findings. From this, Workshop 2 was designed.

Workshop 2: Narrowing Down

In the second workshop, the aim was to work more concretely with developing ideas for specific exhibits. The parents and children were divided into separate groups for the first hour and then united for the last part of the workshop. It was decided that the children would use Lego to elaborate on exhibition ideas. The adults would generate ideas using picture cards as a tool for facilitating dialogue. The adults were asked to choose three picture cards from a large pile that had been spread out on the table. They were asked to choose pictures that offered an atmosphere they hoped to find in the final exhibition. From the following discussion, the adults formulated three core characteristics for the exhibition: joy, togetherness and learning. The children crafted a range of specific exhibit ideas, which especially involved using the body, i.e. through hanging in ropes and elements of danger, i.e. getting electrified when touching the floor in a game of 'the floor is made of lava'. At the end of the workshop, parents and children were united and presented their ideas to each other. They discussed how ideas could be merged and unfolded.

Workshop 3: Testing

The exhibition designers conducted a third workshop. Here three concrete ideas for activities were tested using prototypes and mock-ups. The families were presented to the idea for an overall narrative and gave their say. In the third workshop, the familiarity between designers and families was an asset, allowing a more open and honest conversation, also allowing the families to challenge design ideas and add perspectives.

The PULSE-Plaza Exhibition

The co-design process between families, exhibition designers, and researchers carried out in the PULSE exhibition development had a distinct influence on the final product: the exhibition (see Fig. 3.2). The initial exhibition ideas consisted of a

Fig. 3.2 Images from the PULSE exhibition: (**a**) the Balance Kitchen and (**b**) the Dance Bathroom. Both examples of how the exhibits were designed to suggest playful movement in familiar surroundings. (Used with permission from Experimentarium)

universe where the visitors could encounter families in risk of losing their pulse (and thereby their life!) due to extensive sedentary behaviour and exhibits where the visitors could individually read about official health recommendations and, for example, fill out a daily calendar with blocks of ideas for physical activity – with the aim of reaching the recommended 30 min daily activity. The co-design process with the families and the theoretical perspectives from health promotion challenged this risk-based and moralising approach to health education. As a result, the final exhibition consists exclusively of multi-user exhibits – that must be performed together in order to succeed. The issue of sedentary behaviour is thus approached through a 'team-spirit' approach, because both the empirical data and health research shows that the level of physical activity increases if you have someone to be physically active with. The total of seven exhibits uses recognisable environments such as kitchen, bathroom and hallway to connect the experiences made at the science centre with the lived everyday family life. The exhibits facilitate physical activity in these everyday environments rather than writing about it – you experience your body and its ability in action. By designing an embodied experience of physical activity performed *together,* the exhibition designers aimed to inspire visitors to increase their level of physical activity in everyday life, by letting them feel the joy and the blood pumping. The textual communication in the exhibition is primarily made out of fun-fact quizzes of bodily competences you can take together with your family. The focus is on joyful health experiences rather than being reminded of physical activities you ought to be performing in everyday life in order to follow official health recommendations.

Discussion

As I have exemplified in the preceding, the participatory approach taken in the PULSE project shaped the development process significantly. The participatory approach is here understood as the collaborative work between exhibition designers and researchers and the extensive user-involvement process with families. The participatory approach was a crucial phase for shaping the conceptualizations of health in the exhibition, which resulted in an exhibition focusing on facilitating action competences in the form of promoting bodily awareness and network building within the family.

The participatory approach, however, did not come easily, which I will elaborate on in the discussion. Different actors, belonging to different communities, came together in PULSE. This collaboration gave a wide variety of knowledge, values and social practices represented in the exhibition development process. This process was both exciting and demanding, filled with negotiations and sometimes resulting in frictions. Many of these experienced discrepancies arose from differences in knowledge, values and practices. An increased understanding of the divergent ways of knowing that coexist in a given development project can help solve potential conflicts or discrepancies and increase the understanding of project-team members skills and competences (Lee, 2007). It therefore becomes imperative to linger on these differences.

Addressing Health

For the Experimentarium, one of the main motivations for engaging in the PULSE project was to work with a research-informed, health promotional approach to physical activity and sedentary behaviour. However, adhering to the core principle in health promotion to work with a positive and open approach to health and thereby rejecting a risk-based health communication promoting health as an imperative (Grabowski et al., 2017; Jensen & Johnsen, 2000; Wackerhausen, 1994) became one of the biggest challenges in the project. It proved difficult for the science centre to find a proper way of operationalizing this approach in an exhibition environment previously characterised by the communication of scientific facts.

Since the PULSE project worked with health, especially sedentary behaviour, from a health-promotional approach, it was important for the development team to not come across as health experts by telling visitors the right ways of changing sedentary behaviour. Instead, the ambition was to involve families in developing an exhibition that would inspire families to be more physically active through their experienced challenges and motivations. The promotion of a sense of ownership in the participating families, and the decision to re-create everyday settings in the exhibition, build on a belief that it would convey a positive and enabling experience of health and inspire to increase movement in everyday life. It was important to not only focus on organised sports activities and events, but also acknowledge playing with your kids or going for a swim in the ocean as 'legitimate exercise'. The tension in knowledges, social practices and values was therefore very much on the how rather than the what to be communicated. It is therefore an interesting example in a science centre setting because the subject is not new, but the approach to communication is, because it becomes closely tied up to the user-involvement strategy and thereby shifts the power structure and enables a more dialogic approach.

When addressing wicked problems, one of the challenges is that the problem and the solutions are difficult to define and keep shifting (Dillon et al., 2016). To work with wicked problems, one can therefore benefit from constant reflections on the implicit values in the given project. In the PULSE case, it becomes relevant to look at the certain kinds of health behaviours and bodies the PULSE exhibition promotes (Bønnelycke et al., 2018; Mol, 2013).

The normative foundation in both the open and the health imperative approaches to health is that change in behaviour (in accordance with, for instance governmental health recommendations) is good and something to aspire for. A healthy and active life is thus a good life. How broadly health is defined can vary, but an open and positive approach to health is not in opposition to findings generated in medical research on the dangers of, for example, sedentary behaviour. Disagreements are not on the final destination, so to speak, but on the process of getting there.

Where the health imperative approach to health believes that rational, fact-based information on the risks of, for example, sedentary behaviour will change inexpedient behaviour, the open and positive approach pleads for context-based interventions that take life conditions as much into account as lifestyles and include network-based solutions (Jensen, 1997). This important premise turned into an ever-present dilemma in the PULSE-project, posing a significant challenge in the user-involvement strategy: we asked families to act as experts of their everyday life and asked them to help us define and broaden our approach to health. We asked how, but not whether or why. The overall frame was set by us meaning we took more physical activity as a good for granted. The space for challenging perceptions of health was therefore limited, and the contributions thus narrowed down to only encompass those suggestions that would support the goal of increased physical activity.

Our experiences in the PULSE project were, as such, in line with the conclusion of Bønnelycke et al. (2020) that health promoting exhibitions are not value-neutral. This is important to remember when addressing wicked problems such as the issue of health and physical activity: a participatory approach can be a fruitful path to follow in order to design more relevant and contextually sensitive out-of-school science learning experiences. It can also be a legitimizing factor in a design process because the involvement of end-users includes otherwise silent voices. Having outlined these pros it is also important to note that the normativity and taken-for-grantedness in a project (here that increased levels of physical activity is good and something to strive for) can risk blurring underlying agendas. In PULSE, the science centre wanted to engage their visitors in relation to how the predefined health targets could be achieved in everyday settings. It did not aim to question or discuss health recommendations, their relevance and their achievability (Bønnelycke, 2018). This is not to say that the PULSE-project should have questioned official health recommendations, but it is important to note the limited space for contributions that was granted the participants, and that influence over the codesign process was granted the participants with certain conditions and delimitations.

Research Versus Practice Knowledge

When working with a participatory approach to address wicked problems in out-of-school science education, a collaboration between research and practice is a relevant path to choose. Addressing wicked problems characterized by complexity requires multifaceted solutions better crafted through cross-disciplinary efforts that are able to address the many interrelated aspects and different levels of the problems. This penultimate section reflects on the experiences made in the PULSE project concerning the collaborative venture. Exhibition planning and development involves a negotiation of expectations and agendas (Lindauer, 2005). In projects where the development team consists of exhibition designers, as well as other participants, not normally a part of the museum or science centre regular staff – such as researchers – this process of negotiation and balancing of expectations becomes even more important to give attention.

The collaborative structure of the PULSE project was a key component in the development process and created a valuable opportunity for two ways of knowing to learn from each other. The value of research knowledge in a development process is not necessarily obvious, which is evident in the following anecdote from an informal talk on research capacity at a meeting at the science centre. Here an exhibition designer inquired about the value of research. I answered that in my opinion research does not provide clear-cut advice or consultant-like right ways of doing. But it can provide a more qualified basis for decisions made in the design process, and it can help exhibition designers ask better questions along the way – being just as confused as before, but at a more qualified level. As a response another of the exhibition designers teasingly asked me: But why should we spend so many resources to be just as confused?

This anecdote is quite illustrative of the challenges of understanding and acknowledging the value and relevance of each other's competences that we faced in the collaboration between research and practice in PULSE, which is a known challenge in research and practice collaborations (Lane et al., 2004; Myers-Walls, 2000; Silverman, 2000; Spear & Rawson, 2002). The collaboration proved to be an ongoing negotiation and exercise of trust in each other's contributions. It was at times unclear to the exhibition designers how inputs from the PULSE researchers could be incorporated in the design process. On the other hand, the researchers were challenged by the request of concreteness brought forward by the exhibition designers.

Researchers struggled to formulate clear inputs often referring to the complexities in the data. The designer's established skills of taking an idea and simplifying it into a clear-cut, playful exhibition idea was an entirely different approach, which the researchers had difficulty in encompassing and acknowledging. Finding each other at the mid-point between abstract and concrete thinking was an important aspect of the collaboration. Notably, the extent of negotiations needed was also an unforeseen aspect of the collaboration – a collaboration, which in the original PULSE funding application was listed as the place for innovation. It is my conviction that this cross-pollination finally happened, creating more reflexive designers and more practice-oriented researchers, but it is important to acknowledge the negotiations made in the process as a product and deliverance in itself.

The work needed to make such cross-pollinations succeed is also touched upon by criminology researchers Lane et al. (2004). Lane et al. draw on their experiences that it is generally easier to sign letters of agreement and initial declarations of intent on expected outcomes of research and practice collaborations when seeking funding, than it is to put in the actual work this cross-pollination need once the funding for an exhibition project is granted (Lane et al., 2004). The difficulties of establishing consent and making clear-cut input in collaborative projects is thus not an unknown challenge (Lee, 2007; Lindauer, 2005). For instance, museum researcher Line Knudsen's work with developing a museum for rock music shows how what she calls a participatory collaborative design process 'often seemed to pose more questions than ideas and solutions' (Knudsen, 2016, p. 208). Trust and respect are key words in these collaboration projects across disciplines, and the time spent together in a project is a key factor in this because shared meals, excursions and tasks makes it easier to overcome tensions and disagreements (Lane et al., 2004).

Another challenge related to time in the collaboration between researchers and exhibition designers in PULSE was divergent timeframes. The time required to produce something valuable and useful was set very differently by the two working groups, which created frustrations on both sides. This challenge was most explicit in the early stages of the project where research and practice had to find each other: in the negotiations concerning the front-end study, the exhibition designers were eager to know more about the families and how this could be useful in the exhibition development process. Furthermore, they were pressured by future deadlines for getting the exhibition produced in time and making sure everything turned out as intended – from technological solutions to safety issues to colours on the exhibits. The researchers saw the exhibition development as secondary in the process of planning the front-end study; acknowledging that the generated data was to be used in the exhibition development, but for them more importantly that the data constituted a valuable part of further research agendas. For the data to live up to validity standards, the researchers were demanded to make a range of considerations and theoretical choices. The result was a longer production time, thus the exhibition designers had to be armed with patience, even when the researchers rushed the process compared to usual research data production processes (Lane et al., 2004; Myers-Walls, 2000). The differing work phases and priorities also exemplifies differences in orientation in time, where practitioners often focus on producing value in current development processes and researchers tend to focus on producing value in a more long-term timeframe (Myers-Walls, 2000). The efforts of engaging different publics in the development process of PULSE (here both designers, researchers and target groups) made it clear that the design process in itself, perhaps even more than the finished exhibition was a demonstration of the entanglement of identities, disciplines, values and practices in a wicked problem. The process showed that much care and consideration is needed when designing – and thereby defining – the learning experiences that address wicked problems.

Summary

In this chapter, I have used the development process of a health exhibition at a science centre to illustrate how a participatory approach can be a way to address wicked problems in out-of-school science education. I have shown how the involvement of visitors and the collaboration between researchers and exhibition designers enabled a development process where the exhibition designers could work with the scientific subject (health exemplified through the issue of sedentary behaviour) from a point of departure in social data on relations, motivations and challenges concerning the scientific subject. This led to a science educational design, which was sensitive to context and focused on creating relevance with the audience. It also gave a multitudinous and interdisciplinary approach to the scientific subject in the development group.

I have also shown how such collaborative endeavours can pose challenges when designing science educational experiences. It is important that involved institutions and the development group reflect on the values and social practices they promote through their communication of scientific knowledge – because when working with wicked problems, the science educational design inscribes in a political and cultural agenda. It is not relevant to talk about science and society. Rather, science becomes an integral part of society. Lastly, the collaboration between research and practice must be given extra attention and dedication to ensure the valuable contributions from all project participants are shared and recognised within the development group. Only then can they be translated into design solutions.

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Chapter 4
Connecting Museum Visitors to Nature Through Dioramas

Annette Scheersoi

Biodiversity Loss and the Role of Natural History Museums

Most environmental learning is not acquired in school, but occurs outside of school through free-choice learning experiences, for example in museums (Falk, 2005). Natural history museums, as 'biodiversity inventories' (Alberch, 1993), seem to be ideal places for stimulating people's awareness and engaging the public in biodiversity issues. They provide lifelong exposure to science and scientific discovery, offer an encounter with nature, attract huge audiences, and invoke a feeling of trust in the public (Novacek, 2008). Their high credibility ratings seem to be especially important in times of 'fake news', when individuals have to be empowered to evaluate the news they encounter (Lazer et al., 2018). Addressing the biodiversity crisis, natural history museums, as political organisations, have to make their own contribution towards the conservation of nature and natural resources (Vogel, 2015).

The traditional role of natural history museums has been to collect objects, to study and interpret them and to present them to the public. The objects and collections represent natural history content, such as evolution and diversity of life, as well as scientific processes (e.g. identifying, modelling, and hypothesising), behaviours and values (e.g. conservation) associated with these areas (Dillon et al., 2016). The collections contain evidence about wicked problems we are facing today, such as climate change and biodiversity loss. Modern research in natural history museums focuses on the origin of biodiversity, the structure of regional and global biodiversity, ecological features and characteristics of species and their integration into the ecosystem, distribution patterns, and the sustainable use of biodiversity by humans (Beck, 2018). Nowadays, many natural history museums incorporate

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M. Achiam et al. (eds.), *Addressing Wicked Problems through Science Education*, Contributions from Science Education Research 8,
https://doi.org/10.1007/978-3-030-74266-9_4

biodiversity conservation as part of their mission and programmes, aiming at raising the visitors' awareness and engagement (Arengo et al., 2018).

Natural history museums can play a key role in providing understanding of biodiversity and its degradation but many of them have not fully capitalized on their reputation (Mujtaba et al. 2018; Novacek, 2008). Dorfman (2018) argues that nowadays, coming to the museum to see a 'dead zoo' is no longer enough and raises the question of how museums compete in this 'noisy world' (p. 3) with a relevant offer that is uniquely theirs? Museums' contribution to environmental education is to deal with current environmental issues, such as the biodiversity crisis, and to provide a scientific perspective that goes beyond presenting factual information. It is not to teach the 'right answers' but to educate citizens and to enable them to take part in debates focussing on environmental issues (Slingsby & Barker, 2003). They have to be dynamic places that incite curiosity, stimulate activities that enhance knowledge of biodiversity, and promote respect and protection of our environment (Omedes & Páramo, 2018). The challenge is to design such learning experiences and to show that biodiversity loss represents a complex problem which has serious impacts on the functioning of ecosystems and their ability to provide goods and services to humanity. As Novacek (2008) argues, engaging the public in biodiversity issues is especially challenging since environmental issues generally rank lower in salience among the public than many other problems, such as terrorism and poverty.

Biodiversity Loss as a Wicked Problem

We are at a critical moment for the Earth's biodiversity. The variety of life, in all its forms and all its interactions, is declining rapidly worldwide. The extinction of species and changes in ecosystems have major consequences. However, this phenomenon is complex and poorly understood, it involves many stakeholders with different value sets and perceptions of the problem, and it is not solvable with established methods. Biodiversity loss is therefore one of the wicked problems we are facing today.

Biodiversity (biological diversity) is the variety of life on Earth. It is comprised of several levels, starting with genes (the genetic variability between individuals of one population as well as between populations), then species (inter- and intraspecies diversity), then communities of living beings and entire ecosystems (the range of communities with their habitats, that is biotopes and habitats as ecosystems, their correlations among each other and processes taking place within the ecosystems) (e.g., Baur, 2010; Wittig & Niekisch, 2014).

Humans are embedded in ecosystems. Just as is the case for every other species on Earth, we depend on our surrounding ecosystems and cannot exist without them. Plants, animals, fungi and microorganisms provide us with food, medicine, clean air, water and recreation and are the basis and the initiators for pioneering innovations. In this respect, the significance of biodiversity is undoubted. Understanding biodiversity and preventing biodiversity loss, however, is more than challenging.

Biodiversity loss is caused by multiple drivers including the intensification of land use; the destruction, fragmentation and pollution of habitats; the overexploitation of species through hunting; the spread of diseases; the substitution of species and local breeds in agriculture by a limited number of high-output breeds; and the introduction of exotic animal and plant species. The global resource utilization clearly exceeds the biologically possible resource and the situation is getting worse. To prevent the further loss of biodiversity, there is not a single countermeasure and any 'solution' can generate another problem (Sharman & Mlambo, 2012).

All environmental conflicts share their complexity: Firstly, the scope of relevant correlations at the ecological level can hardly be conceived; secondly, at a social level, several parties up to complex groups of players are involved via representatives; thirdly, environmental conflicts should be perceived from both a local and global perspective as every local conflict affects the overall socio-ecological system, and vice versa (cf., e.g., Ittner & Ohl, 2012; Müller, 2012). It is essential to carefully and strategically test a combination of measures or approaches which consider different system levels and perspectives to avoid conflicts as much as possible.

Nobody is solely responsible for destroying biodiversity; many players make their contribution. In the majority of cases, the decrease of biodiversity is not caused wilfully or with malicious intent, but is a consequence of activities that pursue another purpose. In light of the pluralism of values, environmental protection competes with other socially accepted values such as economic growth or personal freedom (Ittner et al., 2018). Our destructive handling of the global biological diversity is often justified by the optimistic belief that technical-artificial resources can be substituted for natural ones (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit [BMUB], 2007). However, technical solutions are clearly more expensive (e.g., fertiliser v. natural soil fertility, or recovery of drinking water v. self-purification through soils and waters) and in many cases a substitution is not even possible, for example, replacing insect pollination of cultivated plants (Ott, 1999). Neither can the accomplishments of nature regarding aesthetic qualities (beauty, landscape) and recreational values be replaced by artificial alternatives.

An important reason for the ever-progressing biodiversity loss is seen in a lack of knowledge at three levels (Mehring et al., 2017) – system knowledge (factual knowledge – what is true?), orientation knowledge (normative knowledge – what should we do?), and transformation knowledge (operational knowledge – what can we do?).

System Knowledge Currently, we know far too little about biological diversity to adequately appreciate, preserve and use it in a sustainable way that benefits everyone (e.g., Dierßen & Huckauf, 2008). The significance of biological diversity for the functioning of ecosystems has been discussed with some controversy for several decades. We need to know more about mechanisms producing and sustaining biological diversity at different levels (genomic, species and ecosystem) in order to be able to predict the effect of global change on biodiversity. To this day, an easily approachable description of all existing species and their interdependency is missing; even a simple list of all known species does not exist. There are neither data about the species' population status nor models to describe their expected growth rate and to characterise factors which jeopardise or improve a sustainable population growth. Many species are lost before we are even aware of them or their role in the ecosystem. In addition to an organism-centric perspective, the comprehension of global and local material cycles and flows is important to understand the dynamics of ecological communities. These cycles have still not been sufficiently explored to this day. There is an urgent need for a large-scale multi-disciplinary research initiative to fill these knowledge gaps.

Orientation Knowledge System knowledge alone is not enough. The knowledge needs to be processed and used appropriately. In the context of environmental questions, this invariably calls for ethical standards. To balance possible choices and boundaries and to determine guiding principles, it is essential to find ways to structure and interlink the system knowledge as well as ways to understand the role of humanity. Ecological, economic and socio-cultural perspectives need to be regarded. What matters are the protection of habitats and ecological communities; the protection of wild plants, animals, fungi and microorganisms; the sustainable use of wild and cultured species and their genetic diversity; the access to the world's genetic resources; the fair distribution of advantages that come from these resources; and improved development opportunities for poorer countries which are richer in biodiversity and whose population is often dependent on the use of limited resources. A stronger inclusion of social sciences is necessary to develop guidelines and measures towards the protection of biodiversity that are more legitimate, salient, robust and effective (Bennett et al., 2017).

Transformation Knowledge Finally, there is an urgent demand for research dealing with the development of instruments and governance approaches aimed at the solution of conflicts and at the implementation of guiding principles. This situation equally calls for an interdisciplinary approach to ensure that these processes are guided by the best available information (Jahn et al., 2012). Every change regarding the natural environment depends on a change in human behaviour and on public acceptance: technological products need to be bought and used productively; decision-makers need to be willing to invest in environmental protection and new technologies; and eventually, politicians will only implement measures the publics approve of.

Halting Biodiversity Loss

Governments worldwide have committed to international agreements aimed at reducing biodiversity loss such as the Convention on Biological Diversity (CBD, 2010) and United Nations (UN) Sustainable Development Goals (UN, 2015). However, success to date has been limited (e.g., Johnson et al., 2017; Waldron et al., 2017).

Rodríguez et al. (2007) point out that large-scale international development initiatives, designed centrally and implemented top-down, have rarely met expectations. They argue that biodiversity will only be conserved if such approaches recognise the importance of locally produced strategies and agendas and are integrated in local conditions. Additionally, an increased inclusion of each individual is seen as a central precondition for the effective protection of biodiversity (e.g. Sharman & Mlambo, 2012). Up to now, few people have felt personally responsible for the loss of biodiversity. Even though the problem of biodiversity loss has been addressed in scientific discourse and by environmentalists for a while now, relatively few people are familiar with the term biodiversity itself. A survey among 28 EU countries with ca. 28,000 participants (TNS, 2015) gives an indication of the role that biodiversity loss plays in the public awareness.

Respondents were asked whether they were familiar with the term ‘biodiversity’. From the 60% of respondents who have heard of the term, only half of them also know what it means. They were also asked how informed they felt about the loss of biodiversity. Two thirds (66%) of Europeans did not feel informed about the loss of biodiversity, with 22% saying they did not feel informed at all. There are no notable differences based on age, but there is a trend based on education levels: the longer a respondent remained in education, the more likely they are to say they feel informed about the loss of biodiversity. Just 21% of those with the lowest education levels said they feel informed, compared to 30% who finished education aged 16–19 and 44% of those who completed education aged 20 or older.

At least six in ten respondents (61%) believe the decline and possible extinction of animals, plants, natural habitats and ecosystems is a very serious problem, at least at a global level. However, at European level, only just over a third perceive a serious problem (35%) and only 19% with reference to their local area.

Respondents were asked whether they thought they would be personally affected by the degradation of nature and the decline and possible extinction of animal and plant species. A majority answered affirmatively (58%), with 23% saying they are already affected and 35% saying it will affect them in the future. One third (33%) said they will not be personally affected but the next generation will be, while 6% said there would be no effect.

In every member state, respondents were most likely to agree that we have a responsibility to look after nature. Almost two thirds of respondents felt they were already making a personal effort to protect biodiversity and nature (31% considered they were making personal efforts while a further 34% would like to do more). One quarter thought they were not making any effort because they did not know what to do, while 7% explained that they were not making an effort for other reasons. The longer a respondent remained in education, the more likely they were to be making a personal effort. Unsurprisingly, those who had heard of the term ‘biodiversity’ were much more likely to say they were making a personal effort (73% v. 54%) than those who had not. The same pattern applies when comparing those who felt informed about biodiversity loss with those who did not (81% v. 58%). Respondents who thought the degradation of nature will impact them are also much more likely to be making a personal effort to protect biodiversity and nature than those who said they will not be affected (74% v. 54%).

Many people lack awareness of the significance of both biodiversity and its loss. Others are aware of the problem and their own role but need more information about what to do personally to protect biodiversity. Many in the Global North perceive the loss of biodiversity more as a global problem, thinking perhaps of tigers and rhinos, as something affecting tropical forests or coral reefs, geographically far away, and disconnected from their local concerns. Gelsthorpe (2017) argues that such perceptions might stem from the way children are taught about the natural world in schools: if they are continually taught about endangered animals from far away ecosystems and habitats, they risk losing an important connection to their local wildlife and green spaces. To strengthen the appreciation of biological diversity as a crucial precondition for its protection, it is vital to impart its significance and importance appropriately.

There is a need for broader and deeper public understanding and reaching, hence involving the public seems to be the key to achieve the biodiversity conservation goals (Cosquer et al., 2012). Someone ignorant of the meaning of biodiversity cannot be expected to take a stand for its conservation. Emotional involvement (the extent to which we have an affective relationship to the natural world) requires a certain degree of environmental knowledge and awareness (Kollmuss & Agyeman, 2002). Yet, how can we raise people's awareness of the significance of biodiversity and have them interact with nature carefully?

Besides missing knowledge, there is a second factor of crucial importance: the perceived human disconnection from nature – mainly due to urbanization and people spending less time in regular contact with natural environments ('extinction of experience', Pyle, 2003; Soga & Gaston, 2016; 'nature deficit disorder', Louv, 2005) – is widely viewed as a driving force behind global ecological problems or even as the very crisis itself (Weston 2004). Humans act as if they were separate from nature, as if they could get along without it (Schultz, 2002). It has been stated frequently that a responsible behaviour towards nature correlates with feelings of being in touch with nature (cf. Nisbet et al., 2009; Pyle, 2003). These thoughts arise from the hypothesis of biophilia (Kellert & Wilson, 1993). In the course of evolution, a bond between humans and the multiple forms of life, habitats and ecosystems has formed. Thus, it is argued, there is a genetically determined human desire to connect with non-human organisms and nature on an emotional and cognitive level. However, nature connectedness is not uniform; it incorporates cognitive and affective factors; is dependent on individual features, experiences, and social influences; and therefore depicts a subjective, multi-dimensional construct (Lumber et al., 2017).

To better understand human-nature connections, five types of this multi-dimensional construct have been described (Ives et al., 2018): (1) material (extraction and consumption of materials from nature); (2) experiential (activities in natural environments); (3) cognitive (knowledge or awareness of the environment, attitudes/values towards nature); (4) emotional (feelings of attachment or empathy towards nature); and (5) philosophical (world views on what nature is, why it matters and how humans ought to interact with it). While some of these dimensions are more internally defined (people's inner world: philosophical, emotional and cognitive), others are more external connections (experiential and material) (Ives et al., 2018). Research has shown that these types of connections interact with each other and influence one another as, for example, nature experiences and physical interaction can foster environmental knowledge and values towards nature as well as a positive emotional relationship with nature (e.g., Bögeholz, 2006; Bratman et al., 2015; Lude, 2006; Otto & Pensini 2017). Accordingly, several authors state that educational programmes should include meaningful nature experiences to strengthen people's connection with nature and foster nature-protective behaviour (e.g. Kals et al., 1999; Miller, 2005; Soga & Gaston, 2016).

It has been shown that the loss of human-nature interaction not only diminishes benefits to health and well-being but also reduces emotional affinity to nature, thereby having negative effects on attitude and behaviour towards the environment (cf. Soga & Gaston, 2016). The call to reconnect people with nature as a 'treatment' for individual health as well as social and environmental problems (Ives et al., 2018) is therefore commonplace in the scientific literature and popular environmental discourse (Restall & Conrad, 2015; Zylstra et al., 2014, for a review). Ives and co-authors (2018) argue that stronger connections in several of the above-mentioned dimensions have potential to support a profound social change towards/in terms of sustainability. But how can nature connectedness be fostered – for instance, in cities where the population is often disconnected from experiences of nature? How can we provide opportunities for meaningful interactions with the natural world?

Nature Experiences to Facilitate Nature Connectedness

Empirical research has found that nature-protective behaviour cannot be sufficiently explained using a pure cognitive approach, but that it is positively associated with the strength of emotional connections towards nature (e.g., Hinds & Sparks, 2008; Kals et al., 1999; Lumber et al., 2017; Otto & Pensini, 2017). Besides the cognitive dimension, interventions that connect people to nature emotionally and philosophically are perceived as particularly important to achieve profound and sustainable social change (Ives et al., 2018). To generate nature connectedness, activities are required that illustrate the importance of nature through experiencing it and thereby facilitating emotional attachment, for example, by promoting an involvement with nature's beauty (Lumber et al., 2017).

Experiencing nature can take place in many different ways, such as outdoor versus indoor, active versus passive, secluded versus crowded and plant-involved versus animal-involved (Howell et al., 2011). On a more general level, experience of nature has been classified in three ways (Kellert, 2002): *direct* (actual physical contact with natural settings and nonhuman species, spontaneous and unplanned), *indirect* (actual physical contact in restricted, programmed and managed contexts) and *vicarious/symbolic* (absence of physical contact with the natural world: films, books and technologies). Kellert (2002) stresses the importance of direct and physical experiences with nature as they offer unique opportunities for intimacy, challenges, creativity and active participation. He argues that indirect experiences, such as encountering plants, animals and habitats in natural history museums, do not provide an adequate substitution for declines in direct encounters with the natural world. However, indirect experiences might help to acquire basic skills such as naming, labelling and classifying (Kellert, 2002) and thereby foster the cognitive dimension of nature connectedness. In addition, seeing Natural History Museum specimens can inspire wonder (e.g., Valdecasas et al. 2006). Duerden and Witt (2010) compared the impact of direct and indirect experiences on the development of environmental knowledge, attitudes and behaviour. Their findings highlight the complexity of this relationship and indicate that a combination of both indirect and direct experiences appears to be an effective method of promoting pro-environmental behaviour. Equally, based on their research, Soga and co-authors (2016) highlight that different ways of encountering nature – direct as well as vicarious – should be promoted to support nature connectedness and biodiversity conservation.

Nature Experiences Through Natural History Dioramas: A Visitor Study

Based on the results of previous visitor studies concerning natural history dioramas[1] in museums (Scheersoi, 2015; Scheersoi & Weiser, 2019), it can be argued that indirect experience of nature, under certain conditions, does not only promote basic skills but also discovery, creativity and positive feelings towards nature, sometimes even fostering ecological awareness. Nature experiences at natural history dioramas therefore appear to be suitable to enhance several types of nature connections (cognitive, emotional and maybe even philosophical; see above) and might help visitors to get an idea about biodiversity and its complexity. Dioramas offer opportunities for animal encounters that are not possible in the wild and therefore might complement direct encounters in a meaningful way.

I decided to take a second look at the data from an earlier study and to analyse them with a specific focus on the potential of dioramas to foster the visitors' knowledge and awareness regarding biodiversity and to address ecological issues. The study was conducted in a German natural history museum with a diorama gallery presenting 15 different habitats. The dioramas were built in the 1990s, and biodiversity loss is not addressed explicitly in this exhibition. However, different ecosystems (e.g., farm land, natural beech forest, pond, moorland and home garden; Fig. 4.1)

[1] A natural history diorama (or habitat diorama) is a representation of a natural environment, generally behind glass. It consists of a naturalistic background painting that merges into the foreground and includes animal and plant specimens. Natural history dioramas depict a scenario in a specific environment, ranging from local places to other parts of world. They represent interactions and relationships between animals and plants, illustrate habitat characteristics as well as adaptations, and can even include human traces, such as cultural relics.

with characteristic biotic and abiotic components (animals, plants, soil, water, etc.) are represented and can be compared. Species lists in the form of labels on the wall next to each individual diorama are provided by the museum. All the dioramas represent habitats local to the museum. In accordance with several authors who advocate environmental educational programmes that focus on immediate surroundings and local environments (e.g., Garthe, 2018; Kellert, 2002), I suggest that meaningful nature experiences, interaction and participation might be easier to foster in local and familiar habitats. They might be particularly important for the visitors' awareness in the light of the popular notion explained in the preceding that biodiversity loss only affects distant tropical regions.

Visits to this diorama gallery might raise people's awareness of the diversity of local habitats, species diversity, and the connections between them. At some dioramas, the visitors might even perceive changes in ecosystems that have occurred since the dioramas were built 25–30 years ago.

Leisure visitors (n > 300) were observed (unobtrusive observation) during their visit to the diorama gallery in order to determine where they stopped and engaged with the diorama gallery's content and which exhibition components caught and maintained their interest. Spontaneous conversations were noted down as far as possible. After the visit to the diorama gallery, semi-structured interviews (n = 276) were conducted in order to identify more clearly the types of experiences and their role in fostering environmental knowledge, attitudes and awareness.

As a first step, the observational data and the interview transcripts were analysed by establishing categories in relation to diorama components/characteristics that caught the visitors' attention and fostered engagement with the diorama content. In a second step, the data were further analysed with regard to the different dimensions of human-nature connections identified by Ives and co-authors (2018; see above). The aim was to find out which specific aspects of nature experiences at dioramas supported human-nature connections to eventually provide 'reconnection strategies' for environmental and conservation education in natural history museums.

The results of the observational study show that the museum visitors had at least a quick look at all the dioramas in the gallery. However, they did not stop and spend an equal amount of time in front of the different habitat representations. Visitors stayed longer at dioramas displaying *animals in action and/or interaction*, for example, animal families (e.g., 'The father pig is called a boar, the mother pig is called a sow') or predators hunting their prey (e.g., 'The poor fish' [killed by an otter]). These kinds of representation often stimulate the visitors' imagination and incite storytelling, especially in children (e.g. 'The cat is looking at the mouse. She'll shortly attack it'). Dioramas also maintained the visitors' attention and interest when they offered *unfamiliar insights* into specific habitats, for example life underwater, in the soil or inside an anthill. Visitors studied these habitats intensively and for a long time and sometimes commented on environmental challenges and the species' adaptations (e.g. 'Here, the entrance to his [muskrat] cave is underwater'). Especially long dwell times and intensive conversations were observed at dioramas in which the habitat was *reconstructed in a particularly detailed manner*, for example showing many different species, including small ones like insects ('The beetles

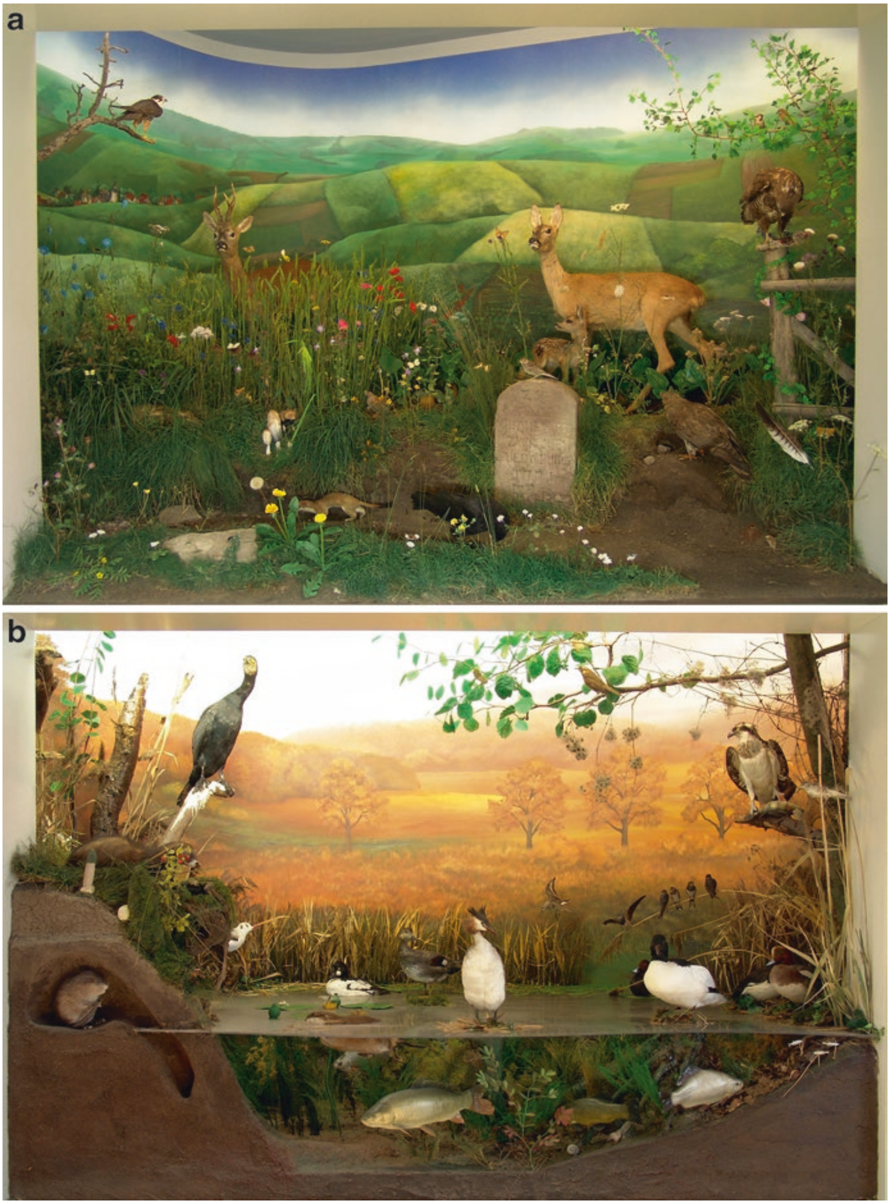

Fig. 4.1 Natural history dioramas: (**a**) farmland, (**b**) pond and (**c**) attic, Vonderau Museum Fulda, Germany. (Photos: © Zbigniew Jez, Vonderau-Museum)

Fig. 4.1 (continued)

[burying beetles] devour the dead squirrel'). Visitors talked about the species' characteristics (e.g., 'The crab has scissors as hands'), described relationships (e.g., 'The fungus [tinder fungus, *Fomes fomentarius*] grows on the tree trunk') and tried to name the different species. For a reliable identification, most of the visitors used the species lists provided by the museum (e.g., 'A snake' – 'Yes, a smooth snake').

In the post-visit interviews, visitors were asked to talk about their experiences and what they liked most during their visit to the diorama gallery. The visitors' answers also help to shed light on the reasons behind the observed visitor behaviour. Visitors emphasised their appreciation for the detailed and accurate reconstruction of habitats, not only offering context to the specimens presented but creating the impression that one looks into a real habitat through a window. Some visitor statements are quoted as examples:

> What was really amazing for me was the love for detail in this diorama. Very interesting with all these little bits and bobs.

> It looks like real life.

Visitors were impressed by the way of presentation and the subsequent feeling of immersing oneself in the habitat and being part of it (immersion experience, e.g., Bitgood, 2014). These specific experiences, the visitors' feeling of time and place and some kind of perceived interaction with natural environments were also explicitly mentioned in many interviews as a strength of these habitat dioramas:

> It was really as if I walked outside along a path. Absolutely authentic. That's a lasting impression.

> You just feel like being in the forest.

Visitors explained that they particularly appreciate animals that are 'frozen in action' as this kind of representation increases the feeling of authenticity and makes the scene more vivid:

> Because there is so much activity.

> The fact that the hawk is about to catch the other bird, that makes it look even more real.

Represented interactions between species did not only catch the visitors' attention and increased the feeling of authenticity but also offered opportunities to recognize the interrelations between species. In the dioramas, visitors identified relations between species of the same kind (e.g., family structure or brood care) and between different species (e.g. symbiosis or predator and prey):

> There's the male deer and on the other side [in the diorama] the doe and the fawn. That makes it really life-like. The male is just lying there on his own, but you notice the tension of the doe.

> You get to see herons quite often, but it's fascinating to see what fish species they catch.

In the interviews, visitors also mentioned species-specific behaviour that they had observed in the different dioramas:

> You can also see how the beaver cut the trunk and used it to build his dam.

> The anthill: the sleeping chamber, the feeding chamber, (...) and there, the queen can lay eggs.

Through their observations, visitors could find out about individual species characteristics. They appreciated the experience with real specimens, for example, seeing them in life size, in comparison to symbolic nature experiences via books or films:

> I was impressed by its [eagle owl] size!

> For example, the beaver, I was stunned that it is so big because I have not seen a beaver in reality yet. Just in films or on pictures. And because you only seldom see these animals.

New insights were also provided when dioramas offered unusual perspectives into habitats, such as a pond or a stream with over−/underwater split-level effect (Fig. 4.1 B), the cross-section of an anthill or a muskrat's nest. Visitors appreciated these novel perspectives; some even started raising questions about ecological adaptations:

> Because you can look straight into the water and you normally cannot see the fish like that, from that perspective.

> [Muskrat] The den from its side. Because you never see it like that in nature.

> From down in the water [underwater entrance] is leading a tunnel up into the soil. How does it [the muskrat] get oxygen in there?

Some visitors explicitly mentioned the value of these unique learning opportunities at dioramas. They acknowledged the diversity of local species that can be discovered, observed and identified. Moreover, they realised and understood the value of being able to show them to their accompanying children:

> This whole diversity.

There are some animals I know by name, but I have never seen them before.

I like these dioramas where you can see the real animals like that. Many children do not know them – I have worked in a Kindergarten – and I appreciate this kind of exhibit.

Because it's native animals [...], especially to show it to the kids.

The visitors valued the close encounter with animals. In contrast to living animals in the wild, diorama specimens obviously do not run away or hide and the visitors can get close to them. Some of the visitors' comments show that they experienced such encounters to some extent as authentic:

At home, in the backyard, the ground is often dug up by boars and you never catch sight of them. Here you get them in plain view.

You rarely see the otter. Usually, you only catch sight of it when it's dead.

They look so real, you can be lucky that the glass is in between!

Other aspects that were often mentioned in interviews are the dioramas' aesthetics and atmosphere. Visitors enjoyed bright colours and colourful presentations:

Just because of the colours and because of the brightness and friendliness, the flowers.

Because it's so green and not so dark. It's just beautiful.

Reassuring.

More introspective experiences referred to the relationship between mankind and nature. Such experiences were often supported at dioramas with human traces or artefacts (such as a fence or a boundary stone) and at dioramas that represent man-made habitats, such as a garden or an old building's attic (Figure 4.1 C).

I would like to have a garden like this. Human culture in combination with nature. This always fascinates me.

Animals living in areas developed by man. That's really interesting.

I like the attic the most. Because it is the closest to us humans.

The visitors state that they especially liked the depicted direct relation between humans and nature. Furthermore, many visitors expressed their astonishment about the diversity of species, which they would not have expected at those places.

There are many different animals of which you don't even believe that they live in the attic.

What animals have their habitats there. You just don't expect that.

However, the elderly in particular visiting the diorama gallery realized that changes have occurred in the environment of these local habitats. In the interviews, they talked about the loss of biodiversity in general but also about the decreasing occurrence of individual species, sometimes mentioning the impact of humans. Visitors recalled personal memories and experiences, often involving a concern for other natural entities:

Yes, the flowers, because I still experienced that as a child, this huge plant diversity.

Thus, colourful meadows or fields with the flowers, this you don't see anymore because over here, everything is fertilised away or destroyed as weeds.

And this often doesn't exist today. Today, mankind intervenes an awful lot.

This also reminds me of my childhood, these salamanders. I have not seen them for a long time.

Because of the bats. Almost all of them are endangered, they are very rare now.

These results from our visitor observations in a diorama gallery as well as from post-visit interviews show that museums with natural history dioramas provide an opportunity to encounter nature and that this encounter is perceived as authentic to a certain extent. The detailed and accurate reconstruction of habitats with original specimens supports the visitors' feeling of authenticity (cf. Köstering, 2015) and **experiential human-nature connections** ('It looks like real life'). Represented activity with animals 'frozen in action' increases the vividness of the scenes ('… makes it look even more real'). Many visitors are fascinated by the immersion experiences ('You just feel like being in a forest'), creating for the visitor a feeling of being in the time and place simulated by the exhibit. Bitgood (2014) lists a number of factors contributing to the immersion experience, which also characterise the dioramas in the study: realism of the illusion, dimensionality, meaningfulness, mental imagery, and the lack of interfering factors (e.g., presence of text labels in the diorama).

The feeling of authenticity and the visitors' fascination for the detailed and accurate representation of the habitats ('really amazing', 'lasting impression') can support **emotional human-nature connections** at dioramas. Dioramas enable several further affective experiences, such as surprising moments when realising the actual size of an animal ('I was impressed/stunned …'), species diversity in local environments ('You just don't expect that'), sympathizing with vulnerable species (e.g. small or baby animals) or being moved emotionally by the beauty of a colourful meadow ('just beautiful', 'reassuring'). Perceiving the beauty of nature and its diversity seems to be particularly beneficial for the development of an emotional human-nature connection (cf. Lumber et al., 2017).

The data also show that nature experiences at dioramas offer multiple learning opportunities, such as the extension of species knowledge and the perception of biodiversity at different levels – diversity of species, communities and habitats ('This whole diversity'). **Cognitive human-nature connections** are supported as natural history dioramas present specimens in carefully reconstructed ecological contexts, which help to visualise ecological knowledge. Through this visualisation, knowledge becomes easily accessible without the need to read any long explanatory texts. Visitors, especially parents or teachers who come to the museum with their children, appreciate these learning opportunities immensely ('... especially to show it to the kids'). Dioramas offer nature experiences that are not possible outdoors in natural environments: animal specimens can be observed at rest ('here you can get them in plain view') ('stand and stare'; Reiss & Tunnicliffe, 2011), and their individual characteristics, such as their size, shape or colour, can be detected and compared. Their behaviour and interrelations, for example predator-prey relationships, can be identified and interpreted ('… to see what fish species they catch'). Some dioramas offer new perspectives into specific habitats as they represent life underwater or the cross-section of an animal's den. Visitors value such unfamiliar insights ('Because you never see it like this in nature'). They can find out which animals or plants live in these 'hidden habitats' (e.g. shells or fish species under water), and they can recognize the species' specific adaptive traits or behaviour.

Even **philosophical human-nature connections** can be supported at natural history dioramas, especially when they represent habitats that are influenced by humans, or man-made habitats, for example' farmland, houses or gardens. In the post-visit interviews, visitors stated that they enjoyed seeing habitats where humans and the other species live undisturbed and in harmony with each other ('Human culture in combination with nature'). However, at such dioramas – and even at dioramas that just include discreet human traces, such as a boundary stone – introspective experiences often also refer to the question of how humans (should) interact with nature ('Today, mankind intervenes an awful lot'). Visitors reflect on the fact that biodiversity has been reduced due to human influences ('Thus colourful meadows or fields with the flowers, this you don't see anymore because over here, everything is fertilised away or destroyed as weeds') and consider the extinction of species ('Almost all of them are endangered, they are very rare now').

In summary, the data suggest that indirect nature experiences with dioramas can foster several dimensions of human-nature connections: cognitive, emotional and philosophical. As it can be assumed that interactions among different dimensions of nature connections exist (cf. Ives et al., 2018), dioramas seem especially promising to appeal to visitors. Furthermore, through a foundation of knowledge, values and attitudes, dioramas can cultivate awareness and ecological sensitivity as a central basis for pro-environmental behaviour.

The results of this study also show that dioramas trigger the visitors' imagination and inspire storytelling. The 'power of story' is seen as an important aspect of using emotions in biological education and enables (young) people to reconnect with nature (Barker, 2007). Narratives help to create meaningful experiences as they can bridge the gap between everyday concepts and scientific conceptions (Cotumaccio, 2015; Tunnicliffe, 2015). Hence, they are considered to be an important tool for understanding and remembering in biology education (Zabel, 2004).

Nature experiences through dioramas differ from outdoor experiences in natural environments, but complement them in a meaningful way due to certain diorama features:

- Dioramas depict the character of specific biotopes and their inhabitants, including biotic and abiotic relationships.
- The specimens can be viewed and compared at rest.
- The visitors can have a close encounter even with rare and dangerous animals.
- Dioramas can provide unique perspectives on habitats, such as life underwater or life in the soil.
- Diorama galleries offer immediate comparisons between different habitats and adaptations.
- Habitat changes can be visualised through historical dioramas.

Museum Visitors' Awareness of Biodiversity and Their Connection to Nature

Modern exhibitions in natural history museums need to address contemporary challenges and wicked problems such as biodiversity loss. Natural history dioramas provide one distinct way to foster environmental knowledge, create awareness of biodiversity in its different forms and reconnect people to nature. Knowledge and the people's appreciation for nature have the potential to effectively promote pro-environmental behaviour (Roczen et al., 2014). Therefore, dioramas need to be repositioned in present-day science education. In contrast to museum exhibitions where specimens are presented one by one in display cases, dioramas replicate natural wildlife scenes and direct the visitors' attention to whole landscapes with their diversity of biotic and abiotic phenomena (Tunnicliffe & Scheersoi, 2015). Dioramas provide opportunities for meaningful interactions with the natural world. They can help us to visualise the consequences of human activity (Wonders, 2016). Indirect nature experiences at dioramas, enhanced by emotions and feelings of immersion, complement direct encounters with the natural world in a significant way and can promote the perception and appreciation of biodiversity.

In the study reported here, certain diorama characteristics have been identified that support interest and biodiversity awareness as well as several dimensions of human-nature connections: Dioramas are most promising if they:

- Represent animals in action ('frozen in action').
- Illustrate interaction/relationships between species (including between animals and plants).
- Offer new perspectives into habitats.
- Show habitats that are reconstructed in a very accurate and detailed manner.
- Represent biodiversity at different levels (species, communities and habitats).
- Relate humans and nature.
- Visualize environmental changes (landscape, habitat degradation).

Nature experiences at dioramas should be considered as a starting point for further engagement, preferably focusing on interaction and participation (Garthe, 2018). Museum visitors might benefit from the opportunity to encounter scientists to find out about biodiversity loss and the complexity of the problem. They might have the chance to engage with people who do not just present factual information but compassionately tackle ecological issues, stimulate activities, and discuss about the effectiveness of actions.

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Chapter 5
Family Interactions with Biodiversity in a Natural History Museum

Patricia G. Patrick and Alexandra Moormann

Introduction

Wicked problems are difficult to solve, because they are multifaceted (Radford, 1977; Rittel & Webber, 1973). In this chapter, the wicked problem is biodiversity loss. Biodiversity loss is an intricate web of answers, assessments, theories, origins, and public consciousness, which makes it a wicked problem. This chapter focuses on utilising biodiversity education as a way to increase the understanding of the problem. Problems related to the environment are especially difficult to solve, because environmental problems by nature are complicated, somewhat uncertain, and rely on human understanding. Moreover, environmental problems involve many actors in addressing the issues. The actors base their view of the problem and solutions on personal perspectives (van Bueren et al., 2003). We introduce actor-network theory (ANT) as a way to define how visitors, specifically families, interact with wicked problems represented in informal science learning institutions (ISLIs).

We focused on families, because their interactions are socially constructed as they view the exhibit object. The ways they interface with the exhibit object and each other are a catalyst for learning opportunities. When family members embed in engagement with the exhibit, they are constructing knowledge and ways of understanding as a social group. Engagement among the group members and with the exhibit object is important, because knowledge is built through active engagement and experiences, which leads to learning (Wenger, 2009). Each person in the family

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M. Achiam et al. (eds.), *Addressing Wicked Problems through Science Education*, Contributions from Science Education Research 8,
https://doi.org/10.1007/978-3-030-74266-9_5

group has a perspective, and as they interact, they make connections with each other and the objects. With whom they interact in the group can make a difference in how they reach out to the exhibit object. For example, if an adult male begins the conversation with an adult female group member, the subsequent contact with the object may be different than if the conversation were started by a male child to an adult male. Defining these nuances is important, because engagement and experiences can make a difference in learning about and attitudes toward biodiversity.

Because wicked problems are not solvable, an awareness of how they are shared with the public is an immediate concern. As ISLIs play a major role in addressing and defining wicked science problems for visitors, there is an increased need to research and understand how people interact with exhibits. Museums need to maximise the effectiveness of boundary objects by finding ways to encourage families to interact. The boundary objects are the museum's exhibits and displays. In this chapter, we describe a study in which we employed boundary objects and applied ANT as a theoretical and methodological lens for understanding the interactions of human and nonhuman actors at the Museum für Naturkunde Berlin (MfN), Germany. Even though we concentrated on biodiversity and how the museum displayed biodiversity as a wicked problem, ANT and our methodology may be used across ISLIs to track and understand how families interact with exhibits dedicated to wicked problems.

Boundary objects are nonhuman actors that allow groups with differing knowledge to share ideas, which can influence a situation (Thompson, 2016). ANT views and attempts to understand all interactions and relationships in the social and natural worlds as a web that continuously generates effects. Specifically, ANT identifies an act and the actants that influence an act, which we should consider simultaneously. An actor-network is an act linked together with all its influencing actants (which again are linked), producing a network (Adamides, 2015; Latour, 2005; Law, 2009). Even though the example in this study is a natural history museum, we may use ANT in a similar way across ISLIs to define visitor interactions with boundary objects. Any institution may apply ANT to define how the boundary object becomes part of the exhibit network.

To address audience interactions with museum exhibits and the implications for museums, we incorporate a study of families at the Museum für Naturkunde, Berlin (MfN), with networks that identify actor interactions. The exhibit studied was the Biodiversity Wall, which aimed to develop awareness of worldwide biodiversity and included organisms representing classes from the Animal Kingdom. Acknowledging the exhibit aim, alongside the views held by the museum educators, we focused the study on the following four objectives: (1) to determine predictors of exhibits that encourage family interactions, (2) to develop a deeper understanding of the value of exhibits that represent biodiversity and the role of those exhibits in engaging families, (3) to increase collaboration between education staff and exhibit design staff to address how the MfN can use the collection to address biodiversity education and (4) to provide a basis for training museum educators to discuss biodiversity in relation to the family interactions.

For wicked problems, such as biodiversity loss, to be better understood education programmes need to challenge the public's beliefs, attitudes and mental constructs about its importance and develop their knowledge of the forces influencing the decline of organisms (Kaltenborn et al. 2016; Loyau & Schmeller, 2017; Patrick, 2017). Hence, this study explores the wicked problem of biodiversity through an education lens within the constraints of the MfN's resources.

Museum research centred on families over the last 30 years has dedicated itself to conversations, knowledge, learning, motivation for visiting and movement (Harris & Winterbottom, 2018; Idema, & Patrick, 2016a; Wu & Wall, 2017). We were most interested in how families interacted with the exhibit representations and involved others in their group with the exhibit, with whom they first chose to interact in the group and if initial interaction with the exhibit encouraged all family members to involve themselves with the exhibit. That is, our work explored group structures when in contact with exhibits concerning wicked problems.

Although ANT seemed an ideal theoretical lens for framing this work, a review of the research did not reveal its application in such a setting. Defining interactions is particularly acute for understanding the networks families build around a boundary object. The differences between family members and how they interact may be a barrier to knowledge transfer. We focus on the importance of shared experiences within the network, as family member interactions with a boundary object create an atmosphere conducive to extended conversation about the object. More interactions lead to more conversations, which may increase sharing science knowledge with other actors. The challenge is defining the effectiveness of an exhibit in representing a wicked problem and encouraging family interactions.

Defining ANT, Biodiversity Knowledge and Family Learning

A primary audience visiting museums are families, which by default makes them an important group for research and evaluation. Understanding how families interact within their group at an exhibit can aid ISLIs with the development and delivery of concepts. Family groups can be a determinant of good exhibit design. The literature presented below provides information about the MfN and explains further the theoretical lens of the study and the relationship to biodiversity knowledge, and family learning.

Museum für Naturkunde Berlin

The MfN is a Natural History Museum in Berlin, Germany, and an autonomous foundation under public law. The MfN is a research institution and a member of the Leibniz Association. Visitorship is over 800,000 per year with many of them being families. The museum collection is on display across the museum in permanent exhibits, while additional collections are on display during touring and special exhibits. The permanent exhibits include the 'Experimental Learning Lab', 'World of Dinosaurs', 'System Earth', 'Evolution in Action', 'Cosmos and the Solar

System', 'Wet Collections' and 'Minerals'. The cost of admittance is 8 Euros/Adult and 5 Euros/Child. However, a group ticket for a family of two adults and up to three children is 15 Euros. Visitors may choose to participate in a guided tour or walk around freely.

The MfN recognises in its 2020 Strategy (MfN, 2012), that 'Grand challenges such as protection of biodiversity' are part of its responsibility to science and the community. The MfN identifies its role as, 'helping society to address these Grand challenges and to find scientific and societal solutions' (p. 2). To drive their goal of tackling Grand challenges [wicked problems], the museum focuses on five research questions, one of which is: 'How can the infrastructure of our collections and exhibitions be best developed to meet both the present and future demands of science and society?' (p. 12). To address the museum's research question, the MfN is prioritising research in the areas of education and communication through regional, national and international research relationships. The MfN uniquely is poised as a location for defining the wicked problem of biodiversity and delivering biodiversity education, because it houses 30 million items, one of the largest collections in the world many items of which are extinct or near extinction. The MfN 2020 strategy (MfN, 2012) states the museum will make a 'contribution to the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) and engage the public with this important development' (p. 6). The strategy described a research area designated to focus on, 'public engagement with science, cultural knowledge and biodiversity policy' (p. 9). The MfN identified education as an important tool for aiding the public in developing biodiversity knowledge (Chaudhuri, 2012; Ramadoss & Poyya Moli, 2011).

Theoretical Framework

ANT developed in the 1980s as a framework allowing the researcher to trace and understand action and interactions between individuals, objects and information (Bingham & Thrift 2000). The foundation of ANT holds that the roles of actors, human and nonhuman, are a part of reality and we may not separate them (Arora & Glover, 2017; Bajde, 2013; Callon & Muniesa, 2005; Latour, 2005; Law, 2009). The focus of ANT is to understand the interactions within the network and the links occurring between the actors to form the network (Bajde, 2013; Fox, 2000; Latour, 2005). Moreover, ANT defines the roles actors play in action and the transformation processes that occur between actants (Harman, 2010; Latour, 2005). Defining biodiversity as a wicked problem through the application of ANT allowed for us to view biodiversity education as a problem of interaction (van Bueren et al., 2003).

Actor-networks are important facets of pushing museums to consider the contextual dimensions of the boundary object and the object as a wicked problem messenger. Boundary objects should maximise the communication between the museum and the visitor. For example, the specimens in the Biodiversity Wall exhibit hold meaning for the museum (representing biodiversity), which they desire to communicate to the visitor. However, as a boundary object, the Biodiversity Wall may be viewed differently by the visitor. The visitor may or may not interact with the boundary object and discern the message of biodiversity, preservation and conservation. To build a relationship between the Biodiversity Wall and the visitor, the visitor must interact with the communication being supplied by the Wall and become involved by conversing with each other. We used ANT to provide a description of the complexity of family interactions while at a museum exhibit. ANT relies on translation to demonstrate how the construction of reality occurs. Translation is the process of the actor-network becoming more extensive and reaching group convergence, which occurs when the actants are establishing identities and interacting based on the social and ambient conditions (Crawford, 2020).

The process of translation at the museum occurs as the actors (family members) visiting the exhibit converge in one place or are mobilised by a primary actor and the boundary object (part of the exhibit). Translation occurs in four steps (Callon, 1984; Law, 2009), which we describe as:

1. Problematisation—defining the problem and identifying the actors and boundary objects. For this chapter, the problem was identifying family interactions at a boundary object. The boundary object was the Biodiversity Wall exhibit at the MfN and the actors were individuals in family groups. Translation began when the primary actor (first person in the group) interacted with the boundary object.
2. *Interessement* (an ANT concept which is synonymous with interposition)—primary actor turns to convince other actors to participate with the boundary object.
3. Enrolment—when another actor in the network involves with the boundary object.
4. Mobilisation—when all actors engage with the same boundary object.

The processes of translation are multidimensional; therefore, we focused on the primary actor as a point of reference and defined the resulting patterns of the family. We define effectiveness of the boundary object as mobilisation of the family group with the object; therefore, we utilised observations of family interactions within a network to define the process of translation.

Wicked Problem: Biodiversity Loss

DeLong (1996) defined biodiversity as, 'an attribute of a site or area that consists of the variety within and among biotic communities, whether influenced by humans or not, at any spatial scale from microsites and habitat patches to the entire biosphere' (p. 745). The attitudes people have toward biodiversity are complex, and their mental constructs of biodiversity influence these attitudes (Bakhtiari et al., 2014; Fischer & Young, 2007; Kaltenborn et al., 2016; Loyau & Schmeller, 2017) as do perceived local benefits (Vodouhê et al., 2010). Though people generally possess certain basic ideas of biodiversity and values towards biodiversity, they have little awareness of the complex forces that cause species decline (Bakhtiari et al., 2014; Hunter &

Brehm, 2003; Lindemann-Matthies & Bose, 2008). The complexity of the causes and solutions for biodiversity loss and public awareness and opinions make the concept of biodiversity loss a wicked problem.

The extent of biodiversity is mostly unknown to the public which hampers support for conservation. Across the world, natural history museums have the largest collection of extant and extinct biodiversity. Even though these large collections exist, the organisms on exhibit to the public are a small portion of the available specimens. Because museums are a safe place for collections and exhibit few specimens, they are gatekeepers of biodiversity knowledge. The exhibitors, in cooperation with others in the museum, choose the specimens to display and the ways to exhibit the objects. The specimens on exhibit represent biodiversity in that moment and in that space for the visitors. The traditional role of museums has been to ensure the visitor has contact with representatives of biodiversity, but that is no longer enough. Museums must now consider the visitor interactions triggered by the object are as important as the way in which the biodiversity is displayed. Research shows that contact with biodiversity and conversations about biodiversity lead to a better understanding of biodiversity and biodiversity conservation (Patrick, 2017; Stamm et al., 2000).

Because of their 2020 Strategy focus on biodiversity, education and public communication, the MfN is an ideal place to determine the interactions families have with representatives of biodiversity. Note that our analysis focuses on the nature of family interactions that involve organisms, not on whether the interactions are correct or incorrect.

Family Learning

ISLIs are toiling to operationalise the ways they communicate science to visitors, the goal being to increase visitors' science knowledge (Christensen et al., 2015; Hine & Medvecky, 2015). To achieve this goal, ISLIs need enhanced understanding of the relationship between the exhibit and visitors (Falk & Dierking, 2012). By understanding the relationship, ISLIs can increase the success of exhibit design and science education. Because families make up the largest visitor group, research in family learning has emerged as a major component in visitor studies research (Ellenbogen et al., 2004; Kropf, 2016).

MfN educators may maximise the knowledge visitors have of biodiversity by becoming more aware of the interactions families have with museum objects. Identifying how families interact at exhibits representing extant biodiversity is important because children's conceptualisations of biodiversity influence their conservation attitudes (Rakotomamonjy et al., 2015) and shape their adult knowledge and capacity to learn about the world (Shepardson et al., 2007; Sorin & Gordon, 2010).

When visitors conceptualise local biodiversity, their commitment to conservation stewardship may increase (Patrick, 2017; Ugulu et al., 2008). The interactions between family members are most important, because people cite family members and family experiences as sources of knowledge of scientific concepts (Blatt & Patrick, 2014; Patrick, 2014a; Ugulu & Ayden, 2011). Moreover, the interactions families have in informal settings influence their conversations about science (Idema & Patrick, 2016a, 2016b; Uzick & Patrick, 2018; Zimmerman et al., 2013). During a museum visit, families talk about what they know and their previous experiences (Astor-Jack et al., 2007), which means museum educators and exhibit designers must understand who begins the conversation at an exhibit and if the conversation encourages others in the group to join.

ANT allows for an analysis of these interactions. Museum educators may consider that visitors are unlikely to develop an understanding of biodiversity through personal interactions with the exhibit, but may through social interactions (Bogner & Wiseman, 2004; Eagles & Demare, 1999; Korhonen & Lappalainen, 2004). The importance of family members discussing science and family members as the primary source of science knowledge is important for museum educators as they develop exhibits. Exhibits are a fundamental catalyst for the conversations that occur between family members; therefore, exhibit designers and museum educators need to understand how exhibits stimulate conversations among the groups.

Methodology

The first author utilised an ethnographic nonparticipant observation design as a qualitative approach to perform an analysis of family interactions (Spradley, 2016). She collected the interactions while families visited the Biodiversity Wall at the MfN. This analysis allowed her to define interactions occurring naturally in the moment and context of the situation (Leech & Onwuegbuzie, 2007), because she was a 'temporary member of the setting (and thus) more likely to get to the informal reality' (Gillham, 2010, p. 28). The nonparticipant observation design was important as it allowed her to observe participants and focus on the interactions within families without disturbing the intimacy of the group dynamics (Angrosino, 2008; Spradley, 2016; Yin, 2011). Moreover, the nonparticipant observation provided an approach to examining the representations of family members' roles within the museum setting. An extended and sentient observation, in which the researcher spends ample time at the study site (Altheide & Johnson, 1994; Lincoln & Guba, 1985), allows the researcher to acquire a better understanding of the mellifluousness of the interactions within a particular network (Bryman, 2004; Grand & Sardo, 2017).

She examined interactions between families and boundary objects using ANT as a pragmatic lens. Pragmatic in that she explored the practices of family members within the network and the realistic expectations museums may have of building knowledge of wicked problems. The focus on interactions connected with the boundary object (exhibit) and the analysis of the interactions within an actor-network differentiates this study from other efforts to understand family interactions during a museum visit.

Setting

The first author collected data in the 'Evolution in Action' exhibit hall. MfN describes the exhibit hall as displaying, 'selected evolutionary mechanisms that explain phenotype and behaviour of plants and animals' (https://www.museumfuer-naturkunde.berlin/en/museum/ausstellungen/evolution-action). The hall has two entrances, but visitors usually enter through the same one. The entrance boasts the Biodiversity Wall, four metres (13 feet) high and 12 metres (39 feet) long, displaying 3000 animal phyla from various habitats. A publicly available photograph of the Biodiversity Wall is at https://www.museumsportal-berlin.de/en/museums/museum-fur-naturkunde/slideshow/#1. To determine which Biodiversity Wall boundary object occurs most often in the actor-network of translation, she divided the Wall into the following boundary objects: Amphibians, Reptiles, Fishes; Mollusca, Annelids, Cnidarians, Echinoderms, Nematodes, Rotifers; Mammals; Arthropods; and Birds. In addition to the Wall, the exhibit included an information kiosk that provided a view of the Wall with the organisms labelled. The kiosk was not included in the data collection.

Participants

The participants in this study were 190 families (305 children, 273 adults), who visited the MfN Biodiversity Wall. We defined family units as an adult with at least one child. We identified children as someone who appeared to be under the age of 12. The 305 children consisted of 123 females and 182 males. Table 5.1 presents the 190 family groups, which consisted of six family types: (1) two parents with more than one child (n = 49), (2) two parents with one child (n = 34), (3) male parent with more than one child (n = 12), (4) male parent with one child (n = 33), (5) female parent with more than one child (n = 22) and (6) female parent with one child (n = 40). Additionally, Table 5.1 provides information about the children who visited with each family.

Data Collection

The first author and an assistant completed observations on different days. We observed families during the week and on weekends in the months of May and November 2016. We sat in a location near the entrance and angled to the side of the exhibit where we could see all of the exhibit and visitor interactions.

We recorded family interactions for each group as they moved through the exhibit and interacted with the boundary objects. We recorded the following data on an observation sheet: (1) amount of time family spent in the exhibit; (2) number of

Table 5.1 Family groups (N = 190) with number of adults and children in each family

Family group	# of adults	# of children	Female child	Male child	>1 male child + 1 female child	>1 female child	>1 male child	1 male child + 1 female child
Two parents/ more than one child n = 49	98	112 Female = 46 Male = 66	0	0	8	3	10	28
Two parents/one child n = 34	68	34 Female = 19 Male = 15	19	15	0	0	0	0
Male parent/ more than one child n = 12	12	35 Female = 11 Male = 24	0	0	9	0	0	3
Male parent/one child n = 33	33	33 Female = 9 Male = 24	9	24	0	0	0	0
Female parent/ more than one child n = 22	22	51 Female = 22 Male = 29	0	0	4	3	5	10
Female parent/one child n = 40	40	40 Female = 16 Male = 24	16	24	0	0	0	0
Total N = 190	273	305 Female = 123 Male = 182	44	63	21	6	15	41

adults and children in the group; (3) presumed gender of each member; (4) first family member who interacted with a boundary object and led interessement—when someone pointed to, called attention to or paid attention to a boundary object; (5) first family member the primary actor enrolled in the network—the first person who reacted to the primary actor through speech or paying attention to the object; (6) if all members of the group mobilised in the network; and (7) boundary object at which the family member stopped to engage. We recorded translation once for each family. If family members left the exhibit and returned, translation did not begin again. Family members may have interacted with different parts of the Wall, but we recorded interessement when the first family member began interacting with the Wall. If they did not interact with other family members, then interessement did not begin and we recorded no data for interessement. We recorded mobilisation if all family members interacted with the section of the wall at the same time. We recorded the Biodiversity Wall boundary object with which the Primary Actor interacted. Later, we transcribed the data to an Excel file.

Data Analysis

To define the interactions of families at the Biodiversity Wall, we aggregated the data for the four family groups and separated them into family-group types and carried out a comparison. Utilising two views of the data allowed for more easily identifying the translation process, as ANT focuses on patterns among groups. The process of interpreting the family group interactions allowed for defining the enrolment and mobilisation steps of translation and a better understanding of the actor-network (Verschoor, 1997).

For each family, we recorded the translation process once and placed the data in an Excel file, so we had a record of the order in which they interacted with the exhibit. Data analysis used counts for each step of translation, considering the translation process most closely associated with the primary actor and the subsequent interactions at the Biodiversity Wall. On completion of the analysis of the translation process, we compared the data across the four types of family groups to develop a better understanding of the family actor-network.

Results

The goal of this study was to identify the process of translation among family members, who interacted at the Biodiversity Wall. As stated earlier, we focused on the primary actor, the person with whom the primary actor began the conversation (interessement), the primary actor's ability to involve the other person in conversation (enrolment) and whether or not all family members were involved in the conversation (mobilisation). Table 5.2 presents the data from each family group type. We discuss the data aggregated for all families and separately for each family group type. This process allowed for a clearer look at the interactions between family members during translation.

Primary Actor

Children were primary actors most often in all groups except the group with two parents and one child. Looking at the data across all families (N = 190), children (n = 142, 75%) were the first to interact with the Wall and encourage another person in the group to look at the object. Parents (n = 48, 25%) were less likely to be

Table 5.2 Family groups (N = 190) and steps in translation

Family group	Primary actor (PA)[a]	Interessement[b]	Enrolment[c]	Mobilisation[d]
Two parents/more than one child n = 49	Female parent n = 3	Male child = 3	Yes	Yes = 1 No = 2
	Male parent n = 6	Female parent = 5 Male child = 1	Yes	Yes = 2 No = 4
	Female child n = 20	Male Pparent = 6 Male child = 14	Yes	Yes = 3 No = 17
	Male child n = 20	Male child = 20	Yes	Yes = 5 No = 15
Two parents/one child n = 34	Female parent n = 3	Male parent = 3	Yes	Yes = 1 No = 2
	Male parent n = 18	Female parent = 2 Female child = 6 Male child = 10	Yes	Yes = 6 No = 11
	Female child n = 7	Male parent = 7	Yes	Yes = 3 No = 4
	Male child n = 6	Female parent = 6	Yes	Yes = 5 No = 2
Male parent/more than one child n = 12	Male parent n = 0	0	Yes	0
	Female child n = 4	Male parent = 1 Male child = 3	Yes	Yes = 1 No = 3
	Male child n = 8	Male parent = 2 Female child = 2 Male child = 4	Yes	Yes = 2 No = 6
Male parent/one child n = 33	Male parent n = 6	Female child = 1 Male child = 5	Yes	Yes = 6
	Female child n = 8	Male parent = 8	Yes	Yes = 8
	Male child n = 19	Male parent = 19	Yes	Yes = 19
Female parent/more than one child n = 22	Female parent n = 2	Female child = 1 Male child = 1	Yes	Yes = 2 No = 0
	Female child n = 10	Female parent = 1 Female child = 2 Male child = 7	Yes	Yes = 7 No = 3
	Male child =10	Female child = 3 Male child = 7	Yes	Yes = 8 No = 2
Female parent/one child n = 40	Female parent n = 10	Female child = 4 Male child = 6	Yes	Yes = 10
	Female child n = 12	Female parent = 12	Yes	Yes = 12
	Male child n = 18	Female parent = 18	Yes	Yes = 18

[a]The number of primary actors for each gender and age
[b]If enrolment occurred with the interessed person
[c]Yes = number of families mobilised by the primary actor, No = number of families not mobilised by the primary actor
[d]The person the primary actor interessed and how many of each gender and age they interessed

primary actors and lead translation. Male children were primary actors in 81 (42%) families and led translation more often than female children, who were primary actors in 61 (32%) families.

Interessement and Enrolment

All families (N = 190) had a primary actor, who successfully moved from interessement to enrolment, meaning that the person in the group to which they spoke engaged in the network. In 62 (33%) families, children interessed another child, while 80 children interessed a parent. Parents interessed a child (n = 38, 20%) more often than a parent (n = 10, 5%). Across the 190 families, female parents (n = 10, 5%), male parents (n = 16, 8%), female children (n = 24, 13%) and male children (n = 31, 16%) interessed male children more often than other family members. Female children (n = 22, 12%) interessed male parents more often than female parents. Male children (n = 5, 3%) interessed female children less often than other group members.

The following data represents separate family group types. When we analysed the families as separate group types, the data provided a closer look at translation. In this study, the steps of translation (interessement, enrolment and mobilisation) demonstrated how the actors in the network established identities as actors and reached group convergence. Convergence occurred when all family actors interacted with the boundary object, which was different depending on types of family groups.

Family groups with two parents and more than one child (N = 49) had 98 parents and 112 children. Even though the number of parents and children were similar, adults were primary actors in 9 (18%) families and 40 (82%) primary actors were children. The number of male (n = 20) and female children (n = 20) were the same, but interessment occurred most often between male children (n = 20, 41%) and female children to male children (14, 28%). Male children did not attempt to interess a parent or a female child. In families with two parents and one child (N = 34), the families consisted of 64 parents and 34 children. Even though the number of parents was double the number of children, a parent interessed another parent in 5 (5%) families. However, children interessed a parent in 13 (38%) families and the male parent interessed children in 16 (47%) families.

Families (N = 12) with one male parent and more than one child did not have male parent interessment. Male parents did not interess a child; instead, children interessed each other (n = 9, 75%) most often. Female parents with more than one child (N = 22) interessed two (9%) children; however, 19 (86%) children interessed another child. Families with one adult and one child were similar to these results. Even though parents had an equal opportunity to begin a conversation, children who led interessement dominated in male parent (N = 33) and female parent (N = 40) groups. In male parent groups, male parents led 6 (18%) interessements, while children led 27 (81%) interessements with the male parent. Female parent groups saw 10 (25%) interessements led by the female parents and 30 (75%) led by the children.

Overall, children led interessements when adults dominated the family groups and when the number of adults and children were equal. In groups with more than one parent, parents rarely interessed each other. When more than one child was part of the family group, the children interessed another child most often.

Mobilisation

Even though the time families remained at the Biodiversity Wall exhibit averaged 2.5 minutes and all reached enrolment, time did not ensure mobilisation. When we analysed the data across all 190 families, 108 (57%) families reached mobilisation, which means all family members engaged in the network. However, this number is deceptive, because 73 families consisted of a parent and child, which all enrolled and reached mobilisation. Therefore, the following data concerning mobilisation focus on the 117 families with more than 2 family members. The data show 71 of the 117 families with more than 2 people did not reach mobilisation. Of the 46 families that reached mobilisation, 34 (74%) children were the primary actors, while 12 (26%) parents were the primary actors.

Boundary Object

As was mentioned above, we divided the Biodiversity Wall into the following boundary objects: Amphibians, Reptiles, Fishes, Molluscs, Annelids, Cnidarians, Echinoderms, Nematodes, Rotifers, Mammals, Arthropods and Birds. Table 5.3 presents the Biodiversity Wall boundary objects and the primary actor, who led translation. The boundary objects Arthropods (n = 52, 27%); Amphibians, Reptiles and Fishes (n = 50, 26%); and Molluscs, Annelids, Cnidarians, Echinoderms, Nematodes and Rotifers 38 (20%) became a part of the actor-network more often than the other boundary objects. A total of 140 families had primary actors who interacted with these boundary objects and interessed others to interact. Female and male children interacted most often with Arthropods, while female adults interacted most often with Mammals and male adults with Amphibians, Reptiles and Fishes.

The data indicated that children and parents interacted with the boundary object and each other. However, the larger the family group, the less likely mobilisation was to occur. By using ethnographic nonparticipant observation, we uncovered some of the complex processes by which a family participates during a museum visit. Utilising ANT as a methodological perspective allowed us to define the interactions that took place with the Biodiversity Wall. In the discussion below, we

Table 5.3 Number of participants who led translation at each section of the Biodiversity Wall (N = 190)

	Male adult	Female adult	Male child	Female child	Total
Amphibians, reptiles, fishes	9	3	25	13	50 (26%)
Mollusks, annelids, cnidarians, echinoderms, nematodes, rotifers	7	4	15	12	38 (20%)
Mammals	3	7	9	10	29 (15%)
Arthropods	5	1	27	19	52 (27%)
Birds	6	3	5	7	21 (11%)

address how the current study fits into biodiversity as a wicked problem and situates within an actor-network framework.

Discussion

This study used ANT to examine how boundary objects in a museum influenced the mobilisation of family groups. The interessement stage data strongly support that the boundary object and the primary actor are an important aspect of the actor-network and do attribute to the enrolment and mobilisation stages of translation. A closer look at the data revealed that the primary actor did influence the interessement of all the actors in a family group and whether mobilisation took place. Actor-networks develop through interactions with one or more objects. Identifying the actor-networks among family members is important, because the network promoted interactions. The networks established at the Biodiversity Wall among family members indicated that certain behaviours are predictable. In particular, gender and age of the actors may be predictors for the interactions and determine the translations (or not) that will occur in relation to the boundary object. Determining how the place (exhibit) functions in establishing a relationship, or prevents someone from entering the network, defines the way in which scientific knowledge is shared and potentially accumulated. The interactions within the network then propel cooperation and learning among the group (Klijn & Koppenjan, 2000). Distinguishing who interacts and how is a way to analyse the process that develops during an actor-network.

Family actors in museums explore the boundary objects and look for opportunities to share their discovery with others in their group. However, far from simple, conflicts of interest with other objects and family attention can hinder the primary actor as they attempt to involve others at the exhibit. Moreover, as this study shows, the gender and age (child/adult) of the primary actor may play a part in the network interactions. The network develops through a process of decisions and interactions with others. The type of boundary object, in this study the sections of different organisms on the Biodiversity Wall, and the outcome of the decisions made by the primary actor, can influence the level at which others interact. The findings suggest a need for a further large-scale study.

As previously stated, biodiversity loss is a wicked problem. Biodiversity loss is a complicated, diverse, disparate, similar and dissimilar concept. To address this scientifically complex issue, public education should promote conversations about biodiversity loss by supporting people as they utilise their knowledge and question conservation values. The museum actor-network, which includes the museum exhibits, staff and visitors, has an agenda that consists of knowledge and research. The museum network focuses on process and product of exhibit quality, education, learning and scientific research and on the modifications that should take place to keep the foci current. The family actor-network focuses on fun, learning and the next exhibit. The museum and family actors are interdependent actors, because the museum influences family interactions and interest through exhibit design and representation of the boundary objects. Defining biodiversity within the exhibit in a way that increases family interactions and dialog is the role of the museum actor. The role of the family actor is to interact with the exhibit and understand the importance of biodiversity and human impact on biodiversity.

The museum and family roles are interdependent and complex, because museums have agendas and families have agendas. These agendas may become blocks to cognitive engagement and interactions. Understanding how the family-actors interact during a visit and their decision-making at a boundary object highlights the problem of museums identifying institutional constraints. Identifying the institutional constraints will lead to the development of positive museum attributes that advance constructive interactions among families. Encouraging families to interact with the organisms and fostering conversations may lead to the capacity to understand the problem of biodiversity decline. This was not a part of the study; therefore, a future study should identify the relationship. The notion that families are not interacting with boundary objects in a way that leads to mobilisation presents a challenge to the museum. The challenge is to consider the mind-set of the families and apply strategies across the museum and family actor-networks to foster the transfer of information. Museums must promote an active solution to biodiversity decline and build the capacity to solve the problem.

In this case, the museum actor-network must evolve to deal with the notion that children interact with the object most often and mobilisation with the object seldom occurs. This study focused on the structure of the relationship between the object and the family actors. The findings have implications for visitor behaviour within an exhibit, to enhance object performance and ways for museums to build collaborative dialogue among families. The family actor-network, when they act as a collective through dialogue, will enable family members to better understand the exhibit and will create a sense of value for the boundary object (Büchel & Raub, 2002). The learning that takes place through the sense of value created within the network may transmit to views of biodiversity decline.

Actor-networks connect participants through a transfer of knowledge across the network. However, if the actors are not interacting, the transfer of knowledge within the actor-network does not occur. Unseen rules or norms can influence or inhibit the interactions that occur within the network (Gargiulo & Benassi, 2000). The findings of this study indicate that children lead the interactions with males being the most interessed. These unseen or even unrealised norms among families are influencing the ways in which families interact at boundary objects. This influences the conversations that occur. Actors within a network, including the boundary object, must share information in a way that develops the network and the network's capacity to focus on wicked problems. Even though the network actors share a common experience when they view and discuss a boundary object in a museum, the actors bring different experiences and knowledge about the object. The social interactions with others in the group provide valuable opportunities for group members to share their experiences and knowledge, which is a time when learning can cultivate.

The MfN recognises its role in biodiversity education and the challenges of defining biodiversity loss and promoting dialog associated with biodiversity and its decline. One way they address educating the public is with the Biodiversity Wall. The purpose of the Wall is to provide families with learning experiences which lead them to understand the significance of biodiversity. However, the actor-network that develops at the Wall shows that mobilisation happens in some groups and not in others. The goal is to determine what techniques may increase mobilisation. The interactions that occur at the Wall appear to be bidirectional (one to one) among the human actors instead of multi-directional with others in the group involved. All actors in the network have the potential to bring experiences and expertise to the interaction through social interactions (Rogoff, 1995, 2003). When family members interact with the boundary object, they develop the knowledge within the group by questioning and sharing experiences. Group size may be a confounding variable in reaching mobilisation. If the group never reaches mobilisation, then the multi-directional interactions are not occurring that would give meaning to the boundary object and the development of knowledge. If museums do not evaluate and recognise the interactions that occur with boundary objects and the resulting socially constructed networks, they will hinder the possible effectiveness of the object on exhibit. The challenge is to identify the ways in which the actor-network develops around the boundary object and how the museum can influence the actor-network.

We need research that aims to understand how boundary objects become a part of the family actor-network and lead to interessement and mobilisation. The research should include how museums display the boundary objects. We first must understand the challenges posed by knowledge transmission within an actor-network by defining who the actors are and how they interact and second by what conversations the objects prompt. Museums must understand the visitor, how they interact with boundary objects, engagement of other actors in the network and the resulting group dynamic. Museums might record these in a database of information to use to develop future exhibits.

Conclusion

In the analysis, we were interested in the extent to which the boundary object became a part of the network, if the primary actor interessed others to interact with the boundary object and if the group reached mobilisation. In the network perspective, the explanation of biodiversity as a wicked problem focuses on the degree to which families succeed in interacting. The network approach emphasises the interactions of all in the group and often pays less attention to the content of the process. Because paying less attention to the process may develop conflicting perceptions about the nature of the problem, mapping the interactions of the actors is vital.

To delineate the family interactions at an exhibit, we developed the term synergy of the unresponsive, because even though they are viewing the same exhibit at the same time, their interactions with the boundary object may not result in mobilisation. This means conversation among all actors does not result from the interaction. The unresponsiveness of other actors in the group will influence the synergy, or interactions, that develop during translation. Their diverging interest in the boundary object becomes a conflict and the result is the family does not interact at the exhibit. Museums must try new strategies to encourage family interactions and dialogue that include a common frame of reference—the boundary object. Dialogue is a primary construct of learning. Defining the synergy of the unresponsive may provide a breakthrough in techniques and strategies for coaxing visitor interaction around a common frame of reference (exhibit).

The results of this research have important implications for the way museum educators think about the importance of the interactions among family groups and addressing wicked problems. Parents and children interacted in the exhibit in ways that did not lead to mobilisation or entire family interactions. Mobilisation rarely occurred, which may be because the Wall has so much to see and families are scattered across the Wall with little interaction. The Wall size is a limitation of the study. Mobilisation occurred least often in families with more than three people and most often with families with two adults and one child and with families of one adult and one child. Moreover, children most often were the primary actors at the Biodiversity Wall.

Other museums could easily adapt this simple but versatile methodology as they determine how exhibits addressing biodiversity engage groups. We must address the synergy of the unresponsive using analytic tools and management of boundary objects. The lack of mobilisation at an exhibit means that conversations will not result in knowledge shared, received and assimilated. Efforts to address wicked problems in museums require a broad range of knowledge and interactions of the visitors. The visitor voice, or dialogue, is important (Patrick & Tunnicliffe, 2013), but the visitor interactions begin to address the complexities of the transfer, reception and integration of knowledge during conversations. The interactions at a boundary object are multi-dimensional and we should not consider them solely through language. Instead, we should determine the interactions with an overlay of when words are exchanged and what those words are.

Opportunities for families to interact and the consequent integration of ideas and perspectives into existing cognitive structures are enticing. An emphasis on exhibit design that focuses on community should reflect learning through shared participation. Learning is a process of assimilating community actions, beliefs and language (Sfard, 1998). In actor-networks, learners, as part of an interacting community, rely on the participation of others in the network to learn. The subsequent discourse facilitates learner engagement through the actor-network as actors agree and disagree, reach understanding and encourage, acknowledge and reinforce concepts (Reznitskaya et al., 2001).

Use of ANT to determine the relationship between visitors and boundary objects is significant. Use of ANT will provide a compelling and coherent structure to organisations interested in defining their audience. The next step in this research will be to record family conversations and complete interviews and/or questionnaires with family members.

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Chapter 6
Real-World Problem: Connecting Socio-Scientific Contexts and Dioramas

Jung Hua Yeh

Introduction

In Taiwan, an important requirement to support continued social development is keeping the energy supply stable. At the same time, there is an increasing global focus on ensuring that energy is both clean and sustainably sourced. In response to the need to slow global warming, the Taiwanese government has proposed a policy to reduce coal-based power generation by increasing the use of alternative energy sources. In order to educate citizens of the importance of non-fossil fuel power generation for carbon reduction, the Taiwanese government funded a program to introduce nuclear power and several natural energy power facilities. The National Science Council (NSC) of the Executive Yuan, the predecessor to the Ministry of Science and Technology (MOST), funded The National Energy Program-Phase I (NEP-I) from 2008 to 2015 (National Energy Program Phase Two Program Office, 2013). According to the mid-term report, NEP-1 established four directions for future energy programs: energy efficiency, energy usage and energy sustainability, renewable energy development and utilization and formulation and evaluation of energy technology development strategies. The main purpose of NEP-1 was to introduce the idea of energy saving and reduction of carbon dioxide emission through formal and informal education. In March 2011, the disaster at the Fukushima nuclear power plant in Japan caused many of the NEP-1 granted projects to highlight the importance of introducing green energy (i.e. diversified natural power). Thus, there were several NEP-1-funded projects that had the objective of evaluating the National Energy Program through three aspects: students' energy literacy (Shen, 2011; Yeh et al., 2017), teachers' attitudes toward teaching energy issues (Yeh &

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M. Achiam et al. (eds.), *Addressing Wicked Problems through Science Education*, Contributions from Science Education Research 8,
https://doi.org/10.1007/978-3-030-74266-9_6

Ku, 2011) and public constructs of energy values and behaviors (Chiu, 2012, 2013; Chiu et al., 2016).

Empirical research shows that the National Energy Program prompted both the acquisition of knowledge about climate change and changes in attitudes toward energy conservation behaviors among citizens (Shen, 2011; Yeh & Ku, 2011, 2017). However, there were also many misconceptions or naïve ideas with respect to energy saving actions and rewards (i.e. improvement of climate change) (Shen, 2011; Yeh et al., 2017). The NEP-1 final report utilized an open agenda forum approach to examine the influence of the program and found that it enabled citizens to have rational discussions about energy issues but that these discussions were still to some extent affected by subjective and selective estimations and value judgment (National Energy Program One Executive Office, 2015, pp. 128–129). Chiu et al. (2016) analysed ten statements about energy saving and carbon reduction publicized by the government through NEP-1, and factor analysis revealed that these declarations included three value constructs and three behaviour constructs. Further, correlation and regression analyses showed that value constructs (nature and domestic technology values) were able to predict behaviours that were easy to carry out but could not predict behaviours that required more careful consideration. For example, people knew lots energy-saving products, and they were willing to purchase these products for to save energy then decrease carbon dioxide emission; but they would not always turn off electrical appliances in their house because of “energy-saving products won’t take too much energy”. These studies point out the same phenomenon: Citizens acquired relevant knowledge of global warming and environmentally friendly behaviours, but they still acted in accordance with common values (such as the big industry emits a lot of carbon dioxide than me, my environmentally friendly actions cannot contribute to saving the world) rather than consideration of public welfare, evidence and science knowledge. People took up energy conservation behaviours that were easy for them to carry out but prioritized other perceived needs over enacting consideration behaviours, for example, the importance of quality of life, personal safety, economic status or timing.

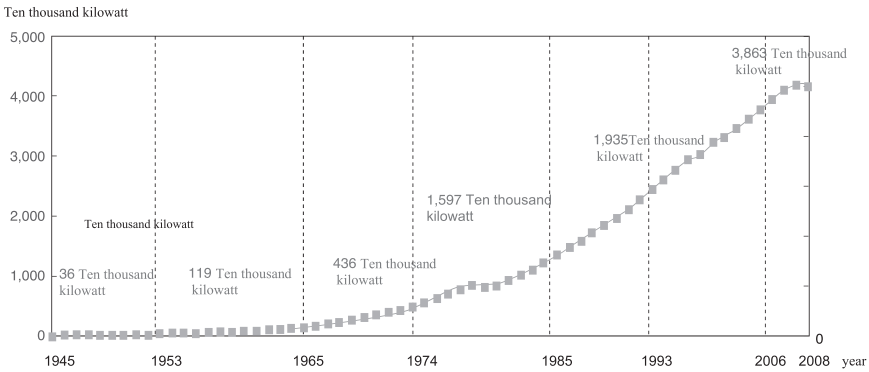
The National Museum of Natural Science (NMNS) engaged with NEP-1 from 2008 to 2013. This engagement included activities such as teacher workshops, family energy quiz competition, outreach education kits and regular museum lectures for promoting participants’ awareness of the importance of reducing carbon emissions. These diverse activities were well received in schools and family groups. After the NEP-1 finished, most of these activities were discontinued. However, because the energy-related issues are important to society, and due to the museum’s commitment and social responsibility, a decision was made to incorporate the energy education initiatives in a deeper and more sustainable way in the museum.

The National Museum of Natural Science was built in the period 1984–1996. It is a natural history museum which also includes a science centre. Its galleries include a large area of dioramas, the main purpose of which is to pass on knowledge about and enthusiasm for nature. It is a conjecture of the NMNS that this enthusiasm for nature could motivate reflective thinking among its visitors about how to deal with the tension between societal development and environmental protection.

The present study is a case study about how dioramas can facilitate discussions about socio-scientific issues on human energy facilities and nature conservation. Special attention is also paid to how museum visitors of different ages make their decisions and how they engage with the conflict between energy development and nature conservation. The context for the study is Taiwan, a society where massive use of technology represents a materialistic lifestyle, but a low-carbon future is now also an aim for both the government and the general public.

The Electricity Consumption Increases with Population and Economic Growth

According to the Taiwan Power Company's history on their official web page (https://www.taipower.com.tw), Taiwan's use of electrical power began with the Qing Dynasty Taiwan governor Liu Mingchuan who founded the first power company in 1888. This company utilised several small coal-burning steam generators for city lighting. Later, the Japanese governance established several hydroelectric and coal-burning power plants. At the end of World War II, the Taiwan Government took over those power facilities that the Japanese left. During the period 1945–1953, the government was committed to increasing the electric power infrastructure and built several large-scale hydraulic power plants. During the most intensive period of Taiwan's industrial production, more than 20 coal or oil-burning power plants were built, leading to the present total power capacity of 300,000 kilowatts. These fossil fuel burning power plants have provided 70–75% of the electricity that Taiwan has needed since 1975 up until today (Fig. 6.1).



Duration	1946～1953	1954～1965	1966～1974	1975～1985	1986～1993	1994～2006	2007～2008
Economic growth rate（%）	No data	8.25	9.93	8.35	8.56	4.89	2.84
Power generation growth rate（%）	20.28	12.54	13.72	8.92	8.61	5.19	0.93

Fig. 6.1 The electricity consumption growth. (Figure redrawn from Chang et al., 2011, p. 58)

According to demographics information from the Ministry of the Interior, Taiwan had a population of approximately five million people in 1945. At the end of 2017, more than 23 million people lived in Taiwan. Thus, the population quadrupled during the past 72 years, and at the same time, the electricity consumption increased more than 100 times. As discussed previously, most of the electricity came from coal burning power plants. In addition, three nuclear power plants joined the ranks of power generation in 1976, contributing 32% of the electrical power for Taiwan from 1976 onwards. However, nuclear power contributed only 12% towards Taiwan's total power generation in 2017. Accordingly, since 2000, the government has encouraged a diversification of energy sources, including renewable energy in order to decrease carbon dioxide emissions. This resulted in an increase of the contribution of photovoltaic and wind energy into 12.9% and hydroelectric energy to 5.8% of the total power generation in Taiwan in 2017.

The Wicked Problem: Which Energy Is the Best Choice for Environmentally Sustainable Development?

"Wicked problems" are complex problems that cannot be easily solved because (among other reasons) they are located at the intersection of science and society. Dillon (2017) suggests that labelling issues as wicked problems may serve to prompt science museums' sense of social responsibility and thus encourage them to take a more active stand in promoting and facilitating changes in both policy and in public practices. Following this argument, the NMNS cast "next-generation electricity" as a wicked problem to help the public to understand and address the issues facing them and to not rely solely on politicians and policymakers.

The wicked problem at stake in the present study is thus the following: Since the 1980s, coal-based and nuclear power have been the main source of electricity in Taiwan. The clear trend is that greenhouse gases intensify global climate change. Accordingly, the government wishes to decrease reliance on fossil fuel-based power plant. Alternative energy sources include nuclear power as well as natural power sources: wind, hydroelectric and photovoltaic power. However, each of these energy source has its specific advantages and trade-offs.

Coal-Burning Power

In Taiwan, the atmospheric particulate matter sized under 2.5 μm (PM2.5) has been steadily increasing. Recent years saw more than 100 days per year over the serious pollution level. The citizen groups consulted in NEP-I considered coal burning power plants to be the main source of air pollution and asked the government to reduce the loading of the biggest coal burning power plant, located in central Taiwan. This request would impact the electricity availability in Taiwan.

Nuclear Power

The island of Taiwan is located at the edge of the Pacific Ocean seismic belt, and this island also on the intersection between Philippine Sea Plate and Eurasia Plates. The whole area of the island is 36,000 km^2. The oldest stratified rock layers date back about 6 million years. It is difficult to find geologically stable places to store nuclear final waste. Even so, in 1985, the government announced the construction of the fourth nuclear power plant without a well-conceived plan of how to treat nuclear final waste. As a consequence, a group of environmental protection campaigners proposed a "Non-nuclear home town", and this became an important agenda in Taiwan (Public Television Service, 2000). In 2011, the Fukushima nuclear disaster terrified publics in Taiwan, and as a result, public opinions tended to support closing the nuclear power plants in Taiwan (Huang et al., 2012). In response to this pressure, the government and electricity supply company temporarily shut down the two oldest nuclear power reactors and constructed several wind power electricity test stations around Taiwan.

Natural Power

To collect enough natural energy to convert into electrical power, the energy collecting devices have very specific requirements, such as stable winds coming from certain directions, or sunny conditions throughout the year. In some cases, the locations that are suitable for natural energy collection are most often found in natural reservation areas. For example, several existing wind farms are located along the west coast of Taiwan which are also found important for waterfowl habitats and migratory bird stopover habitats. Furthermore, wind turbines placed in wetland and intertidal zones impact the intertidal ecosystem. However, solar photovoltaic power devices need to be in locations with direct sunlight for more than 6 hours a day. Thus, they seem suitable for fitting on roof tops in cities without harmful effects on the environment. Easy access for the recycling of the power storage (chargeable battery) and the solar photovoltaic plates must be considered.

Taiwan is on the Pacific Ring of Fire, and there are a number of extinct volcanos on the island. Further, it has rich geothermal resources, but most them are located in geological fracture zones, where they are hard to exploit. The island of Taiwan has a mountain range located in the center of the island like a spine. These mountains were the site of rich hydraulic power generation facilities constructed during the 1950s to 1970s. Those facilities provided steady power for economic development but also caused certain endemic species of Taiwan to become extinct. Since the twentieth century, however, the monsoon in northeast Taiwan has weakened. This means that in recent years, the monsoon does not contribute as much water as previously. In the summer, the amounts of rain from the typhoons flush great amounts of soil into the water reservoirs, making the hydraulic power supply unsteady.

The south west of the island is drier and sunnier, thus making it suitable for harvesting solar energy. Both solar thermal power and solar photovoltaic power require large areas to collect enough energy for operation. Solar thermal power generation is more stable than solar photovoltaic power, but it requires a larger area and carries with it risks (e.g. heat leakage) to surrounding areas. The heat collection area cannot be subdivided into smaller areas, unlike the collection area for photovoltaic power generation.

In summary, it is urgent for Taiwan to employ alternative energy sources to substitute coal-based and nuclear power. The natural power sources (i.e., wind-based, photovoltaic, geothermal, and hydroelectric power) are all valid choices, but each natural power can only be collected from specific locations with suitable ecological conditions. This tension became the operationalization of the wicked problem by which the Museum connected the socio-scientific issues with the ecologies depicted in its dioramas. For each diorama, the question was: What kind of natural power plant would be suitable for this ecology? In which ecology would you prioritise power generation over the environment? What are the disadvantages of natural power generation facility?

Inquiry Learning: From Theory to Practice

The science curriculum developed by the NMNS follows the K-12 National Curriculum Standard in Taiwan. The science curriculum standards highlight the importance of cultivating inquiry abilities (Ministry of Education, 2018); to this end, they list several literacies that students should acquire by interacting with the curriculum. The literacies described in the curriculum include, for instance, "students are students are able to carry out several scientific inquiry steps in order to investigate questions". Taking an example, by acquiring the literacy "systemic thinking and problem solving" in elementary school, students were expected to have the "Ability to ask questions based on their curiosity and imagination, to explain information following the scientific inquiry codes (from observations, reading and thinking of information or data, and to interpret data), to imagine what might happen, and to understand that scientific facts are based on different arguments, evidence, or methods of interpretation by known scientific knowledge, scientific concepts and methods of exploring science" (Ministry of Education, 2018, p. 4). These descriptions imply that teachers' pedagogy should be focused on helping students to build on their science inquiry experience.

Pedagogy to Promote Inquiry

Educational researchers have developed a variety of instructional strategies and curricula to promote students' scientific inquiry practices and help them think and act like scientists when exploring the world. Examples of strategies are discovery learning that enhances students' inquiry abilities (Bruner, 1961), inquiry-based learning with different levels of teacher guidance (Banchi & Bell, 2008), problem-based learning (PBL) (Hmelo-Silver, 2004), and others. Collectively, these strategies aim to promote competencies such as generating questions, making predictions, designing and conducting experiments, modeling, applying and evaluating (White & Frederiksen, 1998).

Further, there is an extensive body of research on scaffolding learning in inquiry (Collins et al., 1989; Davis & Linn, 2000; Jackson et al., 1996; Reiser, 2004; Toth et al., 2002). Both theory-driven and empirically based design guidelines for incorporating effective scaffolding strategies have been developed to support learning (Hmelo-Silver & Barrows, 2006; Quintana et al., 2004; Reiser et al., 2001).

Most studies of inquiry-based learning are based in classroom settings and focus on single subjects such as biology, physics or chemistry (Bybee et al., 2008). Furthermore, many inquiry education initiatives take many hours or even days to carry out. This means that the research on inquiry-based science education is not immediately applicable to museum visits, which often take less than 2 hours and, in the case of school programs, rarely involve laboratory settings that allow for experimentation and hypothesis testing. How can the strategies for inquiry-based science education be translated to the science museum setting to prompt inquiry among visiting school groups?

Facilitating Inquiry in Museums

Since the 1990s, numerous studies have focused on learning in museums. Falk and Dierking (2000) presented the influential Contextual Model of Learning which suggests that museum learning results from the interaction between learners' social, personal and physical contexts. This emphasis on the learner as well as the setting is also apparent in Stocklmayer and Gilbert's (2002) personal awareness of science and technology (PAST) model which describes how effective learning can result from interactions between visitors and exhibits. Other researchers (Hein, 1998; Russell, 1994) ground their notions about museum learning more explicitly in constructivism, suggesting that museum learning is the result of direct or indirect interaction with museum staff members. Direct interactions refer to face-to-face interactions, while indirect interactions refer to interactions with staff members' thoughts, manifested through exhibits. Other perspectives based on constructivism suggest that museum learning results from the interaction between exhibits (representations of knowledge), identity, and learning environment (Abu-Shumays &

Leinhardt, 2002; Leinhardt & Knutson, 2004). Collectively, these studies point out that museum learning occurs when visitors interact with exhibits, museum staff or peers.

In many science museums, docents take the role as the point of human contact for visitors, especially for school classes on field trips, who are routinely led on guided tours through the exhibitions (Cox-Petersen et al., 2003). The discourse of the docents thus becomes part of the museum learning experience and influences how and what students learn. Studies show that although school groups may express satisfaction with docents' guided tours, they do not necessarily feel that the guided tour was a learning experience per se (Cox-Petersen et al., 2003; Davidson et al., 2010; Kisiel, 2010). Other researchers suggested that museum educators played an important role in turning school field trips to a "learning activity". Cox-Petersen et al. (2003), Kisiel (2010), Tran (2007) and Yeh (2017) found that docents' pedagogy and their goal for science learning contributed to students' learning and concluded that the docent's personal interest in science and their museum-learning experience diversified their teaching practices.

Other studies explicitly studied the scaffolding of learning in science museums. Gutwill and Allen (2010) provide several guidelines for educators to facilitate deeper thinking in visitors while they operate hands-on exhibits. Yoon et al. (2013) investigated six different combinations of scaffolding for an interactive science exhibit which introduced concepts of electric circuits and found that only the highest scaffolding condition could help students to experience deep cognition such as forming theory. However, under this condition, students performed fewer informal engagement behaviours, such as touching or watching exhibit, and peer interaction for how to manipulate exhibit. Other studies affirm that learning science concepts or inducing deep learning in informal settings requires deliberately designed interactive exhibits (Han et al., 2016) or scaffolded learning activities (Achiam et al., 2016; Scott, 2010).

For instance, Achiam et al. (2016) studied a school program in a natural history museum which involved objects from the collections. These researchers showed that the objects, the museum educators and the research question collectively scaffolded learners to carry out paleontologically authentic inquiry activities. Scott (2010) organized a forum to help visitors' reflective thinking about what they had seen in hominid dioramas and what their observations implied about the origins of humans. Though both studies observed how educator-led activities enhanced visitors' inquiries about objects and exhibits, the scaffolding visitors received was based on how the science discipline in question observes, reasons and concludes to produce science knowledge. In particular, the questions which the visitors dealt with were so-called tame problems, that could be pursued through the academic framework to find solutions and that did not present conflict or dilemma in these solutions.

Inquiry in Museums: The Benzene Ring Heuristic

As demonstrated in the preceding, it is difficult for science museum educators to find one instruction guideline to promote inquiry in interactions between individuals and exhibits, and at the same time, in interactions between peers. In fact, in the present case, when NMNS worked to adapt the inquiry approach in order to develop its education program, the result was quite similar to what would be considered inquiry in the formal science classroom.

Erduran and Dagher (2014) proposed a visual heuristic, the benzene ring heuristic of scientific practice, which aims to take the often-disparate theoretical accounts of scientific practices and synthesize them into a whole. The heuristic clarifies several science practices that are prevalent across international science curricula (classification, observation, and experiment) and their relationships among cognitive, epistemic and discursive practices of science. The benzene ring heuristic of scientific practice categories practices into six families: real world, prediction, explanation, model, data and activities. In the model, these six practices are connected like six carbon atoms in a benzene ring, while the social contexts (such as discourse, representation, reasoning and social certification) of scientific practice can be thought of, metaphorically, in terms of the diffuse pi bonds of the benzene ring (Fig. 6.2).

This model presents the science inquiry practices at the same level of importance and without a rigid sequence and illustrates how these inquiry practices are enabled by the social practices of reasoning, representation, discourse and social

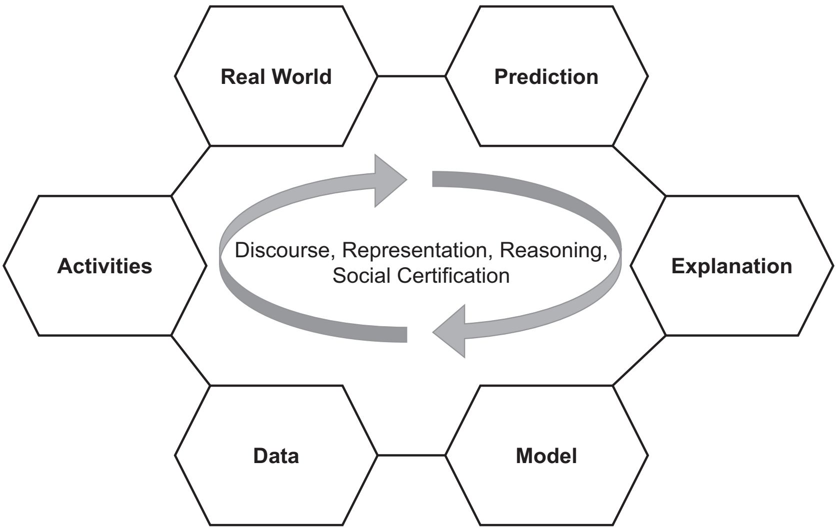


Fig. 6.2 The "benzene ring" heuristic of scientific practice. (Picture redrawn from Erduran and Dagher, 2014, p. 82)

certification. This model also points out how these social factors function in between the inquiry practices.

The hypothesis of NMNS was that the benzene ring heuristic of scientific practice could guide the scaffolding of visitors' connections to dioramas and their thinking about socio-scientific issues. While the real world provides a problem space for visitor' inquiry, the dioramas provide clues as data sources; as a result, visitors can make their explanations by way of social interactions (discourse, representation, reasoning, social certification). Accordingly, this study combined inquiry with dioramas in an education program. In order to deal with real-world socio-scientific issues, the program focused on visitors' decision-making about the wicked problem at stake, rather than their explanation of the phenomena they can observe in the dioramas. Thus, in the development of the program, the term "justification" replaces "explanation" in the benzene ring heuristic.

Study Process

In the following, the case study is presented in two parts. The first part illustrates the development of the inquiry scaffolding program which related the observation of dioramas with a socio-scientific context. The second part details the implementation of the program in a series of teaching trials.

As mentioned, the development of the program is referred to the benzene ring heuristic of scientific practice (Erduran & Dagher, 2014). To get an initial idea of teachers' conceptions of scientific practice, I (the author) carried out informal interviews with five museum partner teachers. In these interviews, I drew the benzene ring heuristic to elicit partner teachers' responses to the aspects of science inquiry that we would aim to prompt in the prospective museum program. All interviewed teachers agreed that the program should include observation, prediction and explanation. Subsequently, I carried out a literature review of the specific real-world problem and my initial ideas for related activities and explanations through the following questions:

- What are the socio-scientific issues related to development of new energy sources?
- What do students observe from dioramas?
- How do students associate their past awareness of science and technology with their observations and construct explanations for their decision?

Based on the results of this review, the program was designed. In the second part of the study, I included three different age groups in a series of teaching trials: 10-year-old students, 16-year-old high school students and 19-year-old college students. For each age group, two classes participated. There were 134 students in the trials in total. Two partner teachers helped me observe students' behaviour while they interacted with the diorama or engaged in group discussion. The two teachers would watch each group for 3 minutes and fill out a behaviour checklist.

Dioramas in NMNS

Dioramas are one of the main focus points at the National Museum of Natural Science, Taiwan. The museum had dioramas constructed based on pictures of different ecological environments. Generally, in natural history museums, dioramas show relevant ecological contexts: interactions between both individuals of the same species and those of different species as well as their environments and innate nature. Dioramas are an important part of the museum experience as they encourage visitors to discuss what they see. In this gallery, dioramas create an environment in which the visitor is no longer a passive viewer, but an active participant, stimulated to not only think about the exhibition's content but also to ask questions about it. For this reason, dioramas are a highly suitable means of introducing all audiences to the work of a natural history museum (Neitscher & Weon-Kettenhofen, 2019).

There are four types of diorama in the National Museum of Natural Science: The Carboniferous environment, the anthropological archaeological excavation site, the reconstruction of prehistoric human life style and the ecologies on Earth. These dioramas were designed to help students learn those concepts which they out of their own experience could imagine.

The Carboniferous diorama provides a visual presentation about how the environment looked and how – to our eyes – strange creatures inhabited it. The diorama of the anthropological archaeological excavation site shows students how archaeologists collect specimens, and the prehistorical dioramas present what archaeologists infer from these archaeological specimens. Finally, the ecological dioramas represent concepts about food chains, protective coloration, animal adaptations to the environment and environments that are different from where students live.

The ecological dioramas are located in two exhibit areas: Colour in Nature, and Life on Earth. The exhibition Colour in Nature opened in 1988 and includes nine dioramas designed to introduce colours in courtship, warning colours and protective coloration in different ecologies. These dioramas were created to introduce specific biology concepts. The selection, distribution and positioning of animals and plants in the dioramas was based mainly on academic concepts, and it was difficult to construct alternative interpretations for them in order to employ them in the program. On the other hand, Life on Earth (completed in 1993) includes eight dioramas of the ecosystems of the world: Canadian Tundra, Manchurian Temperate Forest, East African Savanna, Sonoran Desert, Borneo Mangroves, Galapagos Coast and Costa Rican Rainforest. These dioramas thus reproduced several ecosystems with the potential to relate to the real-world problem of developing new energy sources (Fig. 6.3).

The dioramas utilized for this study are thus the ecological dioramas which are located in Life on Earth. Each diorama located in this area has the following dimensions: 5–6 meters height, 8 meters width and 6 meters depth. These lifelike environmental replicas were created with mural backgrounds, models and specimens. The exhibit brochure introduces the general idea of the dioramas: "Lively audio-visual presentations and detailed exhibit panels highlight the characteristics of each of the

Fig. 6.3 The entrance of “Life on Earth” gallery

ecosystems. The goal of Life on Earth is to create a renewed respect for life in the hope that people will cherish all living creatures”.

Life on Earth: Focus on the Animal Adaptation to the Environment

Two study sheets already existed for this exhibition hall: *The Adventure of Kitty* (for ages 5–8) and *Why They Lived Here* (for ages 12 and above). The two study sheets had been created in collaboration between museum staff members and school teachers. The content of the sheets refers to the training material for guided tours of the museum, authored by the museum scientists and the gallery design company.

Both study sheets involved three dioramas in Life on Earth: Canadian Tundra, Manchurian Temperate Forest and East African Savanna. The instructions on the study sheets indicate the focus of observation (animals, ground, plants, etc.) and guide learners’ inferences about the climate and animal adaptions in each diorama. *The Adventure of Kitty* presents the comic figure Kitty as a protagonist to inspire students’ inferences about the temperature, humidity and animal adaptions in each diorama. The study sheet *Why They Lived Here* includes an objective narrative with spaces where learners can fill in their inferences about the climate of the three dioramas, based on, e.g. the latitude, the shape of the trees or the morphology of the plants and animals in each diorama. Teachers often focus on whether students find all the correct answers to the questions on the study sheet rather than whether students can find their answers from observing the dioramas. Although these two study sheets were published in 1993, they are still popular among school teachers.

The study sheets were utilized in the implementation of the program in order to accomplish the following goals: to ensure that students noticed specific species in each diorama; to inspire students to notice the relation of all objects in the diorama; and to compare the conditions between different dioramas. Because the tasks in the study sheets all concentrated on ecology, by extension I hoped engaging with the study sheets would enable students to identify suitable environments for specific natural power facilities and prioritize different power generation facilities based on their observations and discussions.

The Natural Power Transformation Clues in the Dioramas

Each diorama is equipped with an exploratory panel on the handrail in front of it. The plate gives a brief introduction to the geographical information, annual rainfall, temperature and specimens in the diorama. Together with the dioramas themselves, the information given in the plates can be used to make inferences about the fit between the environment in question and the various natural power facilities (Table 6.1).

The Education Program

The education program designed as part of this study was based on learners' work in groups. Each group was tasked to find one natural power source to work with. Subsequently, each group was tasked with identifying the most suitable ecological setting (i.e. diorama) for the natural power they chose and convincing the other groups to support their recommendation (Fig. 6.4).

The specific nature of the inquiry that could take place in the exhibition differed from what was possible in the science classroom. In the education program, there was no extra time, nor did the Museum make devices available for students to gather more information from the internet or reading. Students were only able to find evidence for their reasoning by observing the diorama. The educator shared the real-world problem with students, while the activity provided the scientific practice ("what you can see in the diorama?") and generating a justification prompted students' social interactions ("how do you interpret what you have seen?").

Generally, inquiry activities in the science classroom often provide the learners with the chance to gather more data though experimentation, acquiring more information by reviewing relevant texts. The well-defined data generated in this way often becomes clear evidence to support a hypothesis or show a clear trend. However, in the program, the available scientific and socio-scientific inquiry practices were checked against the benzene ring heuristic of scientific practice. The inquiry components included in the program were real world, prediction, explanation (replaced

Table 6.1 The clues present in the dioramas and resulting fit with the various natural power facilities

Diorama	Possible natural power source	Observation	Reasoning
Canadian Tundra	Wind power	1. No forest on it 2. Rocky field 3. Arctic area – high latitude	1. Wind too strong for plants to grow high 2. Sunny less than 6 hours in autumn and winter
Manchurian Temperate Forest	Hydraulic power	1. Forest with stream went through the area 2. Mural makes forest seem to be located at bottom of canyon	1. Wind is not always strong 2. High latitude; sunshine less than 6 hours in autumn and winter 3. Potential to become reservoir catchment area
East African Savanna	Wind power Solar photovoltaic	1. Sparse trees 2. Low latitude	1. Possible windy steady 2. Sunny throughout year
Sonoran Desert	Wind power Solar photovoltaic	1. Sandy landscape 2. Looks dry and sunny	1. Wind may be strong 2. Desert; sunny
Borneo Mangroves	Hydraulic power	1. Mural indicates mountain separating the ocean.	1. Tidal difference could indicate potential for hydroelectric power
Galapagos Coast	Wind power Hydraulic power	1. No plants on cliffs 2. Water looks deep	1. Coastline with strong win 2. Tidal difference could indicate potential for hydroelectric power
Costa Rican Rainforest	None	1. Trees grow tall and dense 2. Land is rugged and not very extensive	1. The wind might not be strong 2. Sunlight does not reach the ground 3. No conditions for hydraulic power

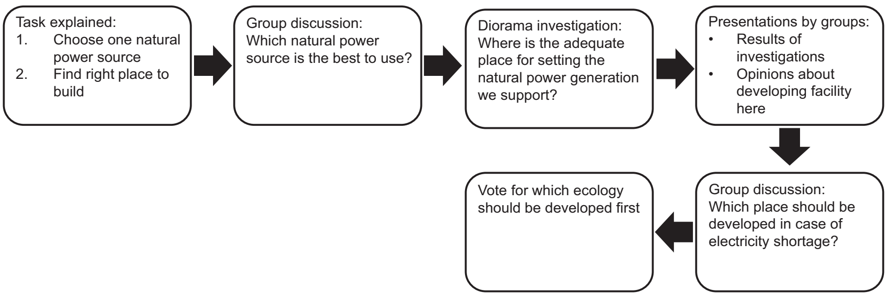


Fig. 6.4 The first iteration of the education program

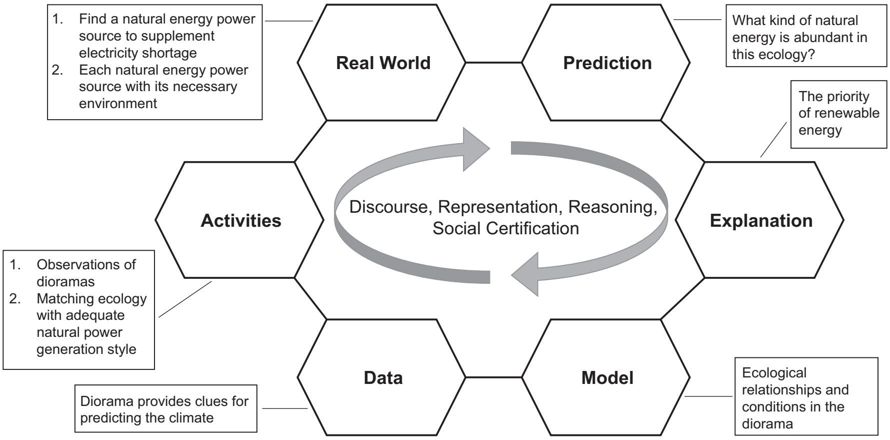


Fig. 6.5 The learning task presented by the benzene ring heuristic of practice

by justification), data and activities. These components are connected in the program by representation, reasoning, discourse and social certification (Fig. 6.5).

Teaching Trials

The education program was a 90-minute activity, run by one museum staff member. In the seven teaching trials, I (the author) ran the activity. Two partner teachers made observations during the trials, taking turns observing each student group for 3 minutes to see to what extent students engaged in task discussions and what kinds of difficulties might arise. There were four classes of fifth graders (10-year-old students; total 96 students), two classes of tenth graders (16-year-old students; total 60 students) and 26 college students (20-year-olds) participated in the teaching trials in 2017.

The students participated in the education program while their class visited the science museum. Before each class visited, I had a 1-hour discussion with their teacher about the exhibition inquiry process and their opinions and advice. All the interviewed teachers appreciated how the education program focused on students' observations, discussions and justifications, but they are worried that those of their students with insufficient background knowledge would not be able to concentrate on the tasks. A week after their visit, I interviewed the teachers again, this time at their school. The purpose of the follow-up interviews was to elicit teachers' opinions and suggestions about the program design, students' performance in the program and the possibility of integrating the program with science or other subject teaching.

During the activity, each class was divided into five groups. As part of the activity, the groups made posters outlining their decision as well as their comments to other groups. After each trial of the education program, these posters, my field notes and the teachers' opinions were used as input to refine the program. Furthermore, in the teaching trials, I predicted that the older students would have sufficient science knowledge to accomplish the learning task. Accordingly, the information I got from older students' trials could be used as feedback to refine the program design for younger students as well as indicating the content knowledge required by the program tasks. This is why the two tenth grade classes participated in teaching trials based on the refined program of the college students, and the fifth grade students participated in trials of the refined program of the tenth graders.

College Student Teaching Trial

The initial teaching process of the program consisted of six separate tasks (Fig. 6.4). As mentioned, 26 college students participated in the initial version. These students had finished introductory physics, chemistry, Earth science and biology courses. First, I introduced the necessity of getting energy from natural energy sources and listed five natural power generation facilities which are often mentioned in the media. Students were asked to choose one natural power generation facility based on their group discussion. Then each group had 30 minutes to investigate all dioramas to decide which diorama was the optimal place to locate the natural power facility. This was followed by a 5-minute group presentation about their suggestions and the reasons. After all these presentations, each group engaged in a brief discussion about their final decision for which ecology (i.e. diorama) they had agreed on and voted on their final answer.

Even though the college students had substantial science training, they seemed to have somewhat vague ideas about the science of the different ways of collecting energy from natural power sources. In the first group discussion session, four groups decided to choose solar photovoltaic and one chose wind power. According to the observers' field notes, in their discussions about developing natural power sources, college students felt that "the solar photovoltaic was easy to place and could be utilized almost everywhere" and they thought "if there was any impact to the environment, such as threats to animals' habitats, the facility could be removed without any adverse effects". During the discussion, none of the groups mentioned hydroelectric power or tidal power.

During their investigation, the four groups who had chosen photovoltaic power walked past the dioramas fairly swiftly. According to the observers' notes, the gist of the students' reasoning was that "solar photovoltaic panels could be placed anywhere, let's find a place without many animals". Thus, their considerations of the best location seemed to be based on impacting as few species as possible.

The group that had chosen wind power generation quickly targeted the Borneo Mangroves as the best place for wind power farm, possibly because wind turbines are commonplace along the middle Taiwan coastline. One member of the group stated "the blades produce a low-frequency noise that bothers the residents", and another student shared their thought on another adverse effect of wind turbines: “those blades would intrude on birds’ flight paths”. Though the group’s members thus explicitly associated wind power with negatives, the group still decided to develop wind power in a mangrove ecology.

One of the observers noticed that several students used their smartphones to search online, apparently looking for evidence of the development of natural power facilities at the same latitude that was represented by the diorama. In these searches, the key words they used were the name of the diorama, natural power facility types and latitude. When the observer asked the students what information they were looking for, the students answered “I want to see whether this place had this specific natural power facility already” or “I just looked for more climate characteristics about the place”.

Even though all five groups made a final decision as to which diorama was the most suitable for their chosen natural power plant, they still suggested *not* to construct a natural power plant there. The most important reason stated by the groups was that “all these dioramas have endangered species”. At the end of the program, all groups were aware of that there was a tension between an “electricity supply from natural power” and “the conservation of ecological environment”.

Based on the first iteration of the program, the college teacher had two suggestions for changes:

1. The program should provide more science about the natural power generation facilities for participants.
2. The first group discussion should be cancelled. Instead, participants should be *assigned* the natural power for them to investigate.

Furthermore, the field notes showed that students had several persistent interpretations about the animals in the dioramas. One interpretation was that the animals represented as part of the environment shown in the diorama were part of a sizeable population. This conception is evident in statements such as “you could find [these animals] anywhere in this area”. Another interpretation was that the animals shown together in the dioramas are animals that are closely linked together in nature. This interpretation is manifested in statements such as “these animals are part of a food chain in the ecology, and any human construction will damage this food chain”.

Tenth Grade Student Teaching Trial

Following the teaching trial with the college students, the protocol for the program was refined according to the college teacher’s suggestion and the observers’ notes (Fig. 6.6). At the beginning of the revised program, I introduced the overall assignment and introduced the science concepts that were related to the five different natural power facility types. Then each group was assigned one natural power source

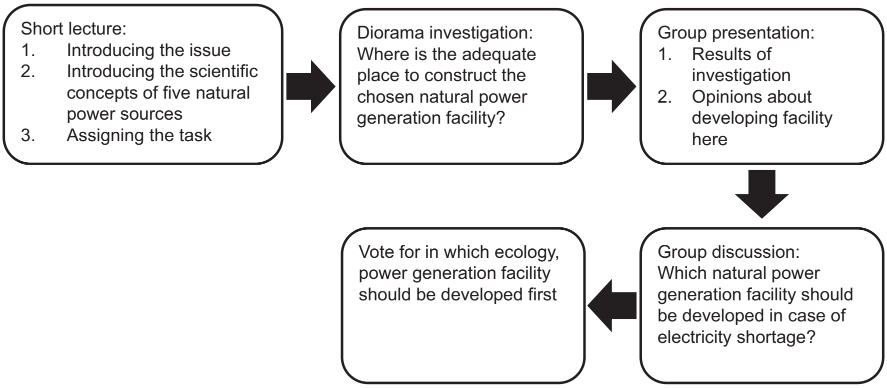


Fig. 6.6 The second iteration of the education program for high school students

Table 6.2 Tenth grade students' responses with an assigned natural power source

Natural power	Diorama	Reasons	Justification of development facility in this ecology
Hydroelectric plant	Manchurian Temperate Forest	1. Many trees, trunks with moss 2. Only diorama with stream in it	Initial disagreement to develop this area, due to: 1. Construction requires removal of trees 2. Construction would destroy animal habitats
Tidal hydroelectric plant	Borneo Mangroves	Coastal area with tides	Initial disagreement to develop this area, due to: 1. High diversity of species in mangroves 2. Mangroves are threatened
Wind power plant	Canadian Tundra	Few trees, uncertain winds Low diversity of species	Agreement to develop this area, due to: Low species diversity
Solar photovoltaic plant	Sonoran Desert	Many cacti, indicating little rainfall	Initial disagreement to develop this area, due to: The construction will damage habitats of some species
Solar thermal plant	Sonoran Desert	Desert climate, probably hot	Initial disagreement to develop this area, due to: Human construction would impact desert animals

and subsequently investigated each diorama to evaluate where that natural power facility was the best fit.

The results of the tenth grade students' discussions are presented in Table 6.2. They show how students were capable of associating the landscape depicted in the diorama with reasoning about the requirements and conditions of specific natural power facility types. However, the tenth grade students had a consistent misunderstanding of solar power, namely, that a high ambient temperature can be converted to solar thermal power, while dry conditions are ideal for the production of abundant solar photovoltaic power. In fact, solar thermal power is collected using high heat capacity fluid and could thus theoretically be employed in high latitude areas where the climate is cold. Students had few considerations of latitude when they discussed the solar photovoltaic power; they related this kind of power generation with the number of sunshine hours and the angle of the sun's rays.

The observers' field notes show that students quickly ruled out the places that were obviously unsuited to the natural power source they had been assigned. For example, one group member exclaimed "this diorama has no river in it, it's impossible for hydroelectric power". Once the groups decided on a diorama with the required conditions for their natural power source, the members stayed longer in front of the diorama and discussed the animals that lived there, e.g., "Look! There are crabs and clams under the root of mangroves…". Before the time for their investigation was up, they would take a quick look at the other dioramas, paying attention to special plants and animals in the diorama and the number of animals in that particular ecology, e.g., "… the desert has so many animals". These conversations during their quick visits to other dioramas had more discursive elements of social interaction than were observed in their on-task behaviour. However, it is beyond the scope of this study to ascertain and discuss the functions of these social interactions.

It is interesting that students wanted to avoid infringing on the ecological environments represented by the dioramas. There seemed to be a discursive assumption embedded in the students' minds: that all human construction will endanger the ecological environment, and the best solution is to do nothing to them. It seems students did not associate the progress of technology and engineering with minimizing impact to the environment, nor did they consider that lowering human electricity consumption might reduce the pressure to impact or even destroy these environments.

The Fifth Grade Teaching Trial

There were four classes of fifth graders from the same primary school, a suburban middle size[1] school located in a zone of Taichung City with reduced access to cultural offers. Thus, there are no art galleries, museums or public libraries in the school district. Each class had equal number of boy and girls.

In the pre-visit meeting, the teachers of the four classes were informed about the protocol of the education program. The teachers suggested that each group be assigned a diorama and tasked with proposing a natural power facility for that environment. The teachers expected their students to observe their assigned diorama carefully.

[1] The elementary school with less than 300 students was defined as small size school. Schools with 301–900 students were defined as middle size schools.

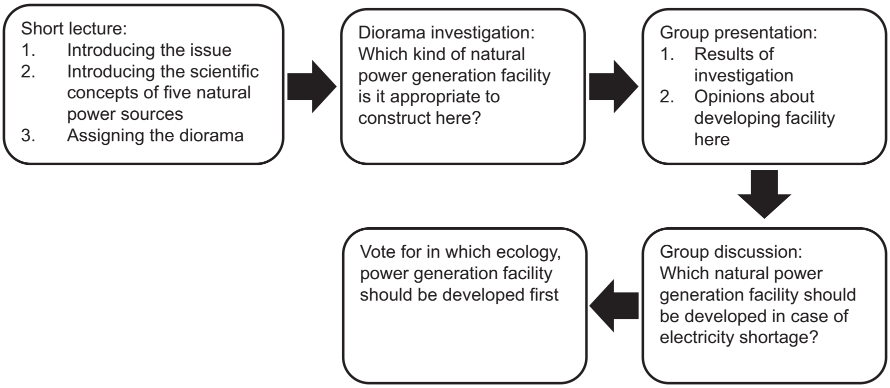


Fig. 6.7 The third iteration of the education program for fifth graders' trial

A second suggestion made by the teachers was for the group presentation to include an introduction of their assigned ecology (i.e. diorama) to the other students and an explanation of the reasoning behind their choice of a natural power facility. The program protocol was modified according to the teachers' suggestions (Fig. 6.7).

The fifth graders' responses to the modified program are summarized in Table 6.3. The students were well able to associate the clues in the diorama with the natural environmental characters and suggest suitable natural power facilities. However, there were some misunderstandings among students, namely, that a high ambient temperature means higher potential for solar photovoltaic/thermal power generation and that cold climates and plains areas have strong winds.

According to the observers' field notes, the fifth grade students took the task seriously. The students had to prepare an introduction of the diorama to their fellow students; this prompted them to look for information from all resources: label text, multimedia devices and the diorama itself. As a result, these students read label texts and watched the available videos much more carefully than was the case with the tenth graders and the college students. Furthermore, the group members stayed together as a group until they had completed their poster for the presentation.

On the posters, students outlined their introduction of the diorama as well as their reasoning for choosing the natural power facility. Just like the more senior students, the majority of fifth graders chose to develop the environments represented by dioramas with few animals. The students considered trees to be effective at cleaning the air by removing pollution and at fixing extra carbon dioxide from air. Thus, cutting down trees was considered to be a bad choice. Even though the revised program restricted students to work on just one diorama, they engaged in the task with enthusiasm. For example, group members would read aloud the label text which they felt useful to help the group member responsible for note-taking. Some group members watched the multimedia program, chose different sections and reported to the group.

Table 6.3 Fifth grade groups' responses to alternative energy and reason

Diorama	Natural power generation facility	Reasons	Judgment of development facility in this ecology
Canadian Tundra	Wind power	The animals found here are furry; thus environment might be cold and windy It is too cold to make solar photovoltaic	Agreement to develop this area, due to: 1. Low biodiversity 2. Few trees 3. No threatened species
	Solar photovoltaic	High latitude area with long sunshine in summer No forest here; so good for solar photovoltaic	
Manchurian Temperate Forest	Solar photovoltaic	Here looks not good for using all kinds natural power, put solar photovoltaic plate on tree tops might barely use	Disagreement to develop this area first, due to 1. To setting facility here needs to remove a lot of trees 2. Tigers are international conservative species 3. There is no adequate facility
	No adequate choice	1. Too much trees would shadow the photovoltaic 2. High latitude place with short day time, it is not good for photovoltaic 3. No strong wind made forest growing densely 4. River is not big enough to set hydroelectric generator.	
East African Savanna	Wind power	There were not many trees, winds might strong here There is space between wind power generators which could let animals moving. Solar photovoltaic plates will become barrier for animals moving	Disagreement to develop this area first. Reasons: 1. There are lot of animals living in 2. Most of the animals live here are international conservation species 3. The populations of animals are large and they need a big area to finding foods. Setting facility here would damage these living things
	Solar photovoltaic	No more tree and mountain to shadow the sun There is often drought in African regions, suitable for using solar photovoltaic	

(continued)

Table 6.3 (continued)

Diorama	Natural power generation facility	Reasons	Judgment of development facility in this ecology
Sonoran Desert	Solar photovoltaic	The only abundant plant is cactus. The sun is strong here	Agreement to develop this area first Reasons: 1. The species of animals and plants are not so many 2. Solar photovoltaic plates could provide shelters for animals living in desert 3. It is no harm to this ecology
Borneo Mangroves	Wind power	Coastal lines are windy The mangroves are not tall; the wind might be strong here	Disagreement to develop this area first. Reasons: 1. Wind power facility would bother the activities of waterfowls 2. It is necessary to remove a lot of mangroves; mangroves are conservation species

Each class had at least one group that proposed the idea of reducing power consumption rather than constructing new power plants that would potentially endanger natural environments.

Discussion and Conclusion

The participants of the three different age groups in this study had different levels of awareness of the tension between generating power from natural power sources and environmental protection. Students of all three age groups seemed trapped by the presupposition that all wildlife should be protected and that cutting down trees is not a good choice. Taking this viewpoint, the logical conclusion is that there are no suitable locations for natural power facilities. Only the fifth grade (10-year-old) students proposed to decrease electricity consumption to avoid endangering or destroying the environment; students in older age groups did not consider this response. Irrespective of whether students chose to decrease electricity consumption to protect the environment or to develop more power plants to satisfy the requirements of human society, they all needed to consider the consequences of these options in making their decision. However, there was no shared discussion that compared the implications of different decisions in the seven teaching trials. The tension between human societal needs and natural environment conservation is a serious problem worth discussion. As a result, in future iterations, this education program will include “lower electricity consumption” as an alternative option for students.

The teachers involved in the teaching trials expected the program educator to offer more substantial scientific knowledge about natural power plants. The teachers believed their students lacked the understanding to assess which natural power plant was suitable for the environments represented by the specific dioramas and seemed more concerned about whether the students arrived at the right or wrong answer to the task than how the students observed, reasoned and justified their responses. This attention to the right or wrong answer was shared by the participating college students, who used their mobile phones to google for clues for their exploration task; indeed, they were not searching for information about the climate conditions related to the requirements of natural power production, but rather for evidence of already established natural power plants. Thus, these 20-year-old students tried to make sure they got the educator’s “correct answer”.

The culture of the “correct answer” is a barrier to the efforts of science museums to “help the public to have more confidence that they can address the issues facing them and not rely solely on politicians and policymakers” (Dillon, 2017). The politicians, policymakers and academic authorities (such as scientists) are the “right persons” who could suggest issues and the way to face them under the “right answer culture” (Garvin, 2001). This might be the reason why students in this study voted for options that they did not think were the best. In one of the tenth grade groups, several members assessed wind power in a negative way; yet the group still proposed wind power as the best natural power. However, the observer was not able to shed light on how they made their decision. It is possible that the group leader could have been instrumental in prompting the “right answer”. In contrast, the discussions of the fifth graders were more open and less focused on the “correct answer”, even though (or perhaps because) they were scaffolded at a much higher level than those of the high school and college students. The fifth graders’ discussions included the viewpoints of each group member and seemed independent of providing their own “correct answer”. It could be hoped that this program though its careful iterations helps the younger generation in our society understand and address important issues by themselves. Instead of accommodating teachers’ requests to identify the right answer, the curator persuaded the teachers to encourage the students to keep inquiring, following the benzene ring heuristic of science practice: to help students understand what data is needed to answer the question and to collect these data, construct explanations and then decide.

In this education program, the iterations of the tasks served to scaffold students’ awareness of how each natural power source was connected to specific requirements of the ecological environment. What kind of questions helped participants focus on making decisions related to environmental protection? How could the educator create an atmosphere for students to become aware of their discursive logical reasoning or misconceptions, while discussing the socio-scientific issue? In the program, the information for reasoning and judgement came from the dioramas. Indeed, there existed the pitfall: In dioramas, animals are necessarily present in a very limited area. Even though the dioramas aroused students' passion toward valuing biodiversity, a fruitful next step in adjusting the education program would be to refine the oral scaffolding to help students become aware of the misconceptions induced by the dioramas and proceed to make their best decision.

Acknowledgements This study was funded by the Taiwan Ministry of Science and Technology project no. MOST-107-2511-H-178-001. The author thanks the anonymous reviewers and Marianne Achiam for comments on earlier versions of the article.

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Chapter 7
Who Benefits from the Natural Gas in Israel? Using a Public Debate to Teach All Components of Education for Sustainable Development

Hagit Shasha-Sharf and Tali Tal

Prologue

For decades, the almost only natural resource in Israel was the Dead Sea. As early as under the British Mandate (1917–1948), before the establishment of the State of Israel, the Dead Sea was the source of minerals which became the country's main industrial export. Over the years, generations of Israelis were taught that due to its lack of natural resources, the country's human resources needed to be cultivated and nurtured, until natural gas was found off the Mediterranean Sea roughly 20 years ago. Since then, the natural gas debate has spiralled into endless conflicts touching on the economy, trade, foreign relationships, and the environment. Given this ongoing social-economy-environmental public controversy, we wondered whether and how the natural gas blessing/curse is addressed in the school curriculum. The response was immediately apparent: the socio-scientific controversies do not appear anywhere, although thousands have protested in the major cities of Jerusalem, Tel Aviv and Haifa, and called for socio-environmental justice in terms of gas distribution and export. This prompted us to write the learning unit (LU) described in this chapter. We then provided it to high school environmental sciences teachers, hoping they would use it to teach about environmental economy. Although teachers liked the LU, to our disappointment, a senior science official at the Ministry of Education criticized the unit saying it "contains too many non-science topics."

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M. Achiam et al. (eds.), *Addressing Wicked Problems through Science Education*, Contributions from Science Education Research 8,
https://doi.org/10.1007/978-3-030-74266-9_7

Introduction

What can be learned by exploring governmental decisions on the use and distribution of natural resources? This question prompted us to concentrate on ways to educate students, as future citizens, on what is known as the "wicked" problem of exporting Israeli natural gas. In this chapter, we present the issue we used to develop a learning unit (LU). This short (8–10 h) unit was designed to be taught in various contexts including classrooms as well as in informal settings such as after-school clubs, science or environmental education centers. It can also be integrated into science, social studies, and civics education courses. This chapter describes the utilization of the LU by environmental sciences teachers teaching in public high schools in Israel, during a 60-h professional development program and how their argumentation and decision-making evolved.

Context: The Natural Gas Debate

Public debates on natural gas have been ongoing in Israel since its discovery (Cohen, 2018; Shaffer, 2011). One of the key issues has to do with the government export policy, which reflects the sustainability dilemma between the long-term utilization of a non-renewable natural energy resource (an inter-generational question) and the current diverse economic interests (an intra-generational question). Energy use is also crucial in terms of its impact on society, the environment, and the economy. While commonly taught as a scientific concept in the physical and life sciences, the science curriculum fails to deal with social, environmental, economic, and ethical factors impacting clean energy today (Sakschewski et al., 2014). Drilling for natural gas also entails planning and engineering problems, which have an environmental and social impact and engender conflicts related to resource distribution and social and environmental justice – all of which involve cost-benefit decisions. Although all are important, we concentrated on the least well-studied facet of sustainability – the economics.

Certain features of the natural gas export issue share much in common with what are known as socio-scientific issues (SSI). SSI, which are widely studied in science education, represent important social issues that are conceptually related to science (Sadler et al., 2007), have a basis in science, and involve forming opinions and making choices at the personal and societal levels (Ratcliffe & Grace, 2003). The Israeli natural gas export dilemma can be characterized as an SSI in that it is ill-structured, has no clear-cut solutions, is controversial, can be considered from a variety of perspectives, involves risks and uncertainties, and cannot be settled by simply appealing to evidence (Levinson, 2006; Ratcliffe, 1997; Sadler, 2004, 2009; Sadler & Zeidler, 2005; Sakschewski et al., 2014). The scientific knowledge related to the natural gas export debate is multidisciplinary and encompasses a wide range of fields including energy, technology, the environmental sciences, economics, and political science. The term "wicked problem" is used by scholars to emphasize serious social challenges that span multiple domains (social, economic, moral, aesthetic, political) and are closely related to other problems. Wicked problems do not have finite or unambiguous answers, but in dealing with them, other interesting questions emerge (Levinson & The PARRISE Consortium, 2017; Sadler et al., 2017). The LU we developed was informed by research on SSI where learners are engaged with a complex issue and are required to employ higher-order thinking in demanding tasks (Sadler et al., 2007; Sakschewski et al., 2014; Tal et al., 2011; Tal & Kedmi, 2006; Zohar & Nemet, 2002). A LU of this type can meaningfully contribute to education for sustainability. In the study that followed the development and enactment of the Natural Gas Distribution LU, we focused on the fostering of students' argumentation and decision-making processes to enable them "to identify science-related social issues, analyze the context in which the issue is played out in society, identify and know the key individuals and groups involved in making decisions and develop their own attitudes" (Tal & Kedmi, 2006, p. 619).

Science for Citizenship

Teaching controversial issues in the context of education for sustainable development and citizenship are acknowledged as core educational elements. It has been argued that the learning of controversial issues in school should help prepare future citizens to participate in conflict resolution and be scientifically literate: "Young people need to be aware of the nature of controversy and be able to see how arguments are constructed to sway our opinions" (Oulton et al., 2004, p. 489). More recently, Roberts and Bybee (2014) defined scientific literacy as the effort to cultivate a scientifically knowledgeable citizenry to take part in democratic decision-making processes of social significance. In Europe, the Science Education for Responsible Citizenship report by the European Commission (2015) stressed that citizens need to have a better understanding of science and technology if they are to participate actively and responsibly in science-informed decision-making and knowledge-based innovation.

Science education for citizenship is developing in different directions and includes actions aiming to enhance public understanding of science, actions aiming to increase diversity in the representation of science and in science and promote its democratization, actions aiming to increase citizen participation, and promoting the view of citizens and the public as stakeholders in the science-politics interface, which "can no longer be viewed as an exclusive domain for scientific experts and policy-makers only" (Bäckstrand, 2003, p. 24). Bäckstrand argued that in international relations, the science-politics interface has been framed primarily as a matter for scientists and decision-makers. Scientists inform policy-makers, and policy-makers turn to science for knowledge and technical assistance. Instead, she explained that the science-politics interface should include the citizens as well, who are not only recipients of policy but also active actors.

The relationships between science and society are also highlighted in the socio-cultural view of science which acknowledges the claim "that there is no such thing as 'pure science' and that science education should follow the way scientific investigation is subject to social, environmental and political considerations" (Tal & Kedmi, 2006, p. 619). When required to form an opinion on SSI or make a decision over and beyond the scientific evidence, one needs to take social, economic, political, ethical, and humanistic factors into consideration (Klosterman et al., 2012).

Argumentation and SSI

It is only natural that teaching science for citizenship through wicked problems or SSI perceives science as a social activity and considers its advancement to take place through thinking processes among people rather than by individuals. Not just theories but also what is defined as scientific evidence becomes structures of arguments, which need to be subjected to public debate (Kuhn, 1993). Thus, through argumentation, students can explore the scientific and other arguments which are raised in the context of SSIs in a critical fashion.

Due to the scope of this chapter it is impossible to fully address the extremely large body of research on the nature and the teaching of argumentation. We thus only we briefly address some key points about the nature of teaching argumentation.

For many years, most research on argumentation in science education has been carried out in the context of teaching SSI (Osborne et al., 2004; Sadler, 2004; Sadler et al., 2007; Zohar & Nemet, 2002) since contemporary developments in science and technology such as genetic engineering, reproductive technologies, and food safety often pose dilemmas for society, particularly where they are based on equivocal findings or contested claims whose resolution depends not simply on a knowledge of science but also on the application of moral and ethical values (Osborne et al., 2004). Kuhn (1993) argued that through learning and practicing, students can improve their evidence-based argumentation. She showed that students from less educated background perform poorly when asked to associate claims with evidence. However, Zohar and Dori (2003) reported that lower achievers improved more than higher achievers if they had the opportunity to practice higher-order thinking in their routine learning.

Learning through SSI engages students in various reasoning and argumentation processes and poses high processing demands on students, such as the expectation to develop the ability to reason from multiple perspectives (Kolstø, 2006; Ratcliffe, 1997; Sadler, 2009; Tal & Kedmi, 2006; Zohar & Nemet, 2002). More generally, Oulton et al. (2004) argued that the purpose of teaching socio-scientific issues should not be to enhance students' decision-making per se, but rather to help them understand the nature of controversial issues and to develop open mindedness, a thirst for more information, as well as the ability to identify bias and reflect critically.

The Local Wicked Problem of Exporting Natural Gas from Israel

The natural gas export dilemma refers to the major debate over preserving the natural gas resource for local use in Israel or exporting it to increase revenues and state income from taxes. Recently the conflict has been extended to include where to build the gas platform. This issue emerged after the development of the LU, but it illustrates how a wicked problem can expand, branch, and impact citizens' lives in ever-increasing ways. Furthermore, since first drafting this chapter, the beach across from where the platform has been built became a site for public gathering and protest and school field trips. It is more common to see field trips to a visitor center of a nearby power plant (still) operated by coal than seeing teachers bringing their students to observe and discuss the natural gas platform, 10 km away, which is easily seen from shore. However, the growing number of informal and formal visits indicates the presence of this conflict in Israeli policy. The dispute between a local organization "The Homeland Guards" that leads the protest against the gas platform and the Ministry of the Environment and other environmental organizations has become a unique opportunity for a informal science and environmental education volunteer scientists' group (Little Big Science) that has a website and a Facebook page, to push the envelope further and offer the public an ongoing platform to discuss evidence versus unsupported beliefs. The natural gas export question and later conflicts that stemmed from the wish to utilize this natural resource reveal complex "real-world" economic and environmental trade-offs. Understanding these trade-offs requires scientific and technological knowledge about the technologies (extraction, transportation, and the uses of gas), the marine ecosystem, and other environmental problems. One issue, for example, is air pollution: burning natural gas produces significantly less pollutants and greenhouse gases than other fossil fuels so that generating energy from natural gas for local industry and public transportation is expected to significantly reduce air pollution. This is an environmental benefit, but only in the short term. Does the discovery and exploitation of natural gas curtail efforts to develop more renewable energy, such as solar energy in a sunny climate? The question of who gains and who bears the cost is not simple, since there are many important factors involved. How can one decide and who should be involved in the decision-making processes?

A governmental committee formed in 2011 to discuss the natural gas export dilemma. It was charged with developing national policy regarding the discovery of Israeli natural gas reserves. Throughout its deliberations, local and international experts and stakeholders presented their views on the rights of different stakeholders; supply and demand forecasts; municipal plans for development; environmental, security, and defense risks; and market failures and benefits. Interest groups submitted their position papers and were later allowed to present their concerns in 20 public hearings. The committee submitted its official recommendations to the government in 2012. After substantial public protest and an appeal to the Supreme Court, a partially redacted version of the public hearings was released to the public in June 2013. In response to the public outcry, the Israeli government reduced the maximum quantity allowed for export from 53% to 40% (Fischhendler & Nathan, 2014).

The natural gas export dilemma encompasses two concepts that are central to its socio-scientific nature: *energy security* and *energy justice*. Originally, the energy security concept was associated with safety and resource diversification of fuels and services, but more contemporary notions capture various energy-related insecurities such as political and economic development (Cherp & Jewell, 2014; Fischhendler & Nathan, 2014). "Energy justice" is defined as a global energy system that fairly distributes both the benefits and burdens of energy services and one that contributes to more representative and inclusive energy decision-making. Heffron and McCauley (2017) showed that both energy security and energy justice are related and that any discussion of energy security should address three questions: "security for whom?", "security for which values?", and "security from what threats?"

The Learning Unit

The natural gas export dilemma was chosen for the development of the LU for a number of reasons: (1) The debate is well-documented by reliable sources and from various perspectives. (2) The natural gas export question reflects a sustainability dilemma, involving inter- and intra-generation resource distribution questions. Different views entail different arguments on energy, environmental, economic, technological, political, and justice issues in real life. (3) Learners need to cope with the question of export policy and develop awareness of the links between economic policy and its environmental and social consequences. (4) The challenge for learners in forming their own opinion involves *constructing knowledge* of the main components of the dilemma and *developing* awareness of the interests of different parties and (5) the need for *weighing* advantages and disadvantages of possible policies to *make a decision*. The dilemma raises (6) the need to *cope with uncertainty* and unknown consequences in the short and long run. It provides the opportunity (7) to *develop higher-order thinking skills of argumentation and decision-making*. Finally, (8) this dilemma that is branching to several other conflicts reflects the calls for science education for responsible citizenship, and more specifically it answers the call "to expand opportunities for science learning, in formal, non-formal and informal settings" (European Commission, 2015, p. 7).

Intuitively, the issue of exporting natural gas is associated with economics, but as we further explored the topic, we discovered there was a broad, complex, and interdisciplinary management issue related to energy resources. The economic aspects of energy issues are fundamental to their resolution, but they are also controversial, in particular from an environmental point of view. For the LU, we found these issues highly suitable for a meaningful environmental education that is interdisciplinary, occurs in real-world contexts, and is transformative in ways that encourage critical thinking and participatory learning that avoids indoctrination. As Robottom (2012) argues, teaching SSI "requires the adoption of curricular and pedagogical approaches that are in fundamental ways informed by constructivist educational assumptions – at least to the extent that community constructions of socio-scientific issues are recognized as being shaped by human interests and social and environmental context" (p. 95).

The literature offers different models for teaching and learning SSI (Levinson, 2006; Presley et al., 2013; Sadler et al., 2017; Saunders & Rennie, 2013). We followed Sadler et al. (2017), who suggested organizing the teaching and learning into three core stages: (a) encountering the focal SSI and making the connections to science ideas and societal concerns; (b) engaging in science practices, crosscutting concepts, and socio-scientific reasoning practices; and (3) a summary in which students synthesize key ideas and practices. The activities included individual reading and writing, role-game based on the stakeholders who appeared in the governmental committee deliberations, small group discussions, decision-making, and whole group discussions. This chapter suggests that a wicked problem such as "The Israeli Natural Gas Export Dilemma" cannot be taught effectively using traditional didactic "teacher-centered" strategies and that a respectful inquiry into different perspectives would involve a process of negotiation, inquiry, and debate of value-based decisions with authentic involvement of the students (Saunders & Rennie, 2013; Tal et al., 2011).

The LU Design

The LU was designed for learners with basic environmental knowledge. It had four sections:

1. ***A preface*** including a short introduction to economics, including the teaching of a few key concepts such as scarcity, allocation, and the economic market, different theories on the relationships between the environment and economy, and a historical background on the Israeli natural gas distribution dilemma with information about the "big players" in the game and their relationships with the general public.
2. ***A role-game*** on the debate over exporting Israeli natural gas. Small groups were asked to prepare position papers of the stakeholders on the export debate. Then, they present each group's position to everyone. This was based on materials drawn from the white papers submitted to the governmental committee as detailed in Table 7.1. We selected the stakeholders' reports based on three main considerations: (a) the reports revealed the different views and controversies around the **environmental** aspects of the export dilemma; (b) the position presented in each report was **explained** in detail and was supported by **data**; (c) overall, the reports represented a **balanced** view on the decision **options**.
3. ***Decision-making exercise***s in small groups of two to three participants aimed to help them review and analyze the information gathered from the reports which were used in the next stage of shaping their own opinions on the dilemma. For

Table 7.1 Stakeholders represented in the role-game

	Stakeholder	Recommendation
1	A governmental committee (government representatives)	Limited export permit
2	Energy and Environment Ministries' chief scientists (government representatives)	No export (at least until 2030)
3	Private producers of natural gas (private firms)	Export permit
4	The Natural Gas Transport and Distribution Company (State owned firms)	Export permit
5	Private sector chemical industry firms (private firms)	Preference for local use
6	The Israeli Forum of Energy and Ecological-Economics Association (civic association)	No export
7	The Israeli Forum for Coast Protection (civic organization)	No facilities on or near the coast

this purpose, we used Paraskeva-Hadjichambi et al.'s (2015) normative rational model of decision-making on SSI as a scaffold for learning. The participants were instructed to assign heftiness (weights) to alternative options for decision, according to various criteria, and use simple arithmetic calculations and assign a total score to each alternative option. According to this model, the option for decision with the highest score is representing a maximization of the learners' values. We used the model to teach (1) the nature of a trade-off strategy for decision-making, in which one has to explicitly consider the advantages and disadvantages of different options, and (2) the role of values in decision-making. Weighing different options when complex trade-offs are involved requires prioritizing different values .

4. ***Group and Personal Summary***. After the group discussion was conducted on the results of the role-game and the decision-making exercise, the participants wrote a summary of their own opinions on the export dilemma.

Research Goal

The aim of this study was to understand ***the characteristics of decision-making and the learners' arguments on the Israeli natural gas dilemma*** before and after the enactment of the LU. In this chapter, we present one iteration of the LU involving teachers. Other iterations, which are not discussed here, were enacted with pre-service teachers and middle and high school students.

The Teachers' Case Study: Methodology, Participants, and Data Collection

The LU was conducted during an 8-hour professional development workshop (PD) for 20 environmental science teachers. In Israel, environmental science is an elective high school course. The workshop was part of a 2-year PD (60 hours) for leading experienced teachers in environmental science with at least 5 years' experience.

We conducted a qualitative interpretative analysis to capture the subjective meaning of learning (Merriam, 2002). Content analysis was carried out according to the procedure in Krippendorf (2004) for analyzing texts with multiple meanings. The first author developed the LU and led the activity and the co-author videotaped and took notes. The analysis was carried out first by the first author, with several rounds of peer debriefing with the co-author and then with a group of five other researchers to achieve a consensus on the categorization, terminology, and classification of the statements emerging from the text analysis.

Data Collection and Analysis

The data were composed of pre/post open-ended questionnaires, worksheets, and videotapes of the entire 8-hour workshop (Fig. 7.1). Due to the late arrival and early departure of a few teachers, we collected 17 pre-questionnaires and 12 post-questionnaires, 9 of which were paired. The 17 pre-questionnaires provided the teachers' demographics: 12 had a master's degree and 5 had a bachelor's degree in environmental science, geography, biology, chemistry, pharmacology, science education, teaching and learning, measurement and evaluation, educational

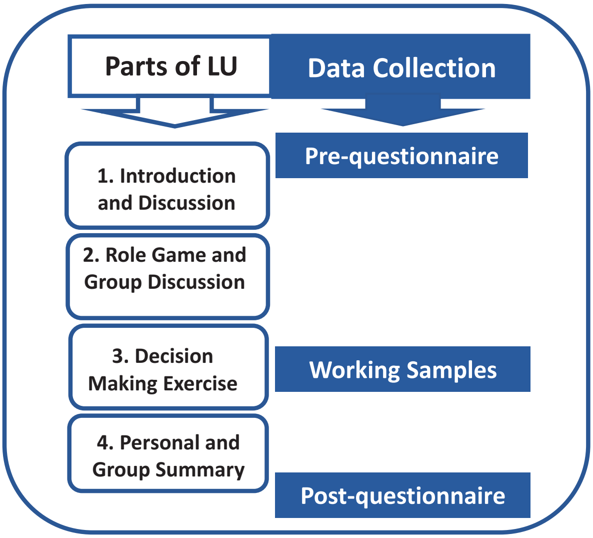

Fig. 7.1 Flowchart of the LU and times of data collection

management, and environmental resource management. The female/male ratio was 13/4. The group was culturally diverse and was composed of Israeli Arabs and Jews from the north and center of the country.

Due to the coverage of the Israeli natural gas issue in the media, it was reasonable to assume that the participants had some prior knowledge. We refrained from measuring teacher knowledge since our focus was on argumentation and decision-making characteristics rather than on factual knowledge.

The Pre- and Post-SSI Questionnaire

We asked the participants to express their opinions about the Israeli natural gas export dilemma on the pre- and post-questionnaires. We had no information on the participants' prior knowledge on the export dilemma and thus needed to provide a brief description. To highlight the controversial nature of the export policy, two opposing positions were presented. To avoid possible bias toward one of them, we presented both sides briefly, but in a convincing manner using the following text in both the pre- and post-questionnaire:

> The natural gas reserves discovered near the Israeli shoreline are primarily used by the national electricity company and large industrial manufacturers. In the future, the use of Israeli natural gas is expected to increase in the industrial and transportation sectors. The gas is produced by companies specializing in the discovery and production of natural gas whose activity involves huge investments with high risks.
>
> Some argue that to provide an economic incentive for the exploitation of these gas resources, the government should allow these companies to export natural gas and use the profits for development. Others argue that exporting Israeli natural gas should be banned to preserve it for future uses in Israel.

After this brief description, we asked the participants to express their own position to allow or ban the export of natural gas. We asked them to discuss different points of view in their responses. This was done to scaffold the use of rebuttals in their answers.

Analysis When exploring an ill-structured problem in which formal logic cannot yield only one correct answer, researchers tend to examine informal reasoning and arguments. In typical SSI arguments, the speakers present causes, consequences, advantages, and disadvantages of a certain position or alternative decisions (Zohar & Nemet, 2002). An argument is not just an expression of an idea or an opinion; it is also the source of opinion validity which is achieved through justification (Rigotti & Greco Morasso, 2009; Toulmin, 2003). Thus, exploring justifications can shed light on the ways in which the teachers reasoned about the dilemma. Therefore, we analyzed every argument according to its structure and content.

Two processes can be distinguished in studying argumentation. One is "learning to argue," which involves the acquisition of reasoning skills such as the use of data, warrants, rebuttal, backing, etc. (Toulmin, 2003). The other is "arguing to learn" in which a specific goal of learning is achieved through argumentation, such as constructing knowledge or promoting understanding (Schwarz, 2009). Schwarz stressed that the two are not independent but rather intertwined and often inseparable. Since we wanted to identify the participants' grasp of the complexity of the natural gas issue, we focused on "arguing to learn" as an analysis perspective.

Each participant teacher was assigned an identification number for purposes of anonymity. We began the analysis by identifying the smallest meaningful units in every statement, followed by several stages of analysis. Each text was divided into two parts: (1) the participant's argument (the stated position and the justifications employed) and (2) the participant's explanation of alternative claims. The interpretative content analysis was based on the premise that there was no correct or incorrect opinion. Therefore, we defined a statement as an argument if it was composed of at least a claim and a reason supported by evidence/data and/or connected to a warrant (implicitly or explicitly) (Muller Mirza & Perret-Clermont, 2009; Toulmin, 2003) and considered that it shed light on the participants' decision-making. As in previous research on decision-making in the context of SSI, the following elements were considered: the decision options, the stated positive and negative aspects of each decision, and other identifiable elements that emerged from the data (Eggert & Bögeholz, 2010; Paraskeva-Hadjichambi et al., 2015; Ratcliffe, 1997).

To analyze the use of scientific/professional content knowledge, we used "line by line" analysis, identifying concepts from different disciplines. Specifically, we employed constant comparisons (Strauss & Corbin, 1990) of the individual texts, both pre- and post- and between paired arguments to elicit the entire repertoire of arguments. The comparisons served to generate a tentative hypothesis about similarities and differences in arguments and reasoning. These comparisons yielded a set of informal reasoning strategies. We examined tentative reasoning patterns to refine the categories until each argument fit into only one category. To increase credibility, we ran several rounds of analysis and eventually conducted peer debriefing with five other researchers, who were not part of the study, to refine the categories until each argument fit smoothly into only one category. Figure 7.2 summarizes the argumentation data analysis.

Since we use both argumentation and decision-making frameworks in the analysis, we employed the terminology of both frameworks. Every opinion on the export policy was defined as a claim, from the argumentation perspective, and as a decision (which was also a selected option by the participant) from the decision-making perspective.

The Decision-Making Exercise in Groups

As indicated, the decision-making exercise enabled us to observe the decisions of participating groups and their considerations. This activity was carried out by 12 groups of 2 or 3 participants. The data analysis of the decision-making exercise was descriptive and aimed to reveal the participants' choices and document which

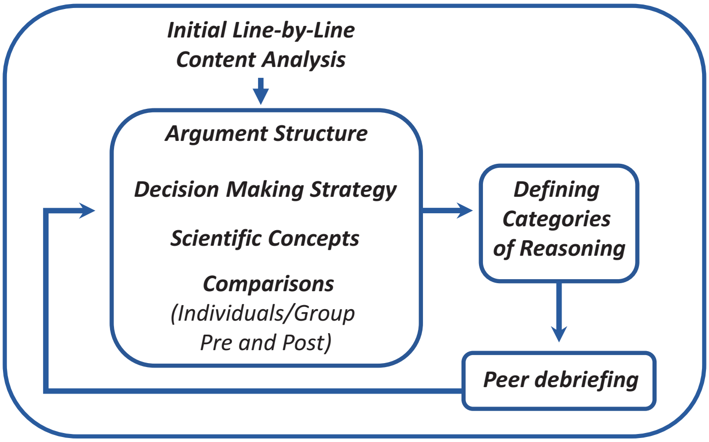

Fig. 7.2 The analysis process

criteria, such as air pollution, energy security, or economic welfare, had the highest frequencies.

Findings

The following positions on export appeared in the pre-/post-texts: free export, export with restrictions (e.g. part of the profits should be invested in renewable energies as a precondition for an export permit or only if the marine ecosystems are protected by law), export with quantity restrictions (henceforth limited export), limited export with a preference for domestic consumption (local uses), and banning exports of natural gas (henceforth no export). Two of the texts did not include a decision at all.

Seven Strategies of Reasoning

Different strategies of reasoning - in both terms of argumentation and decision making characteristics - were found in the pre-/post-arguments. In the following section, we elaborate on seven strategies, labelled Unsolved Dilemma, Trade-off Compromise, Gainful Decision, Minimizing Losses or Risks, Justice and Ethics, Subject Focusing, and Action Plan.

Unsolved Dilemma Reasoning

In this kind of argument, the participant (fully or partially) considered the pros and cons of at least two options. These arguments are presented in an unsolved manner, expressing the unrealized requirement to decide what to give up. The arguer remains on the fence and does not take a stand. This kind of reasoning was found in one text in which the teacher explained her considerations without presenting an opinion about the export policy. She presented the trade-offs between the economic and environmental consequences, including an assessment of different economic consequences and different environmental consequences:

> If the State of Israel starts exporting … it can strengthen the Israeli economy and lower taxes… On the other hand, exporting gas … can lead to further expansion and a preference for export over [local] consumption …this will cause greater destruction of marine ecological systems and further marine environmental pollution from the natural gas extraction operations. Although the consumption of natural gas by the manufacturing and electricity sector will reduce air pollution, its extraction operations pollute the air. (3PRE)

The tension presented in the argument remains unresolved and no decision is made.

Trade-Off Compromise Reasoning

Like the previous type of reasoning, in the "Trade-off Compromise," the participant (fully or partially) considers the pros and cons of at least two export policies. The contradictory elements are presented and expresses tension between them. However, in contrast to the previous type of reasoning, the arguer makes a decision, expressing a compromise. The argument reveals a need to give up on something, aiming to get something else, and compromise, aiming to moderate the losses. The compromise is the arguer's way of justifying the decision:

> Here, what comes to mind is 'conservation versus development'. In my opinion, exporting natural gas should be permitted, so the companies can continue to exploit the reserves. But, to avoid undermining future gas consumption needs, it should be limited. (1PRE)

There were six texts corresponding to this type of argument. The trade-offs considered were economic benefits of an export policy (more development, employment, competition, economic welfare) versus environmental costs of an export policy (rapid depletion of the gas reserves and damage to the ecological system). In other texts, participants opposed economic growth and energetic security for the current generation, in order to receive energetic security and environmental quality for the next generations. The trade-offs were presented differently in different texts, but all ended in a compromise.

Gainful Decision Reasoning

Five texts corresponded to the Gainful Decision type of reasoning, in which the arguer presents and emphasizes the advantages of the position taken. Certain teachers also provided solutions to some problems and this additional solutions served to strengthen the positive aspects of the decision. In this kind of argument, the speaker tends to consider only the advantages, or weights the advantages more than the disadvantages. Some of these arguments used a definite expression and they were structured differently from the trade-off reasoning, with no tension or a need to give up something:

> In my opinion, the State of Israel should authorize exporting natural gas, but with limitations. Local demands should be prioritized and less for export. It is hard to give up export because the country needs to cover its huge investment costs in the gas reserves and limited export would do so … also, the Israeli consumer should be allowed to benefit by lowering the price paid for natural gas. We are living in an age of technology, which requires energy supplies 24 hours a day, the issue of energy security is very important in our lives and the lives of the next generation. (1POST)

The teacher then discusses the problem of the uncertainty of the gas reserves and suggests how to solve it:

> Although we don't know for sure how much natural gas there is and how long it can be exploited, we should use it slowly and monitor the situation. In other words, reassess the environmental concerns – to take the environmental damage into account, find solutions and act accordingly. (1POST)

He then explains the environmental and economic benefits of using natural gas:

> The issue of natural gas extraction is very important to us, because it reduces pollution and global warming, makes the air cleaner and is used in industry and transportation. I object to my friends' position and I am going to convince them by presenting our economic, environmental and energy benefits. (1POST)

The speaker is strongly convinced and believes that all he needs to do is to present his arguments on economic, environmental, and energy profits to convince his opponents.

Minimizing Losses or Risks Reasoning

In this kind of argument, the speaker focuses on costs and/or risks while considering the expected losses or the uncertainties involved. The argument is composed mostly of disadvantages and the risks involved in one or two options. The strategy is to minimize the losses and risks. This argument is expressed in a convincing or convinced manner.

Only two arguments in the corpus matched this type of reasoning. In one example, the arguer begins with his decision of "no export" and explains a set of reasons:

> … because the data on supply and demand are not finalized, the fact that gas exports will lead to increased prices for the local consumer and the competition to find more gas as quickly as possible will cause environmental damage, which we will not be able to fix. An export permit, even if it is limited, will be short and dangerous both to the economy and the environment. (7POST)

This speaker's decision is based on a normative view of risk management, in which a conclusion should be based on a long-term view and a principle of caution. She concludes with the following reasoning:

> My opponents' arguments are based on the extreme scenario that there is a huge reserve of gas but low demands for gas within the country and they will try to convince us that there is no need to safeguard larger reserves beyond the level of current demands. (7POST)

She is referring to "pro-export" stakeholders as in public debates and criticizes the validity of their arguments through references to risk management.

Social Justice or Ethical Reasoning

This type of argument is very different from the previous one and is based on justice or ethics. Usually, these arguments refer to different stakeholders (companies, citizens, the state, etc.) and their conflicting interests. Justice or ethics cover citizens' rights, equality and/or fairness of distribution, responsibility analysis, etc. In all these arguments, the speaker justifies the decision in terms of values or other principles (explicitly or implicitly).

In the following example, the teacher began by presenting the need to address citizens' economic interests, namely, to reduce the price of gas in the long run:

> [We] should take citizens into account and reduce the cost of natural gas in the long term. I am considering the economic impact on the middle class. I, as a citizen, want lower prices for natural gas consumption and for as long as possible. This will not be feasible if Israel decides to sell gas to foreign countries... My colleagues who oppose my position – their considerations are also economic, but serve the economy of the State, which always, but always, penalizes the middle-class citizen and not tycoons and monopolies, which make millions. (4PRE)

This argument illustrates a social justice perspective. The analysis captures the opposing interests of different stakeholders. This teacher also stresses social justice in terms of wealth distribution. The values that dominate the argument are equality, fairness, and rights of the citizens to have their interests represented.

Five texts were classified as presenting social and ethical reasoning. These can be divided into two core areas: (1) equal distribution of profits and benefits and (2) safekeeping citizens' rights to defend their interests in public decision-making procedures.

Narrow Subject-Focused Reasoning

In this type of argument, the speaker focuses on a specific subject. This crucial topic orients the rationale for the decision or the argument. The whole argument is built on a narrow analysis of the dilemma, and the pros and cons of only one or two options are considered. For example, in the following text, the speaker begins with a statement of his decision to authorize natural gas exports and justifies it by explaining that exports will enable a supply of natural gas that can then promote investments in renewable energies:

> As an Israeli resident, I am in favor of selling natural gas outside Israel … to enable the company to continue extracting gas … this can also encourage the government to think about more natural resources, and implementing the use of renewable energies like sun and wind energies … the sale of natural gas will help build renewable energy facilities. (8PRE)

This argument is focused on energy supply and the need for renewable energies. The justification for a free export policy stems solely from these two related topics. Six texts corresponded to this type of reasoning. They dealt with renewable energies, foreign affairs and international trade, energy security, the cost of living, and carbon footprint. All the narrow-focused arguments were found in the pre-questionnaires.

Action and Priority Reasoning

This argument is target oriented. It presents a set of actions with/without priorities or conditions. The argument is composed of a list of verbs, which functions as the backbone of the argument. This kind of argument resembles a management plan with its principles and priorities or conditions. The speaker describes *how* things should be done (as compared to why a policy should be decided upon). The speaker states his claim about an export policy and then explains how exports should be done or what considerations should be assessed when authorizing the export of natural gas. These pragmatic considerations are used to persuade others that the claim is right.

In the following example, the speaker states his position "To permit… but… we should limit production" (9POST). This is followed by his reasons and the four preconditions:

> To permit … But, (we) need to consider several factors: A. we should think environmentally and protect clean coasts and ecological systems. B. (we) should limit production, so we will have enough for many years …. C. (we) should supervise the production process. D. (we) should limit company profits for the citizens' sakes. (9POST)

Five texts corresponded to this type of reasoning. They were noticeably different from the others in their "managerial phrasing" which included specifications such as

- Authorizing an export permit if it is in compliance with environmental laws and conservation of resources

- Priority to local uses of the supply of natural gas
- A supply and distribution management plan with a set of needs, users, and a plan of action, with priorities
- An export policy plan with investment in green energy, with stages and a precondition
- An export permit that complies with environmental, planning, governance, and social justice

Individual Changes from Pre- to Post-arguments

Examination of the pre- and post-arguments in nine paired questionnaires revealed that Subject-Focused and Justice and Ethical reasoning appeared in the pre-questionnaires but not in the post-questionnaires. In addition, most of the opinions about export policy evolved toward advocating limited export, with or without pre-conditions, and only one participant supported the no-export option. Table 7.2 presents the changes in the participants' reasoning and opinions.

In addition, there were other patterns in the teachers' arguments suggestive of increased sophistication in their post-arguments, as shown in Table 7.3.

Table 7.2 Individual changes in pre- and post-arguments

Participant	Reasoning strategy		Opinions about export policy (no-export, limited, yes)	
	Pre	Post	Pre	Post
1	Trade-off compromise	Gainful decision	Limited	Limited with preferences
2	Minimizing risk	Action plan	No	Limited with conditions
3	Unsolved dilemma	Trade-off compromise	No decision	Limited
4	Justice and ethics	Trade-off compromise	No	Limited
5	Subject focusing	Action plan	No decision	Limited with conditions
6	Justice and ethics	Trade-off compromise	No	Limited
7	Justice and ethics	Minimizing risk	No	No
8	Subject focusing	Gainful decision	Yes	Limited
9	Trade-off compromise	Action plan	Limited	Limited with conditions

Table 7.3 Changes in arguments

Type of change	Participants
From indecision to clear decision	3,5
More export policy alternatives considered in the post- compared to the pre-argument	3,4,6,7,8
More considerations put forward in the post- compared to the pre-argument	1,2,4
Only the post-argument includes environmental considerations	1,4, 9
Different pros and cons considered in pre- vs. post-argument	1,6,7,9

Table 7.4 Argument domains ($N = 29$)

	Frequency of domains (%)					Mean number of domains per argument
	Economic	Environmental	Energy	Ethical and social	Foreign affairs	
Pre $N = 17$	88	59	41	35	18	2.4
Post $N = 12$	100	91	91	36	27	3.2

The Argument Domains

The export dilemma was framed in terms of the economic, environmental, social, ethical, and foreign affairs domains. In most arguments (93%) of all participants ($N = 29$), they considered and integrated two to four of these domains, with a clear increase in the number of domains in the post-questionnaires and a substantial increase in environmental and energy considerations as shown in Table 7.4.

Despite changes in the final decisions (Table 7.1), and stress on certain domains, there were different emphases in the participants' arguments which were consistent with respect to the domain/s they referred to the most, or with other issues they highlighted. These emphases are presented in Table 7.5.

The idiosyncrasies in the teachers' arguments even after their decision evolved showed that they mainly refined their decisions from "no" to "limited" or from "yes" to "limited." In addition, they added new considerations but also preserved what was most important to them.

The Decision-Making Exercise

This task was conducted in small groups. Seven groups recommended "no export" after summing up their views on air pollution, the marine ecological system, and energy security. Three groups recommended "limited export" based on their views on energy and economics. Only two groups recommended "free export" based on their views concerning the economy and foreign affairs. Table 7.6 presents the

Table 7.5 Emphases in the pre- and post-arguments

Participant	Common pre/post-domains
1	Economic benefits of natural gas production
2	Foreign affairs and natural gas reserves
3	Economic and welfare benefits and less air pollution and damage to the marine ecological system
4	Distribution between stakeholders and narrow economic interests of the companies
5	Preference for renewable energies
6	Environmental rights and justice
7	No trust in political control and economic companies
8	Target of investment in renewable energies
9	Foreign affairs, depletable resources, and the next generations

Table 7.6 Decision-making exercise (12 groups)

Exercise decision outcome	Three most important criteria	Important domain	Number of groups
Export	Incentives for natural gas exploration Foreign affairs Consumer welfare	Economy and foreign affairs	2
Limiting export	Energy security Local economic needs Incentives for natural gas exploration	Energy and economy	3
No export	Air pollution The marine ecological system Energy security	Environment and energy	7

decisions, the most frequent criteria for each decision, the domains identified in the arguments, and the number of groups selecting each decision.

It seems that some participants presented different opinions when working in small groups, compared to their individual work. Although 8 out of the 9 participants from the paired *individual* comparisons advocated limiting exports, 7 out of 12 small groups with almost the same participants, recommended "no export."

Summary

This chapter examined the arguments written by teachers to support their positions on the use of the Israeli natural gas. This focus on argumentation and decision-making is consistent with work on learning through dilemmas, case studies, and SSI (e.g., Zohar & Dori, 2003; Sadler et al., 2017; Tal et al., 2011; Zohar & Nemet, 2002). The literature suggests that deep learning is enhanced by controversial content and pedagogical affordances such as group discussions, debates, and role-games. Dealing with "wicked" problems in both formal and informal learning opportunities is contextual and value-based, as set out in the Introduction to this volume.

Our findings show that participants' reasoning about the nature of the natural gas export policy could be classified into four different perspectives:

1. *A cost-benefit problem* integrating different stakeholder perspectives.
2. *A social problem* encompassing two interrelated issues: distribution fairness and representation of citizens' rights.
3. *A context-related* problem strongly related to two contexts: energy resources and foreign affairs.
4. *A sustainable development problem* integrating environmental, economic, and social factors with trade-offs between current and future generations.

There was no consistency in the teachers' positions on advantages and disadvantages (benefits and costs), and these considerations have evolved throughout the process and among participants. As shown by Fischhendler and Nathan (2014), various coalitions of companies, government, NGOs, and other stakeholders have advocated or opposed the export of gas. Their analysis of the Israeli debate indicates that while some stakeholders who opposed export refer to environmental issues and energy independence arguments, others prioritize reliable supply and the geopolitical benefits associated with gas export. The complexity of strategies, patterns, and emphases we documented in the teachers' arguments thus reflects the debate on the ground. Moreover, this complexity is typical to other wicked problems. Termeer et al.'s (2013) capabilities for coping with wicked problems include two, which are very relevant to our study: reflexivity, which is the capability to appreciate and deal with unstructured problems and multiple realities, and resilience, which is the capability to flexibly adapt one's course in response to frequent and uncertain changes without losing identity. Although their work comes from public policy and focuses on agricultural policy, some principles are relevant to dealing with public policy in an educational context. Differences in individuals' stances we identified were also indicative of the nature of argument-based decisions as a discursive practice, which is described as "a form of discursive move, in which we do not limit ourselves to expressing or communicating ideas, opinions […] but we want to justify them, prove them by reasoning" (Muller Mizra et al., 2009, p. 67). Our text analysis revealed different reasoning strategies, which we labelled Unsolved Dilemma, Trade-off Compromise, Gainful Decision, Minimizing Losses or Risks, Justice and Ethics, Subject-Focused, and Action Plan. Looking more deeply at these strategies, they seem quite distant from the typical environmental sciences curriculum. They reflect the economic and public policy fields, and we identified much evidence for thinking out of the (environmental sciences) box among our teachers. This strongly reflects calls to adopt more transdisciplinary approaches to education for sustainability, to develop ethics awareness and meta-knowledge in both science education and engineering education (Fadel et al., 2015; Seager et al., 2012).

The Unsolved Dilemma presents the strong *tension* between advantages and disadvantages, resulting in the absence of a decision, whereas the Trade-off Compromise suggests one. Trade-off thinking, which is the ability to weigh advantages and disadvantages across multiple options (Eggert & Bögeholz, 2010), is considered crucial for decision-making on wicked problems. As Eggert and Bögeholz (2010) showed, evaluating different options, when complex trade-offs are involved, is a higher-order thinking skill.

Gainful Decision and Minimizing Losses or Risks reasoning presented partial trade-offs. These strategies emphasized either the benefits or the risks. These strategies have primarily been examined from the psychological perspective. Studies have shown that people tend to consider positive reasons when they accept an alternative and strongly weigh negative reasons when they oppose an alternative (Kolstø, 2006). We found evidence for such behavior in the Gainful Decision reasoning strategy, which was used to justify free export or a limited-export policy, and in arguments in favor of minimizing losses or risks when used to justify a no-export policy.

The Justice and Ethical perspectives revealed the social nature of the problem. This type of reasoning is grounded in value-based decisions dictated by fairness and equality. This perspective reveals a conceptual understanding of the social components of the natural gas export policy wicked problem and suggests that wicked problems can be analyzed through social lenses rather than solely in terms of economic benefits. Moreover, there are calls in both education for sustainable development, in all levels, and in science education to include the practice of ethical consideration. The Center for Curriculum Redesign (Fadel et al., 2015), in its Report, addresses the development of character dimension and lists few qualities, of which ethics is one: “Since ancient times, the goal of education has been to cultivate confident and compassionate students who become successful learners, contribute to their communities, and serve society as ethical citizens” (p. 80). The authors specifically discuss the development of ethics and value judgment in conjunction with technological developments. The European Commission (2015) report “Science for Responsible Citizenship” stresses this point as well arguing that “A more responsive science education can promote broader participation in knowledge-based innovation that meets the highest ethical standards and helps ensure sustainable societies into the future” (p. 7).

The Subject-Focused strategy of reasoning revealed the role of context and conceptual understanding of the two core issues of natural gas as a non-renewable source of energy and international relations. It thus suggested the implementation of scientific knowledge on energy and energy-related issues as well as information on local and regional political issues.

Finally, the Action Plan form of reasoning dealt primarily with the issue of sustainable development and focused on how to export rather than whether to export. The Action Plan reasoning takes a normative perspective on what a public policy should look like or include. These arguments incorporated social, environmental, and energy considerations in their export policy plans.

All seven strategies reflect the complexity of the natural gas dilemma. There is a general consensus that having no clear-cut solutions is typical of wicked problems. Instead, multiple solutions and strategies need to be explored and developed. They all have advantages and disadvantages, and they are subject to ongoing inquiry (Eggert & Bögeholz, 2010; Kolstø, 2006; Sadler et al., 2007, 2017).

The Learning Process of the Natural Gas Export Policy Wicked Problem

All the participants had some prior knowledge about the Israeli natural gas dilemma, which we did not test or analyze. Most participants changed their initial positions toward the "limited export," and they all changed their reasoning strategy, which may point to a learning process where newly acquired content knowledge can explain the changes in reasoning.

In addition, as shown in Tables 7.3 and 7.5, all participants exhibited changes in opinion, reasoning, and content. These changes may indicate increased sophistication in the form of improved decision-making capability, which was evidenced by the articulation of a personal position at the end of the learning process, or developing a more convincing argument.

Increased sophistication also emerged in terms of greater content knowledge as expressed by increased richness: more or other export policy alternatives were considered, and more considerations were made, different pros and cons were suggested, and new environmental or economic concepts were included. Certain topics were discussed in the pre- and in the post-arguments in a consistent way. However, these topics were approached differently or discussed in a different manner. These similarities may indicate personal and idiosyncratic thinking and learning associated with wicked problems. This idiosyncrasy is obvious in the intersection of different human interests, values, and motives (Robottom, 2012).

Teaching this wicked problem was designed to provide a variety of learning opportunities through different activities that included a role-game, a decision-making exercise, group discussions, and individual writing of arguments, all aimed to encourage thoughtful weighing of possible solutions to the natural gas export problem, by taking background knowledge, different stakeholders' interests, value-based decision-making process, and different contextual perspectives revealed in the group discussions into consideration.

Table 7.3 presents the argument domains in the 29 pre- or post-argument texts. It is clear that the number of environmental and energy factors related to the export policy problem increased substantially (59% to 91% and 41% to 91%, respectively). This increase may imply that more participants became aware of the relationship between environmental issues and sustainability and a conceptual understanding of energy-related issues. In addition, the number of domains for each argument increased from 2.3 in the pre- to 3.4 in the post-arguments. This increase may hint at better conceptual understanding.

Table 7.4 summarizes the small group decisions. In this format, more teachers expressed a preference for a "no export" policy based on their references to air pollution, the marine ecological system, and energy security. Individually, most of the participants preferred the “limited export” at the end of the LU. This decision may reflect the nature of this real-life wicked problem, which enables different initial perspectives and positions and requires integrating broader views on multi-domain content, different stakeholders, and different perspectives. These requirements characterizes public decision-making processes related to sustainable development and may suggest that learning about a wicked problem can provide learners the appropriate civic skills and knowledge they need to take part in democratic life (European Commission, 2015).

Conclusion

In the Introduction to this volume, the editors refer to the traditional cautious approach of informal science institutions toward wicked problems. This approach is even more evident in schools, especially in unstable political moments, as is often the case in Israel and during which schools and principals refrain from being seen as radical. Why deal with controversial issues, which are under political debate such as the natural gas export policy? Or include the public’s demand to move the oil refineries away from the city of Haifa, which requires to deal with employment issues relevant to thousands of families? The answer is that both schools and informal science institutions are a sphere where future citizens can communicate with each other and practice science and society relationships in ways that are more engaging and relevant to citizens in a democratic society.

One of the recommendations of the Science Education for Responsible Citizenship report (European Commission, 2015) is that “Collaboration between formal, non-formal and informal educational providers, enterprise, industry and civil society, should be enhanced to ensure relevant and meaningful engagement of all societal actors with science and increase uptake of science studies and science-based careers to improve employability and competitiveness” (p. 22). Recently, “Global Energy,” a global oil company and one of the main actors in the wicked problem discussed in this chapter, announced it was looking for ways to negotiate and collaborate with science educators to come up with innovative programs that encourage students and teachers to learn about and openly discuss energy issues. This is also the case for the Office of the Prime Minister, the Energy Ministry, and the Ministry of Environmental Protection that have developed educational programs to increase awareness of ways to curb fuel consumption and choices of alternative energy. This involvement of industry, government, and various NGOs in matters that have most or all of the features of SSI or wicked problems challenge traditional science education, regardless of where and when it takes place. The ongoing calls to introduce science education for citizenship into the school system (Aikenhead, 2005; European Commission, 2015; Roberts & Bybee, 2014) inspired us to develop the LU and test it on different target learners.

The teachers' case described in this chapter clearly shows that the teachers involved in the LU developed their argumentation and decision-making skills in various ways. They added more domains to their arguments, shifted to more complex argumentation strategies, and added considerations and alternative solutions and they better addressed the environmental aspects. The learner-centered pedagogy we fostered through role-game, small group, and whole group discussions and the decision-making exercise thoroughly engaged the teachers as well as the other groups who have been exposed to the LU. In accordance with Robottom (2012), we see no other way to deal with wicked problems either in schools or in informal environments than this type of pedagogy where learners are scaffolded to practice the variety of ways in which these crucial problems are discussed, debated, or resolved. As described earlier, there is no one natural gas conflict in Israel, at this time, but rather a few conflicts. The more recent one focused on how to and where to place the Gas Processing Platform. One compelling argument in the public discussion was that the main opponent – The "Homeland Guard" organization – represented a wealthy high-profile public, motivated by 'Not-In-My-Back-Yard' (NYMBY) - considerations. Much of the public discourse was focused on evidence vs. beliefs and conspiracy theories and about what is security and who can define what security is. Since early 2020 this debate has been decided and the gas platform is now operating 10 km from shore. However, other debates arise on the utilization of any fossil fuel vs. the further development of renewable energy, over who really benefits from the gas with headlines such as "Israeli Gas Is Great – for Egypt and Jordan: Leviathan gas reserve was billed a 'national project'. It's now online but 85% of the gas will go to Egypt and Jordan for a lower price than Israelis pay" (Haaretz newspaper, January 9, 2020) or "Israeli Tycoon's Win Is a Huge Loss for Planet Earth" (Haaretz newspaper, December 13, 2019). These debates are present in the traditional and social media, teachers use them in schools (Ginosar & Tal, 2017), but so far, we have not seen any planned learning units about such environmental and economic wicked problems, as discussed here, used in schools or in informal science institutes.

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Chapter 8
Climate Garden 2085: An Art-Science Experiment Promoting Different Ways of Knowing About Climate Change

Juanita Schläpfer-Miller

Introduction: Public Perceptions of Climate Space and Time

For several decades now, climate change has been communicated as a global concern affecting every person on this planet, but there is still a widespread disconnection between scientific information and political and social action – the so-called climate paradox. It is a – if not *the* – wicked problem of our age; but if, as psychologists tell us, the human brain responds better to experience than to analysis, then climate change should also be told as a local and personal story. This is the aim of the public experiment *Climate Garden 2085*.

Climate Garden 2085 arose from a very simple question. Although as a science communicator and artist I understood the global climate scenarios, I could not imagine what it meant for me as a citizen of Central Europe. What would the future bring for me and my descendants? What would grow in my garden in 20 years? Or in my daughter's garden when she is a grandmother? I hoped that these personal questions would find resonance with others.

In her essay on the *Climate Garden 2085 'Botanical time travel to unspectacular climatic futures'*, art historian Emily Scott notes that the garden may seem an unexpected medium through which to grapple with a crisis as massive as that of climate change (Scott, 2017). She follows the art historian T. J. Demos, however, in identifying it as a communicative medium of crucial contemporary importance:

> Gardens may seem irrelevant to our world of crises and emergencies […] but in fact they concern the most urgent of global conflicts — including the corporate financialization of nature, […] the production of greenhouse gas emissions, via a monoculture- and export-based agribusiness reliant on the fossil-fuelled transportation industry and chemical

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M. Achiam et al. (eds.), *Addressing Wicked Problems through Science Education*, Contributions from Science Education Research 8,
https://doi.org/10.1007/978-3-030-74266-9_8

> fertilizers; and the destruction of unions and small-scale farmers, displaced by the mechanization and monopoly ownership of the means of production (Demos, 2012, para. 3).

A garden is both a metaphor and a physical manifestation of a wicked problem. In the case of the *Climate Garden 2085*, the climate emergency is primarily addressed, but as is characteristic of such problems, there are many layers to contend with.

As a counter to the information hurricane we live in, the slow medium of a garden presents a narrative environment in which people can immerse themselves: a local story with global significance. We at Zurich-Basel Plant Science Center set out to invite the public to personally experience future climate scenarios and their effect on agricultural plants and our landscape and forests. In collaboration with the Botanical Garden of the University of Zurich, the Plant Science Center initiated this public experiment as an opportunity for social learning to show the impact of climate change on a human scale and local level.

In this chapter I employ Barry and Born's (2013) concept of 'public experiment' to describe the *Climate Garden 2085*. They use the example of Beatriz da Costa's *Pigeon Blog* to illustrate the concept. Beatriz da Costa used electronic sensors attached to homing pigeons to monitor air pollution in inner-city areas. It was not purely a citizen science exercise, nor did it present results to the public, but it contributed 'to the generation of something new within scientific practice itself, challenging the boundaries of disciplinary authority' (Barry & Born, 2013, p. 263). A public experiment is a hybrid approach, somewhere between the disciplines of art and science, using – at times somewhat subversively – the structures of science to provide what Dewey would describe as an embodied aesthetic experience (Alexander, 2012).

In pursuit of this goal, *Climate Garden 2085* created two climate scenarios in greenhouses in Zurich's Old Botanical Garden at temperatures of 2 °C and 4 °C above current annual summer temperatures. To enable comparisons between what we currently grow and eat and what may happen in future, plants that currently flourish in northern Switzerland were grown both in the greenhouses and in open ground outside. Visitors could participate by taking measurements of drought and heat-stressed plants. The greenhouses were complemented by a program of workshops for families and school groups, art performances and talks by botanists, ecologists, plant scientists and geographers from ETH Zurich and the Universities of Zurich and Basel.

The following sections of this chapter will discuss central aspects of learning and knowing about climate change through an artistic narrative environment and will follow with an account of relevant visitor experiences.

Why Art? Different Kinds of Knowing

Earth's ecology is changing rapidly and in many different ways (Küffer et al., 2011). There is strong evidence that this change is human-mediated (Allen et al., 2018). The resulting novel ecologies present challenges to science and society: not only are they new, but scientists do not yet know the extent of the changes or how ecosystems and societies of humans, plants and animals will adapt, or how these changes should be managed (Robbins, 2004, Seastedt et al., 2008). At the same time – and inextricably linked to the ecological changes – societies are undergoing a period of major upheaval (Küffer et al., 2011).

There is an ongoing discussion about the role of individual versus collective action and how to enable reasonably achievable emissions reductions (RAER). For example, individual actions such as household waste recycling and line-drying clothes do have an immediate effect but do not contribute as much to long-term emissions goals as, for example, heating efficiency or solar panels. In the same vein, a controversial paper by Wynes and Nicholas (2017) examined educational messages for teenagers and claimed that some of the most important actions individuals can take to mitigate climate change, such as having fewer children, were entirely overlooked.

When it comes to public agency, many different theoretical and behavioural layers must be examined. Inconsistent public engagement, for example, is being seen by environmental scientists (Agarwal & Narain, 1991), geographers (Brace & Geoghegan, 2011) and science communicators (Leiserowitz, 2007) to result not solely from a lack of information or understanding but also from the tendency of scientists to communicate emissions as a problem on a global scale. According to Agarwal and Narain (1991), this has resulted in scientific study being decoupled from the social and political contexts in which its objects are produced and the terms in which they are publicly understood. Thus, it has been recognized by both social and natural scientists that climate change needs to be understood on a local as well as a global scale (Brace & Geoghegan, 2011, van der Linden et al., 2015).

The concept of climate change – as distinct from the concepts of weather and the seasons, which immediately affect everyday life – is still difficult to grasp for some people. Climate models reduce reality to a statistical construct about the future. According to the fourth IPCC Report, climate is a statistical description of weather over a period of time ranging from months to millions of years (IPCC, 2007). In other words, it is (or can be) an abstraction of a very long-term future, and it is upon this abstraction – in itself difficult to imagine – that the public is expected to base its present decisions. There is evidence, however, that the lay understanding of climate change is framed by the notional and imaginative triangulation of time, place (landscape) and self and the relations between them: what Lorenzoni et al. (2007) (cited in Brace & Geoghegan, 2011) call 'a mingling of place, personal history, daily life, culture and values'. Hence, according to Brace and Geoghegan, it is important to characterize climate change as having not just ecological and economic but also symbolic and cultural impacts, which can readily be seen in this relational context.

More specifically, climate scientists and communication projects such as the Yale Project on Climate Change Communication are advising policymakers to turn to psychology for insights into the question of informing better dialogue and affective behavioural change. In a paper published with psychologists, they advocate five best-practice insights:

> (a) emphasize climate change as a present, local, and personal risk; (b) facilitate more affective and experiential engagement; (c) leverage relevant social group norms; (d) frame policy solutions in terms of what can be gained from immediate action; and, (e) appeal to intrinsically valued long-term environmental goals and outcomes. (van der Linden et al., 2015, p. 758)

To present climatic issues in analytical formats assumes that laypeople process new and uncertain information in a logical and analytical manner (Marx et al., 2007). However, in analysing human responses to climate change, psychologists have shown that we use two different processing systems. The first is intuitive, experiential, affective (emotional) and fast. The second is deliberative, analytical, rational and slow. We constantly make judgments using these systems in parallel, but when they diverge, the first system dominates. In other words, how we feel about something has a stronger influence on how we respond (Slovic & Peters, 2006, in van der Linden et al., 2015). There is also evidence that psychological distance is a result of uncertainty and temporal, social and geographical distance (Spence et al., 2012). A policy recommendation has accordingly been made to translate information about climate change risks into emotionally 'relatable [...] concrete personal experiences' (van der Linden et al., 2015, p. 759) – and such experience is often also local. Thus Evans et al. (2018) call for 'climate change communication that embraces participatory approaches, encourages citizen participation in discussions and decision-making and works towards a shared global climate-change action responsibility' (p. 109). This 'here and now' approach would, for example, allow young participants to apply their skills to current problems promoting deeper learning and thinking (see Giuseppe Pellegrini in this volume). The same considerations provide the rationale for *Climate Garden* 2085 as a way to bring global climate scenarios down to a local geographic and temporal scale accessible to non-scientists.

I would argue that art is uniquely positioned to provide such experiences: it has been called 'the "work" art can do with respect to socio-ecological transformations' (Hawkins et al., 2015, p. 331). The example cited by these authors was a collective knitting project in Scotland, *Bird Yarns*, in which a flock of knitted Arctic terns 'land' in various locations in Scotland, provoking dialogue about the disturbance in migration patterns due to climate change. The project has created an international network of knitters sharing patterns, wool and finished birds: '*Bird Yarns* offered knitters — and, in part, the local community — the chance to register a different imaginary of earthly and atmospheric collectivities than one focused on scientific fact' (Hawkins et al. 2015, p. 336). The artwork offers not only a different imaginative experience but also 'localizes and materializes climate change' (p. 336), bringing epic narratives to a situation closer to home. How exactly this kind of narrative can catalyse an affective response is a question that deserves further investigation.

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I have employed art-science as a means to engaging various publics (often children and youth) in scientific themes for some time now. My conceptual background stems from working at the Exploratorium in San Francisco, California, a 'museum of science, art and human perception' whose founder, Frank Oppenheimer, was fond of saying that one needed both science and art in order to understand the world.

Some artists are concerned about their art being instrumentalized for science. For example, the British artist Cornelia Parker has been quoted as saying that she 'doesn't do' climate change in her art; her piece *Heart of Darkness* in the Royal Academy show *EARTH: Art in a Changing World* 2009 was, she said, conceived as a response to the 'hanging chads' fiasco when Al Gore lost the 2000 US presidential election (Bunting, 2010, online). Nevertheless, her work was chosen by the curators for an exhibition to coincide with COP15 (UN Climate Change Conference, Copenhagen 2009). What I find interesting about this is that, although Parker claims her work is not about climate change, it is about both political mischief (even injustice) and environmentally irresponsible behaviour, both of which are profoundly related to climate change.

Although some artists might not set out to present viewers with behaviour-changing ideas about climate change, others deliberately employ aesthetic tools to encourage environmental stewardship, for example, the Chicago-based artist Tiffany Holmes, who uses eco-visualization to reduce energy consumption (Holmes, 2007). On the other hand, Keith Tyson, an artist also featured in the *EARTH* exhibition, sees his role as 'not to advocate solutions; art is not about protest. It is something much deeper and more subtle – to make us reflect and re-think what it is to be a human being in the 21st century. What do we want to be?' (Tyson, quoted in Bunting, 2010).

In an interview in *Arts and Ecology*, the critic and curator Sîan Ede (2010) asks how artists can, in fact, fail to make art about the environment – no one lives in isolation, but she says, it is not an agenda that should be forced on them. In fact, artists cannot avoid making work about the pressing concerns of our time, and climate change and its associated sciences are urgent. Yet there are both individual choices an artist can make and fine conceptual lines between an aesthetizing legitimation of science and engaging with science on artistic terms.

Modes and Logics of Art-Science Collaborations

> Art-science engages science then, for its conceptual and material armories, in terms of common interests in experimentation and innovation and via critique. (Barry et al., 2008, p. 39)

Despite being around for over 50 years, art-science is considered an emergent field, but at its core are long-standing concerns to shift ideas about the nature and scope of art. The history of art-science has been traced to the *Two Cultures* Rede Lecture of C. P. Snow (Snow, 1959), the Bernal Lecture on the public understanding of science (Bodmer, 1986) and the Wellcome Trust *Sci-art* program of 1996–2006, which funded 124 projects (with a sum of £3 million) in order to promote understanding of science among the general public. It is claimed that the Experiments in Art and Technology E.A.T. collaborations with Billy Klüver brought art-science into the art discussion (see, e.g. La Prade, 2002).

Under What Logics Has Art-Science Been Undertaken?

Participation in art-science has been justified by three logical arguments (Born & Barry, 2010). The *logic of accountability* points to the need for increased public understanding of science and socially robust science. The *logic of innovation* points to the value of art in boosting creativity in science and technology. The *logic of ontology* argues that if artists and scientists collaborate, they will be able to create a new understanding of the nature of art and science.

Aside from the Wellcome Trust, there has been and continues to be considerable interest, at least from the side of science, in engaging with artists under the logic of accountability. In their paper *Art-Science: from Public Understanding to Public Experiment*, Born and Barry (2010) make the sometimes subtle, sometimes not so subtle, distinction between a project that aims to improve public understanding of – or increase public engagement with – science and a project that is a public experiment. This, they argue, is the difference between the logics of accountability and innovation and the logic of ontology. Here they refer to Cassin's discussion of the contrasting Greek rhetorical forms of *apodeixis* and *epideixis*. While apodeixis means a faithful showing of the finished knowledge or truth, epideixis means to make a show, to speak *to* rather than *at* an audience – i.e. to engage the audience rhetorically in a process of knowing that will, as such, lead to understanding: 'Where apodeixis follows the object by confirming what is or seems to be, epideixis *makes it be*…' (Born & Barry, 2010, p. 116).

In order to further differentiate between science communication and public experiment, Born and Barry use Cassin's distinction between 'the presentation of pre-existing proofs' and 'managing evidence by contriving new types of obviousness' (Cassin, in Born & Barry, 2010, p. 116). Thus, they argue that apodeixis equates to public understanding and epideixis equates to public experiment:

> As a form of epideixis, public experiments do not so much present existing scientific knowledge to the public, as forge relations between new knowledge, things, locations and persons that did not exist before. (Born & Barry, 2010, p. 116)

This definition of a public experiment as a form of epideixis relates directly to the *Climate Garden 2085* as an attempt to create an artwork in the form of a public experiment. Here, art is implemented under the logic of accountability in order to engage challenging publics (e.g. teenagers) with environmental science. Practitioners of art-science who may then be concerned about being instrumentalized under the logic of accountability can take comfort in the words of Barry et al. (2008):

> if the logics of innovation and accountability appeared to play a prominent part in art-science […] they should be counted as secondary to the ontological logic unleashed by the fertile genealogies of conceptual art and their heterogeneous issue. (Barry et al., 2008, p. 41)

It can be argued, in fact, that an ontological logic is per se inherent in environmental and climate change research. Models of climate change are imbued with cultural values without even recognizing the fact. Uncertainties both in models and in the claims of scientific knowledge – including climate change research – are rarely acknowledged (Jasanoff et al., 1998). The logic of ontology entails an awareness of the limitations of scientific expertise and the importance of lay and non-expert accounts; these should be recognized 'not just as perceptions but also as a kind of scientific citizenship' (Barry et al., 2008, p. 37).

What Kind of Knowledge Is Produced by Engaging with Art-Science?

An art-science experiment raises interesting questions about what can be learnt from it. How might visitors gain knowledge other than cognitive? In this section, I will attempt to summarize some thinking on artistic knowledge as it applies to the *Climate Garden 2085*.

In *Epistemologies of Aesthetics*, German philosopher Dieter Mersch (2015) discusses the relationship between art and knowledge in the context of artistic research. Mersch reminds us that knowledge is based on thought and poses the essential questions: 'whether art creates (*poiein*) knowledge at all, and if so, how art and *epistēmē* go together, and […] how *aisthēsis* and truth interact or conflict with one another' (Mersch, 2015, p. 44). Several concepts in Mersch's writing stand out as pertinent including aisthēsis – knowledge generated by sense perception and response before it is expressed in an argument or changed by writing (Derrida quoted by Fleischer in Mersch, 2015) – 'reflexivity', 'showing' and knowledge from practice (aesthetics of production).

For Mersch, 'art aims to reflect the perceivable through perception and the experiential through experience' (Mersch, 2015, p. 46). Traditional philosophy rejected aisthēsis as incapable of truth, separating thought and aesthetics, but Lyotard has argued that the power of art stems from 'a sudden heuristics' or an unexpected approach to problem-solving which makes use of inconsistencies within aisthēsis, creating its own evidence (Lyotard 1993). It could be argued that we are dealing here with another way of thinking, a knowledge whose patterns diverge from those of logical ratiocination. This is relevant to the audience's creation of meaning in

Climate Garden 2085, which offers the audience a way to develop an understanding of climate scenarios through immediate physical perception.

The concept of reflexivity is linked by Mersch to artistic practice: it is through practice that art differentiates itself from philosophy and science. The knowledge (*epistēmē*) pertinent to art is generated through reflexive aesthetic practice (Mersch, 2015, p. 51); it is that which 'shows', and 'showing has no [...] dichotomies'. Rather than being subject to a true/false polarity, it is informed by:

> a conjunctionality: a sum of 'this' and 'this' and 'this' […]. It does not compete with, surpass or supplant other works in the way natural science theories are displaced by those that later prove or demonstrate their own superiority. (Mersch 2015, p. 46)

In this sense, *Climate Garden 2085* 'shows', and thereby creates, a body of collective knowledge that is embedded in individual instances of experience: 'this' and 'this' and 'this'.

Such thoughts bring us to the conventional dichotomy of idiographic versus normative knowledge production. This was a tension present in modernist art, inasmuch as modernist aesthetics was coupled to the 'objectifying consciousness' of science (Gablik, 1995; Kester, 2011). Both artists and scientists were taught not to be concerned with the applications or moral implications of their work. Yet just as the limitations of 'objective' science are now recognized, and there are many calls for 'socially robust science', so there is a wide artistic movement outside the gallery system and conventional art criticism that rejects 'the reductive and neutralising aspects of aesthetics and art-for-art's-sake' (Gablik, 1995). A paradigm shift has been called for by (among others) David Levin, who maintains that just as transdisciplinary theory calls for integrative modes of thinking that focus on the relational nature of reality rather than on discrete objectified truths or realities, so art is moving away from a spectatorial epistemology 'from (the normativity of) seeing to (the normativity of) listening' (Levin, 1993, p. 3).

There are two key concepts in this paradigm shift which need mentioning, albeit briefly. The first is the relational nature of reality in Western philosophy, that 'being' is a *towardness* rather than a *state*. Western philosophy has consistently viewed being as a state; but the initial moment of knowledge is one of encounter, and encounter is per se relational: subject and object (I and thou, self and other) meet. (Eastern philosophies, in contrast to mainstream post-Socratic Western thought, see this as an identity of opposites – a thought that can also be fruitfully developed in the context of artistic/poetic knowledge: *aesthesis*).

The other, closely linked concept is the nature of viewing in art, which moves from seeing to listening, becoming participatory and conversation-based. Jürgen Habermas sought to replace the detached spectator paradigm with one that recognizes the importance of democratic participation, grounded in the ethics of communicative processes. For extensive reading on the spectator, I recommend *Modernity and the hegemony of vision* (Levin, 1993).

We can see that participatory art, besides raising the ontological question of what art is today, also raises epistemological issues similar to those of transdisciplinary research. For example, what forms of knowledge are generated and how are they best described? According to the curator and critic Hans Ullrich Obrist, much critical discourse is concerned with judging the epistemic power of art by the standards of science instead of defining separate standards for art (Obrist & Vanderlinden, 2001). By converging on a description of artistic knowledge and giving it equal value to scientific knowledge, and by judging it by its own standards, we can perhaps come closer to an understanding of the kind of knowledge that might be produced by transdisciplinary art-science research and how it might be relevant for education.

Social Learning

According to David Tàbara, 'a new view is required of how human information and knowledge systems operate, how they should be organized and how they relate to the functioning of social ecological systems in the organization of science, education and policy' (Tàbara, 2013b, p. 112). Tàbara argues that we should speak in this context not simply of 'knowledge' but of knowledge systems, a concept that refers to multiple sets of interrelated knowledge components and their interactions with their own internal boundaries, dynamics and logics, which are the result of social-ecological processes:

> If we place learning at the heart of transformation, recognizing that we can only transform in the right direction through learning, a transdisciplinary, integrative, open approach that blends insights from theory and practice, and from multiple disciplines and sources of knowledge and expertise, becomes essential (Tàbara, 2013a, p.112).

This view is based on social learning theory pioneered by Vygotsky, whose theories, although conceived in the 1930s, were lost (or repressed?) until the 1950s. His publication *Mind in Society: The Development of Higher Psychological Processes* (1978) has deeply influenced the way we think about learning in context (Bandura & McClelland, 1971).

Jean Lave and Etienne Wenger propose a more precise term than 'social learning', arguing that all learning is socially situated. Their conceptual bridging concept, 'legitimate peripheral participation', describes learning as integral to social engagement and defines 'a landscape of community membership'. Their words are chosen carefully to describe a type of learning that includes more or less engaged 'ways of being, located in the fields of participation defined by a community' (Lave & Wenger, 1991, p. 36). We were aware that it would be beyond the scope of a public experiment spanning 5 months to create 'a field of participation defined by a community', and it is appropriate to be wary of making grand claims with regard to participatory learning. However, we did aim for an open approach with sources of knowledge from many experts, from visual and performance artists, storytellers and natural scientists from students to professors. In this way the informal science learning field became enriched by multiple perspectives and sources of knowledge.

For a further treatment of forms of knowledge in transdisciplinary or interdisciplinary approaches to environmental education, see, for example, Annette Scheersoi in *Connecting museum visitors to nature* (this volume).

Description of Activities: Garden and Workshops

The public experiment *Climate Garden 2085* was based on IPCC scenarios downscaled specifically for north-east Switzerland by MeteoSchweiz and ETH Zurich (ch2011.ch). The current average monthly temperatures were raised in one greenhouse to represent the emissions control RCP3PD or 'best case' scenario and in the other the A2 or 'business as usual' scenario, both for 2085. This date was chosen as being within the lifespan of younger visitors. To simplify communication, we described them as '+2 °C' and '+4 °C'. The precipitation scenario for 2085 suggests a reduction of 8–28%. We modelled extreme summer drying by giving one row of plants in each greenhouse 30% less water. Air humidity was 40–60%.

The artistic strategy of *Climate Garden 2085* was to show the climate scenarios in an experiential form. The idea was to make the experiment local and personal by using scenarios downscaled for northern Switzerland and growing plants that people in this region know and eat. We also chose a mixture of plants which would be climate winners, such as soya and sweetcorn, and some which would be losers, such as wheat and potatoes. A particular type of greenhouse often found in local allotments and gardens was selected; together with the wooden raised beds and walkway, the whole effect was designed to be familiar. Only a minimum of text information was provided in the greenhouses, as we wanted visitors to observe and feel rather than read: the environment was the narrative. In this I think we were successful. For example, visitors to the greenhouses used terms like 'clarity', 'visualization', 'demonstrative' and 'concrete' as positive attributes of the experiment; it was, they said, 'simple but experiential' and it made 'climate change feel closer to home'.

We also wanted to tread the delicate line between doom and optimism, hence the use of plants whose cultivation may move northwards (e.g. sugar beet) and which may thrive in northern Switzerland despite increasing temperatures. Soybean is a good example, as Switzerland currently grows 3882 tonnes of soya and imports 285,000 tonnes per year primarily for animal feed (see https://www.sojanetzwerk.ch). This approach provoked discussion with visitors as to whether the country could become self-sufficient in soya, particularly if we ate it rather than using it as animal fodder. So, the story was complex, and this proved communicatively challenging, as we noticed that many visitors expected a clear either/or statement. Here the benefit of having small groups that allowed time for social learning came into its own; this was also an integral aspect of the design strategy. We found that in a small group, visitors were more likely to ask questions or make statements, connecting what they saw to their own lives. We could also discuss in greater depth issues to which there is no clear answer, for example, why – and with what implications – some plants in Switzerland are resilient to temperature changes while others are not.

Public Programming

Tree (Art) Walk

While the greenhouses modelled scenarios for agricultural crops and grassland, we also wanted to address the theme of forests in Switzerland. Swiss citizens, like many peoples of the world, have an emotional and cultural attachment to trees. Woodlands are an important part of the Swiss landscape, providing us with food, places to walk and play, a habitat for animals and timber for construction and fuel. According to current climate scenarios, several species of trees will die because of the drought associated with climate change. For example, the mighty beech trees that cover the slopes of the Uetliberg, the mountain next to Zurich, will start to die out within the next 50 years. We wanted to discuss with visitors what our local forest might look like then? What will take the place of the beech? The Old Botanical Garden in the middle of Zurich where the garden was installed is filled with mature trees, some of which will be 'winners' under climate change and others 'losers.' We invited artists, musicians, poets and dancers to pick a tree from a list provided – either trees that are going to leave us or going to join us in greater numbers – and to make an artwork about their chosen tree and install or perform it under the tree during the exhibition. The artwork could be a temporary installation, a performance or an interactive workshop for visitors. There was an open call, and projects were chosen by a jury. Botanist Walburga Liebst developed a tour that wove stories around the trees – stories sometimes punctuated by art performances, enabling visitors to engage with botany and aesthetics, climate change, history and poetry. We produced a map of the trees on the winners and losers list, and going on a treasure hunt for these trees became a very popular activity for both primary and secondary school pupils. They collected leaves from the trees, and we looked for clues in the leaf physiology as to whether or not the tree would be drought resistant.

A recurring theme when we were planning the project was storytelling, especially storytelling for younger children. We got in touch with Minitheater Hannibal, an organization run by a delightfully eccentric couple who developed a story especially for us. Dressed as a flower and a wild boar, the two actors led their young audience through the park on a hunt for butterflies. Along the way they met different creatures who all had something to say about how the climate used to be (an old tortoise) and the problems they were having now (Suzette the bee with her insect hotel). The topics of photosynthesis, water sharing, which plants were still available for food and interspecies (plant/animal) relations were all raised in a playful and engaging way.

Gessner Prints

Making your own wood-cut prints under the trees was a highlight of family activities in the summer. Dennis Hansen, an ecologist from the University of Zurich, developed a set of exquisite wood cuts from the original animal drawings of Conrad Gessner (1516–1565) and botanical drawings from others of that time. Gessner was a Swiss botanist, zoologist and physician, and his prolific illustrations of plants and animals are astounding in their detail. But Gessner was of his time, and plants and animals were drawn separately and rarely interacting. Hansen had the idea to manufacture a set of wood cuts of plants and animals that could be printed on the same sheet; workshop participants could thereby create their own ecosystem of plant-animal interactions. The result was beautiful prints on handmade paper that visitors could take home. An interesting fact about Gessner is that he was probably one of the first climate researchers: he brought plants down from the Alps to see if they would grow in Zurich.

How Many Food Miles in a Snack Box?

Apples, pears, cucumbers and tomatoes are in the supermarkets almost all year round, and they are generally thought to make a good snack. But where do they come from? When do strawberries and apples ripen in Switzerland and neighbouring countries? How can long journeys by train, truck, ship or air make a difference to climate change? It’s a question of ‘food miles’. This workshop was a good opportunity to learn about the different harvest times of domestic fruits and vegetables and to focus on questions of cultivation and transportation from near and far. Baskets standing next to the plants contained tokens with the name of the fruit or vegetable children wanted in their snack box. Their school class (or family) could then discuss and evaluate the various choices. On the basis of the new information, children could then revise their choices.

‘No Thanks, I’ve Got a Bag’: Plastic Bag Upcycling – Craft Activity for All Ages

Ah, the ubiquitous plastic bag! Although of course they should, and will, be done away with, in the meantime it makes sense to reuse or upcycle the ones still lying around. We combined several bright ideas we found online and developed an activity which involved cutting bags into strips and then crocheting them into shopping nets for vegetables. This activity took around 4 hours and required proficiency in crocheting or time to learn how to do it. Unfinished projects could be taken away and finished at home.

Solar-Wind Lights: Tinkering Activity for Children

Using disassembled solar garden lights, we fashioned a mini wind-sculpture that did not chime but flashed like a firefly when blown by the wind. This activity required simple soldering and wiring knowledge, but we did it successfully with 10- to 12-year-olds.

Help! I'm a Stressed-out Plant!

The aim was to introduce the theme of gas exchange in plants to understand why drought and flooding lead to reduced photosynthesis and therefore reduced food production. Pupils used sensors to measure CO_2 uptake, in wet stress, drought and control sets of plants. This workshop was a shorter version of the 'Forecasting the effects of climate change on agricultural crops' and was designed for primary school children.

Forecasting the Effects of Climate Change on Agricultural Crops

High school students investigated how stress – for example, as a result of flooding or drought – affects the uptake of CO_2 in plants. They used sensors to measure CO_2 uptake, flooding stress, drought and control in three sets of plants. A second experiment examined stomata by taking a print with clear nail polish and looking at the imprint under a microscope. A third experiment involved measuring stomatal conductance with a leaf porometer. All the high school workshops integrated a world café where we dedicated an hour to discussion and reflection with the students.

Public Experiment 'Results'

The observable results indicated that an increase of nearly 4 °C average temperature change and a possible 30% less precipitation will have dramatic effects on ecology and food production in Switzerland from 2050 onwards. The plants went through their growth cycles faster in warmer temperatures. The 30% loss of water affected health and growth of plants and visible biomass. The worst affected were animal feed-grass and emmer (a type of wheat). In the plot where the temperature was 2°C warmer than the current summer average, the plants grew well, but growth was reduced by lack of water.

While plant growth was not measured as it would have been in a scientific study (e.g. by biomass), the technical facilities made the experiment as realistic as possible. An important element in conversation with participants was that all scenarios are imperfect, and while the IPCC models are based on real data, there are uncertainties (due to feedback) as to how complex ecosystems will react. These realities about scenarios led to discussions of the limitations of the installation as a model: for example, the fact that CO_2 was not a variable, that severe weather events were not modelled and that it was difficult to simulate rainfall, as in essence the experiment plots were gardens, not fields or woodland, and if we have the means we water gardens during drought.

The post-visit surveys were modest in scope, but they did show that three quarters of the visitors said the installation gave them a feeling about what climate change would be like in the future; more than half made a clear statement in the survey relating the scenarios to themselves or the future of Switzerland.

Participant comments included admissions that the respondent had not previously considered 'how the plants I grow in my garden will be affected' and the statement 'Until now I didn't understand the difference between climate and weather.' They also showed anxiety about the future: 'I have concern and insecurity about future climate developments'; or 'It helps me see 2085 as a time worth thinking about and planning for. Makes me realize how things could change. Emotions: both fearful and hopeful'. Other keywords here are 'climate wars', 'water shortages', 'migration' and 'lack of understanding in politics and society.' When asked post-visit what they could do about climate change, survey respondents mentioned eating less meat, flying and using the car less and reducing general consumption.

The greenhouses provided a visceral space to physically experience and engage in dialogue about climate change in relation to horticultural and wild plants in Switzerland and became a site of reflexive learning. Evidence from surveys and participant feedback showed that they could relate to the timescale represented. The timescale was presented to participants as part of a time continuum, as discussions emphasized that we already had a climate that was 1.7 °C warmer than the pre-industrial average. We also looked at a graph of the downscaled scenario, which represented this continuum flowing from the past to the future.

Perhaps one of the most gratifying results of *Climate Garden 2085* has been its sustained momentum. We created a DIY handbook for communities to create their own public experiment, *Climate Garden 2085: Handbook for a public experiment* (Schlaepfer-Miller & Dahinden, 2017). Versions have been installed in Bern and San Francisco, and it was set up at a technical university and five high schools in Switzerland in the summer of 2019 and nine schools in 2021. Further gardens are in planning, and some high schools are maintaining it as a semi-permanent installation. This adaptation of the experiment to local stories is critical to local agency.

Summary

Science education about climate change – a wicked problem indeed – requires a hybrid approach, in this case an art-science public experiment in the form of a garden. As Demos (2012) has noted, a garden may seem irrelevant in the face of the myriad of complex crises we are confronted with, but within a garden lie many political and economic conflicts surrounding climate change. While many of these may require a global response, *Climate Garden 2085* found moral entry points into local dialogue by talking about local foods and landscapes. However complex, a local narrative was told, a narrative that could be teased apart, making it tangible and relevant. We strove to show that there were options despite uncertainty and emphasized that despite uncertainty as to the extent of the coming changes, the need for immediate action was unequivocal. Such action must involve participation, enabling dialogue, agency and mobilization.

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Chapter 9
Using a Wicked Problem for Inquiry-Based Fieldwork in High School Geology: Addressing Climate Change and Mass Extinction Events

Lene Møller Madsen, Robert Evans, and Rie Hjørnegaard Malm

ELICIT: Setting the Scene for the Reader

In our example of educational design, we transform a traditional topic of high school geology – mass extinction at the end of Cretaceous times – into an example of a wicked problem of climate change. Thus framed, the study of mass extinction works well as an engaging inquiry for high school pupils. For teaching, this exercise in transforming a traditional topic into a wicked problem promotes awareness of future challenges to society and insight into practices for addressing them.

However, before we start, we need to address you as the reader. What is your knowledge of using wicked problems in fieldwork activities for high school pupils? How do you interpret the idea of using inquiry in structuring science teaching? What do you see as the most pressing challenges of science education in today's society? These are questions we would like you as the reader to consider. If we knew your answers to these questions, we would adjust and target the chapter to your present knowledge and interest in the subject and thereby increase the potential learning outcome of your reading.

This approach reflects the idea of the ELICIT phase in our version of inquiry teaching: to establish what pupils know of a specific subject in order to use that knowledge in the subsequent lesson. However, to proceed with the chapter, we have relied on our conjectures and imaginations of who would find it interesting to read a chapter like this and then subsequently targeted the chapter to this imagined reader.

To be faithful to the idea of inquiry, we have organized the chapter as a meta-inquiry of an inquiry of pupils learning at Stevns Klint (exposed sedimentary layers

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M. Achiam et al. (eds.), *Addressing Wicked Problems through Science Education*, Contributions from Science Education Research 8,
https://doi.org/10.1007/978-3-030-74266-9_9

at 55.2795° N, 12.4450° E in Denmark). The meta-inquiry for the reader includes this short ELICIT phase and continues with ENGAGE phase where we introduce a wicked problem. In the following EXPLORE phase, we provide a full inquiry of pupils learning at Stevns Klint. In this pupil inquiry, you will have the opportunity to discover the geoscience content provided through an example of how a wicked problem is used in an inquiry for high school pupils learning science in the field. This is followed by the continuation of the meta-inquiry with the phases of EXPLAIN and EXTEND where we argue for the use of wicked problems in geoscience learning and the use of inquiry. In the FEEDBACK phase, we urge you to reflect on the feedback in the paper. Finally, in the discussion and concluding comments, we stress the need for science instruction of wicked problems. To help you navigate the reading, we suggest you use the Box: Overview of the Structure in this Chapter.

Box: Overview of the Structure in this Chapter

Throughout the text, we provide opportunities for you to reflect on issues in the text in relation to your own practice; you will see them as text written in italics. Conceptualize these opportunities as our feedback to you as the imagined reader of the chapter.

ENGAGE: Using Fieldwork to Learn About the Potential of a Wicked Problem

The idea of wicked problems was raised in the 1960s and 1970s (Rittel & Webber, 1973). At that time, an emerging understanding was established about the shortcomings of using scientific theory building and empirical testing to discover underlying rules (Lawson, 2005) to deal with the rising awareness of environmental problems (Carson, 1962). Inherently caught up in societal issues of capitalism and politics, environmental problems solely addressed by using science solutions came up short. Here, the concept of wicked problems seemed promising. Although difficult to define, wicked problems are often described by a number of distinguishing features, e.g. there is no immediate and no ultimate test of a solution to a wicked problem and wicked problems are never solved but constantly resolved (Rittel & Webber, 1973). See the introductory chapter in this book for an elaborated description of wicked problems. Climate change is one such wicked problem that can be addressed through education (Wals et al., 2014).

The mass extinction observed at the Cretaceous-Paleogene boundary is an example of a constantly resolved, scientific problem. For geologists, decades of fieldwork and laboratory analysis have established a sequence of different theories about why this boundary exists. In essence, the boundary is an archive that has accumulated the consequences of rapid climate change and its influence on biodiversity. The extinction was large with profound effects on life on earth. The scope of this extinction raises many questions such as: What caused this mass extinction? How do scientists establish knowledge about the causes of an extinction? How can engagement with the archive of evidence for Cretaceous-Paleogene extinction events help pupils hypothesize about the nature of large future extinctions? The concept of wicked problems can be a way to conceptualize and connect these questions.

A pupil inquiry into this boundary problem provides a basis in both content and process for addressing the wicked problem of climate change. Pupils' analysis of the location, structure, contents and geological aspects of the boundary can provide the grounds for their predictions about what might define a future boundary between the present Holocene epoch and a new 'Anthropocene' one. Although disputed among stratigraphers, Stromberg (2013) clarified the status of Anthropocene as a proposed name for an epoch of human influence:

> According to the International Union of Geological Sciences (IUGS), the professional organization in charge of defining Earth's time scale, we are officially in the Holocene

> ("entirely recent") epoch, which began 11,700 years ago after the last major ice age. But, that label is outdated some experts say. They argue for "Anthropocene" - from *anthropo*, for "man," and *cene*, for "new"- because human-kind has caused mass extinctions of plant and animal species, polluted the oceans and altered the atmosphere, among other lasting impacts. (Stromberg, 2013, no page numbers)

The analogy between the Cretaceous-Paleogene mass extinction event – a traditional topic of study – and the impact of today's human-induced climate change, a wicked problem, leads to a promising objective for pupil learning. Having considered threats of extinction due to changing climates to the current life on Earth, pupils hypothesize what remnants of today's world might become part of a boundary uncovered 10,000 years into the future marking the beginning of the Anthropocene.

Pupils' understanding and prediction of the geological results of mass extinction events must rely on a specific type of reasoning that is a result of geology being an interpretative and historical science (Frodeman, 1995). In the discipline of geology: "the goal is not primarily to identify general laws [as for instance in physics] but rather to chronicle the particular events that occurred at a given location" (Frodeman, 1995, p. 965). Therefore, the focus of investigation in the Cretaceous-Paleogene mass extinction is to establish knowledge of the cause(s) of the extinction and relate it/them to the chronicling of events through geological time recorded by layers of rock in many locations around the world near the Cretaceous-Paleogene boundary. However, "the problem is that the present is too small a window into the past to provide the geologist with a full set of analogues" (Frodeman, 1995, p. 965) or as formulated by Ager (1993): "is the present a long enough key to penetrate the deep lock of the past?" (p. 81). In other words, no matter how long or how much we search, we will not be able to determine the cause of the mass extinction by using science as a 'benign' science. We need to use other types of reasoning, namely, a 'best fit' type of reasoning, where the result is the best possible explanation with the available data. 'Best fit' reasoning is a search for "a trace that picks out one of the competing hypotheses as providing a better causal explanation for the currently available traces than the others" (Cleland, 2001, p. 988). Exactly this type of reasoning makes an inquiry of the Cretaceous-Paleogene mass extinction event an especially powerful source of content for pupils to use in hypothesizing what a contemporary boundary might look like in the future. An exploration of the Cretaceous-Paleogene boundary can become the basis for a wicked problem projected into the future, with many possible answers based on thoughtful analogies with past boundary depositions.

Thinking of your own discipline may give you an example of a wicked problem that has no solution in the sense of definitive and objective answers. What counts in your discipline as a 'benign' problem? In contrast, what exists as a wicked one? With these two examples in hand, what learning situations would enable your students to see the difference? They might compare and contrast your 'benign' problem with the wicked problem on the bases of resolved versus *continuous attempts at resolution; relatively short-term research work* versus *recurring long-term research; large agreement about a solution* versus *large disagreement over solutions. The* *comparison of 'benign' and wicked problems may begin a search for principles that bridge thinking from between the two contexts in promising ways. In a very real sense, such principles constitute the disciplinary expertise needed to begin to attack wicked problems. They also serve well as objectives for student learning made meaningful by the wicked problem context.*

EXPLORE: An Inquiry for High School Pupils

ELICIT and ENGAGE: High School Pupils' Classroom Preparation Prior to Fieldwork

Before going into the field, high school teachers elicit existing shared knowledge of their pupils' previous experience with sketching profiles and reasoning based on geological time, without addressing the specific expected outcomes of the fieldwork. To provoke interest and engagement in this ELICIT activity, the teachers show general photographs of the site without any reference to the content to be observed and ask questions such as: How could one make observations of this cliff? How would one find out what created the structures of the cliff? The ELICIT phase is a shared discussion where the teachers also need to be aware how it sometimes advantages some pupils and disadvantages others (those with no familiarity with the topic). A common experience or shared knowledge as a starting point for reflection can help. For example, a local engagement is to ask pupils to take a photograph of a street trench-digging site somewhere near their home where they can see layers of past street surfaces and underlying layers of sand, stones, etc. They share these photographs and observations and hypothesize about the story such a dig might reveal about their own neighbourhoods. The ENGAGE concludes with logistic travel details and suggestions for clothing, food and comfort provided by the teacher.

EXPLORE: High School Pupils Conduct Fieldwork at Stevns Klint

In this section, we explore a learning situation at Stevns Klint in Denmark (55.2795° N, 12.4450° E) from a high school pupil's perspective. See Fig. 9.1a and 9.1b for photographs and Box: Stevns Klint, a Geological Description of the Fieldwork Locality.

So, let us go there together:

Imagine you are a high school pupil standing at the top of the cliff at Højerup in Denmark where you have a great view of the sea in front of you. You know that you are standing on top of something, but there are no indicators of what is underneath your feet. Up here you see green grass, bushes and trees. The wind is fresh and

Fig. 9.1a Stevns Klint at Højerup. The black box indicates the fish clay's placement in the profile. (Photo: Rie Hjørnegaard Malm)

Fig. 9.1b Stevns Klint. Detailed picture of the fish clay at Rødvig. (Photo: Lene Møller Madsen)

smells of the salty sea in front of you. A steep staircase leads down to sea level. On the way down the staircase, you get a distant view of a white cliff.

Box: Stevns Klint, a Geological Description of the Fieldwork Locality
Stevns Klint is a 15 kilometres long and up to 41 metres high coastal cliff on the east coast of Zealand in Denmark. Stevns Klint has been known and investigated as a geological locality since the 1750s and in 2014 it gained new status by joining UNESCO's World Heritage List (Damholt & Surlyk, 2012). Stevns Klint has one of the most extensive Cretaceous-Paleogene border profiles in the world and demonstrates all known bio zones with an excellent conservation of a species-rich fossil content with more than 830 species of macro fossils alone and hundreds of nano- and microfossils (Damholt & Surlyk, 2014). Consequently, Stevns Klint is one of the best locations in the world to study biological changes across the Cretaceous-Paleogene boundary 66 million years ago. More than half of all the Cretaceous species including terrestrial dinosaurs and large sea mosasaurs died, and after this mass extinction event, a completely new ecosystem was gradually developed with a large number of new species.

At the bottom, the cliff consists of layers of chalk from the end of the Cretaceous period. Above this is a fish clay unit marking the boundary between the Cretaceous and Paleogene geological time periods. The fish clay reflects an abrupt stop in the chalk production of nano-, micro- and macrofossils (see picture below). This marks the decline in primary production, which is characteristic of the Cretaceous-Paleogene extinction event that has been globally documented (Damholt & Surlyk, 2014). The fish clay is followed by limestone from Dania in the form of major bryozoan mounds. The bryozoan mound geometry, dimensions and architecture are evidenced by thick black flint layers. The mounds are visible throughout the length of the cliff and represent some of the finest cold-water-carbonate bank complexes in the world (Damholt & Surlyk, 2014). The dark flint layers show a precise image of the original surface of the seabed. The upper meters of the cliff consist of moraine clays from the last ice age.

For further reading about Stevns Klint, see Anderskouv et al. (2007) and Surlyk (1997), and see Surlyk et al. (2006) for thorough descriptions and great graphical representations of the cliff along its full length.

You are now standing on a beach; it looks quite different from other sandy beaches you know. This beach consists of black and grey, round, smooth rocks of a very similar size (see Fig. 9.1a). When the waves approach the beach, they produce a unique deep sound due to the rolling rocks. Looking straight up you cannot see the top of the cliff because of a large overhang. When you look along the cliff, you see that the overhang continues along its length. You see white, yellow, green and black colours on its face. The main part of the cliff looks white. The yellow seems most prominent in particular places and not as a continuous colour. In some places it looks like the yellow flows down vertically. You also see some black lines in the white continuing along the cliff. In the overhanging part, the black lines seem wavy. Now your teacher says ‘Welcome to Stevns Klint’.

The teacher continues: ‘Your first task is to describe and draw what you observe. Work in pairs and discuss what you see’. As you and the other pupils find each other and begin to talk, the teacher asks: ‘Do you remember what we discussed in class about observing?’ One pupil tries to recall something and says: ‘I think you can look for colours’. The teacher acknowledges the reply and helps the pupils explore the different colours in the cliff. She talks and discusses with pupils, questioning what colours seem more interesting than others. She uses the pupil observations to ask about the black lines, and the pupils observe that they look different in the top compared to the bottom of the cliff. She asks the pupils to use their observations to begin to suggest a hypothesis about the geological history of the cliff.

EXPLAIN: High School Pupils Interpret the Geology at Stevns Klint

The teacher begins to facilitate pupils’ understanding of their exploratory observations while they are still in their small groups. Questions are asked of each group to nudge pupils to begin to interpret their observations. The teacher is careful not to anoint prior knowledge about the site as ‘correct’ but instead focuses the pupils on their observations and asks them for alternative inferences from what they have recorded.

As groups finish their initial observations, drawings and inferences, the teacher gathers all of the pupils together. Firstly, the groups share their drawings and initial hypotheses about the history of the cliff. Then, a datasheet (see Fig. 9.2) is distributed which denotes the completion of the transition of the lesson from the EXPLORE to the EXPLAIN phase. The task for the pupils is now to figure out what the datasheet shows and how it relates to their own observations. The pupils will notice that there is a significant change in the distribution of benthic foraminifera at one specific point in the graph. This can be interpreted as the boundary between the overhang and the lower part of the cliff face. Above this boundary, there is less species diversity, while some species become more abundant. Pupils reflect on this extension of their own observations followed by a discussion of what it could mean that at one specific point there is a massive change in the distribution and abundance of these benthic foraminifera. Eventually, the teacher confirms their good ideas and introduces current scientific conjecture about the transition between geological epochs.

Now we leave the pupils and their teacher. Together they will work their way through the inquiry lesson.

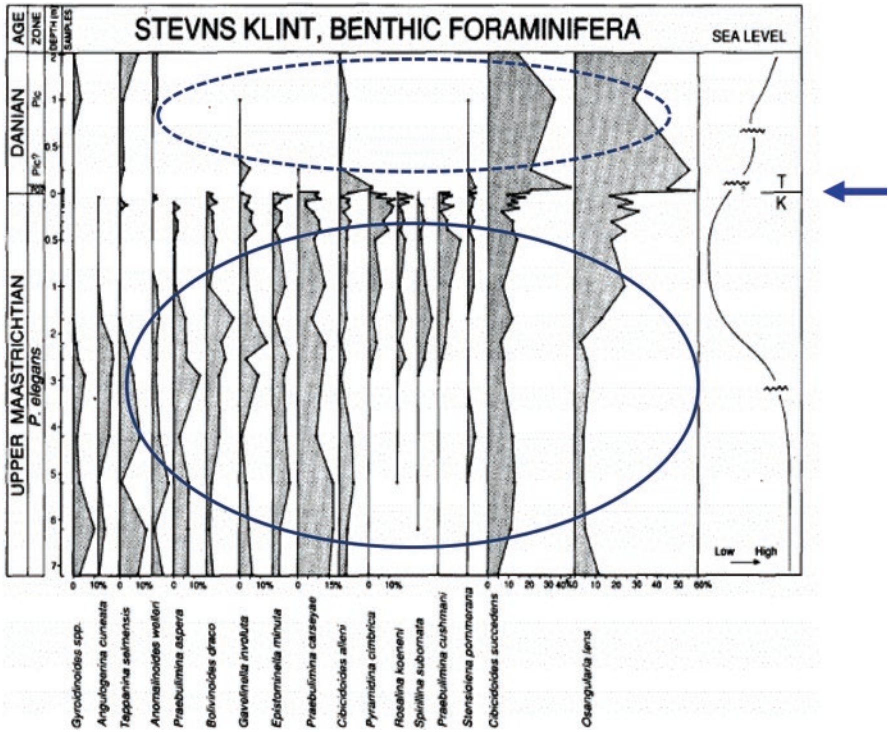

Fig. 9.2 Datasheet: Abundances of benthic foraminifera in Stevns Klint (reproduced from Schmitz et al. 1992 with permission from Elsevier). The datasheet shows abundances and variation of benthic foraminifera vertically in the profile at Stevns Klint. Interpretation of the datasheet shows that many different species of foraminifera are present in the lower part of the vertical profile (oval, fully drawn). There is a significant change in the distribution of the foraminifera at one specific point in the graph (indicated by the arrow); this can be interpreted as a boundary. Above this boundary, there is less diversity of species, and some species become more abundant (oval, dotted). For going in the field at Stevns Klint, use datasheet and original data in Schmitz et al. (1992). Here, only shown for illustrative purposes.

EXTEND: High School Pupils Apply the Learning Outcome from Fieldwork to Address a Wicked Problem

Back at the school, the teacher facilitates applications of new student understandings from the fieldwork by introducing the wicked problem of predicting what a future boundary from our times might be like in 10,000 years. Pupils are asked to imagine what a Holocene-Anthropocene boundary indicating a transition from our current Holocene epoch to the Anthropocene epoch of human influences would look like. They draw such a future boundary based on the transition they studied at the

Cretaceous-Paleogene boundary and their knowledge of what influences humans currently have on the planet. The prior knowledge of human impact on the earth at geologic scale pupils bring to the task of the wicked problem inquiry will depend on the pupils' general knowledge based on prior schoolwork, news and media, visits to Stevns Klint, conversations with family and friends and museum visits. For the inquiry to work, the teacher must engage in the nature, variety and sources of this very important prior knowledge of the pupils. The pupils' predictions need to be logically constructed from empirical information, plausible causal connections and imaginative extrapolations. For example, pupils might hypothesize that the Holocene-Anthropocene boundary would become evident in a sharp decrease in fossil vertebrates going into the Anthropocene or a higher relative abundance of invertebrates due to the higher levels of atmospheric CO_2. Some might imagine that this transition could be visible in their hypothetical Holocene-Anthropocene profile. Their boundary should also represent different types of sediments above to acknowledge different sea levels before and after the future mass extinction.

An advanced class might find reading about the chemical analyses of the Cretaceous-Paleogene boundary components interesting and useful in creating their Holocene-Anthropocene boundary of the future. They will find that while the element iridium is extremely rare in the earth's crust, it occurs everywhere in the world in the Cretaceous-Paleogene boundary and at Stevns Klint it is 160 times the natural occurrence (Alvarez et al., 1980). The hypothesis is that when a meteorite which contained large amounts of iridium collided with Earth, the collision injected this otherwise rare metal into Earth's atmosphere. The iridium anomaly is a predicted effect of a meteor impact, which has since been confirmed by geochemical studies of the Cretaceous-Paleogene boundary sediments (Schmitz & Asaro, 1996). Knowing that one of the characteristics of the Cretaceous-Paleogene boundary they have examined at Stevns Klint is a uniquely identifying component (iridium), they might think of including another rare element in their hypothetical Holocene-Anthropocene boundary.

There are no correct student predictions to a future Holocene-Anthropocene boundary but scientifically good and bad suggestions based on what the pupils know about geological boundaries and present-day climate change. Explore Box: Current Scientifically Viable Reasoning for Future Predictions of a Holocene-Anthropocene Boundary, which describes current scientifically viable reasoning for future predictions. Subsequent sharing of drawings and discussions of pupils' solutions to 'their' wicked problem reveals conceptions and validates scientifically based pupil understandings about boundaries, geological processes and content.

Box: Current Scientifically Viable Reasoning for Future Predictions of a Holocene-Anthropocene Boundary

With our current knowledge of climate change and possible indicators, we can try to predict what will be observable in future geological strata. Having focus on present climate change challenges means that the wicked problem should be situated in a not so far future (we suggest 10,000 years) as today's changes

Box: Current Scientifically Viable Reasoning for Future Predictions of a Holocene-Anthropocene Boundary (continued)

are very rapid compared to pre-historic climate changes observable in currently available geological strata. Independent of the time framing, pupils need to apply what we have termed current scientifically viable reasoning in their exploration of the wicked problem. For a future Holocene-Anthropocene boundary, we find the following arguments viable:

- Sea level rise due to climate change has been accelerating in the past decades and thus is an important factor (for summary see IPCC (2018) Special Report on Global Warming of 1.5 °C). The sediment deposits and biodiversity of the oceans will change with the alterations in the environment and can possibly be visible in a future geological record. Physical changes in the ocean's global circulation might be possible to observe in the future due to the change in sediment transportation. The Atlantic meridional overturning circulation (AMOC) is one example of this (Thornalley et al., 2018). This study shows that the AMOC has slowed over the last 150 years resulting in a change of sediments as weaker currents can carry smaller sand grains. On land we see the areas with permafrost become smaller and change relatively fast due to climate change (Borge et al., 2017). In the future, we might see changes in every type of landscape. Consequently, imaging what forests, desert and mountain areas will look like and how this will be preserved in the geological record is possible.
- A major change in biodiversity on land can also be predicted through what biologists call the sixth mass extinction (Barnosky et al., 2011). If the change in biodiversity is preserved, it could be visible in the geological record in the future, just like change in biodiversity over the Cretaceous-Paleogene boundary.
- Discussing the definition of Anthropocene and geological time could also be relevant (see Box 1.1 in Chap. 1 of the IPCC (2018) Special Report on Global Warming of 1.5 °C). A direct link between the iridium content used to mark the Cretaceous-Paleogene boundary are the transuranic elements, which are suggested to be used to mark the Anthropocene as a geological boundary. Plutonium and other so-called transuranic elements do occur naturally, but at very low concentrations, and thus we assume that when plutonium is found in nature, it is induced by humans (Santana, 2019). Plutonium in the form of 239Pu and 240Pu have long enough half-lives to be visible to the future geologists (Hancock et al., 2014). The nuclear detonations that occurred between 1945 and 1980 distributed plutonium globally and thus ensured that it could be a global marker just as iridium on the Cretaceous-Paleogene boundary (Santana, 2019). The introduction of plastic in the sedimentary record could also be an argument for defining the Anthropocene boundary (Brandon et al., 2019).

FORMATIVE FEEDBACK: Continuous Evaluation Informing High School Pupils About Their Progress

Throughout the previous five phases of this lesson (ELICIT, ENGAGE, EXPLORE, EXPLAIN, EXTEND), both teachers and pupils give and receive feedback about their teaching and learning progress. Teaching using any kind of inquiry is often a challenging task even for experienced teachers since it requires more flexible planning because the exact direction and needs of pupils are not entirely predictable. Pupils sometimes do not prefer inquiry lessons, because they are unfamiliar with them and do not appreciate their value and because they require more work on their part. Furthermore, inquiry lessons take longer, and their exact length is difficult to precisely control.

Let us go back to the pupils at Stevns Klint:

During the ELICIT phase, the teacher asks who among the pupils have visited the cliff before, perhaps with family or another teacher, and then uses this formative feedback from the pupils to improve the lesson in two ways. The teacher assures the pupils that past experience is relevant and adjusts teaching plans according to how knowledgeable the pupils are about the Stevns Klint site, perhaps by grouping pupils according to their previous experience. Pupil engagement based on their previous experience with Stevns Klint can also be more appropriate when the formative feedback about past experience at Stevns Klint is considered. ENGAGEMENT is based on the premise that there are discoveries about the site to be made and if they have been there before that there are also new discoveries to be made. The pupils are taught that what counts is both their past learning and their working with the data, explaining what they both know and observe helps build their hypotheses. With this approach, the pupils both access and use what they know beforehand, as well as what they have just observed. The interaction and feedback from the teacher are crucial in this phase.

During the EXPLORE phase, while pupils are making observations on the beach and beginning reflections, the teacher continuously offers formative feedback by interacting with each group as they are discussing their observations of the cliff and their observations of the datasheet and are starting to formulate hypotheses. In one of the groups, a student whispers to the others: ‘I know that the dinosaurs went extinct very suddenly, I think a lady told me when I was here a few years ago’. The others agree, yes, they too have learned about this, somewhere. Perhaps, this could be it. However, how do they prove it? They discuss if it could be possible to see dinosaurs’ bones in the sediments. No, they have just learned that this is a marine environment, yet, some marine dinosaurs could have existed but they are not sure. They discuss for a while how it would be possible to find traces of dinosaurs to prove their idea. The teacher approaches: ‘Any ideas so far?’ The group shares their ideas about dinosaurs and the teacher replies: ‘That is a good idea and so you should say something about the possible evidence of dinosaurs in relation to this place. In addition, what can you add to these ideas from your cliff observations and the datasheet?’ The group shows the teacher their sketches of the cliff and explains how they understand the datasheet. From this, the group expands their ideas and slowly formulates hypotheses based on their knowledge of dinosaurs as well as their observations and the datasheet. If other groups have some preliminary observations, the teacher gives formative feedback to either assure the pupils that their observations are valid and relevant or redirects them to more salient perspectives. Simultaneously, this same feedback helps the teacher know the progress and success of the explorations, enabling adjustments to time, level of difficulty and grouping decisions.

When the groups are reunited for the EXPLAIN and EXTEND, the teacher continues to formatively assess by giving support to pupils for their observations and hypotheses, rewarding reasonable reflections so that pupils don't feel overwhelmed by the tasks of this wicked problem, but can see that they are making progress with the 'best fit' reasoning of what has happened. With continuous dialogic discourse with the pupils during these phases, the teacher also gets continuous formative feedback on the progress of the pupils in making sense of the site allowing for adjustments to the ongoing learning process.

By interacting continuously with groups of pupils during inquiry fieldwork, high school teachers can assess how their lesson is proceeding. They can make spontaneous lesson adjustments based on feedback from the pupils and maintain their own confidence in the lesson by recognizing gains and adjusting problems.

Now you have 'been in the field with the students and their teacher', how do you perceive the value of formative feedback? Try to think of and maybe discuss with a colleague the pros and cons of formative feedback for learning, for motivation, for developing a science identity for both students and teachers practising formative feedback.

EXPLAIN: Readers' Clarifications

Why Use Wicked Problems to Organize Inquiry and Learn Geological Research Methods

Having explored the teaching from the pupil's perspective at Stevns Klint, you know that it includes many phases of geo-scientific exploration: observations, developing hypotheses, refining the hypotheses, linking observations, interpretation of data and constantly relating the different explorations to understand changes in environment, biodiversity and geological time. In the following, we aim at providing a detailed argument as to why the teaching is organized as an inquiry using a wicked problem, based on the intended learning outcomes, which are ultimately rooted in learning the geological research methods.

The specific Intended Learning Outcomes (ILOs) for the lesson are to:

- Make geological observations of the strata and express these observations in a geological profile of Stevns Klint (55.2795° N, 12.4450° E).

- Compare and contrast the observed strata with the data on abundances and variation of benthic foraminifera vertically in the profile at Stevns Klint.
- Hypothesize a probable boundary in the datasheet based on an interpretation of the abundance and variation of benthic foraminifera.
- Suggest reasons for the abrupt change in biological diversity and the sedimentary structure of the cliff.
- Use generalizations from the study of the Cretaceous-Paleogene boundary to predict the contents of a hypothetical Holocene-Anthropocene boundary 10,000 years in the future.

These ILOs fit into more general goals for learning within the discipline of geology, to:

- Make geological observations and sketches.
- Connect different types of data and construct geological interpretations in the field.
- Project from current analyses to future events.
- Reflect on 'best fit' reasoning in geoscience.

The EXPLORE at Stevns Klint focuses on one of the core elements of geoscientific exploration: conducting observations (Mogk & Goodwin, 2012; Raab & Frodeman, 2002). In the field, pupils are able to observe the different characteristics of the chalk units in the top and the bottom parts of the cliff and draw a geological profile of Stevns Klint. The discontinuity between the two units constitutes a significant boundary in geological history. But the pupils are not able to extract this information from their observations alone. Some pupils might argue that both units look the same; they are both white with black lines. Therefore, the first part of the teaching concentrates on guiding the pupils' observations towards establishing arguments for separating the two units. After drawing the profile, the pupils have some indicators of the boundary based on their observations of the cliff's relief and the difference in the appearance of the black lines. All hypotheses are viable at this point. The next step for the pupils is to find the piece of data or evidence that sets one preliminary hypothesis apart. The teacher then introduces the datasheet (see Fig. 9.2), and the task is for the pupils to identify the boundary in the datasheet followed by a discussion of what could it mean that at one specific point where there is a massive change in the distribution and abundance of benthic foraminifera.

In this first EXPLAIN, the challenge for the teacher is to help the pupils link their observations of the cliff with their interpretations in the datasheet. They realize that the datasheet shows the distribution and abundances of benthic foraminifera in the cliff and establish that the two boundaries go directly together in that the overhanging top part of the cliff matches the top part of the datasheet where fewer species are present. The abrupt change in relief of the cliff matches the significant boundary on the datasheet, and the lower part of the cliff matches the section with many different species of foraminifera. In the field, the teacher's job is to help the pupils describe what they see in the geological profile, in the datasheet, and guide them to make the connection between the two. The teacher's role is to ensure that each pupil gets the chance to formulate a set of observations and create a hypothesis. In the small groups, the pupils also guide each other.

At the end of the first EXPLAIN phase, the pupils can conclude that there is a significant difference between the top and lower part of the cliff. They now know there was a major change in distribution of foraminifera and that change can be traced back to the cliff, which has a prominent boundary that separates the upper and lower section. Following this, a second EXPLAIN phase can be included where pupils discuss what this information tells them and draw on their knowledge of changes in the environment and Earth's history. What could be the reason for such an abrupt change in biological diversity and the change in the relief of the cliff? To support this discussion, the pupils are given pictures of different environments of depositions to discuss and link to their observations and drawing of the profile. An environment of high sea level below the Cretaceous-Paleogene boundary has resulted in a deposit with mainly algae skeletons, while an environment of lower sea level above the Cretaceous-Paleogene boundary has resulted in a deposit of bryozoan mounds (Surlyk, 1997; Surlyk et al., 2006). Two observably different deposits that the pupils have seen directly follow each other in the strata, which is difficult to understand considering the two very different depositional environments, suggesting a very abrupt environmental change. High school pupils can now discuss how this can be, and the teacher helps by guiding them towards an understanding of geological time and the fact that there is a period of time not represented in the strata between the time of deposition of the two layers (a lacuna or hiatus).

In the field, the pupils combine their observations of the locality and their interpretations of the datasheets and pictures of different environments of depositions; this directly simulates the process of going back and forth between observation and data. This iteration we argue would be more difficult if the interpretations of datasheets were reserved for the post-visit classroom.

As a reader with some experience of taking pupils to the field: what are the pros and cons of including interpretations of datasheets in the pupils' learning experience in the field? Make a list and consider if some of the cons can be overcome in order to enhance the pros.

EXTEND: Readers' Applications

Linking Historical Science to Solving Challenges to Society

You have now explored the locality of Stevns Klint as well as how the fieldwork for the high school pupils is organized as an inquiry. In this section, we would like to extend the argument of focusing the inquiry on a wicked problem as a way of enhancing pupil learning about the challenges to today's society and how it is linked to the fact that geology is an interpretive and historical science.

What is common for the historical sciences is that they build on observations of past causes of phenomena. Some of the most familiar hypotheses within the historical sciences mentioned by Cleland (2001) are continental drift, the meteorite impact extinction of the dinosaurs (the Cretaceous-Paleogene mass extinction), the big bang, and the hypothesis that there are planets orbiting distant stars. All of these phenomena are concerned with "long past singular events and processes" (Cleland, 2013, p. 1) that make scientific exploration and reasoning dependent upon often incomplete observations which are significantly different from observations of experiments or tests. Cleland (2013) further argues that: "the dominant form of explanation in the historical natural sciences is common cause explanation. The basic idea is to attribute a puzzling collection of traces to a common cause. The common cause hypothesis that does the best job of explaining the total body of traces available is judged the most plausible" (p. 7). This means that a geologic explanation is often an interpretation of traces of the past embedded in the rocks and carrying a temporal signature.

When geologists work in the field, they search for all the possible explanations often due to the unsolvable nature of many problems, as data are often incomplete and will never be available. They work with multiple hypotheses until they find that one piece of evidence that sets one hypothesis apart (Chamberlin, 1890) and know that today's hypothetical explanations of geological boundary observations are likely to be redrawn in the future (Cleland, 2011, 2013). This way of reasoning is then somewhat connected to creativity and playing with different ideas. In the case of the Cretaceous-Paleogene mass extinction event, there are many hypotheses in play (e.g. volcanic activity, meteorite impact or an interplay between the two) and long discussions in the scientific community illustrating the scientific process in the historical sciences (Alvarez et al., 1980; D′ Hondt, 2005; Sharpton & Ward, 1990).

High schools in Denmark offer Physical Geography as a geoscience subject. Recently a new subject, Geoscience, which includes both physical geography and physics (Malm & Madsen, 2014, 2015, 2015b) has been added to the high school curriculum. Within Physical Geography, 20% of the teaching must be experimental, with a large focus on pupil exploration, the ability to conduct fieldwork and to collect data. Within Geoscience high school teachers are obliged to choose a locality that the pupils visit several times during the school year to observe seasonal changes in nature and on learning different data collection methods (Malm & Madsen, 2014). We argue that wicked problems are a potential part of most fieldwork related to these two high school subjects. Adding them to existing confirmatory fieldwork can provide opportunities for authentic scientific engagement through inquiry. The unknown element of wicked problems provides a real milieu for pupils to genuinely inquire about a phenomenon since there are not any fixed 'answers' to spoil the process. With wicked problems, answers are more speculative and hence encourage pupils to take risks with their thinking while putting their science to work in a context of social value. However, pupil thinking must be within the geological reasoning of common cause explanation.

The Use of the 6F Model for Inquiry Teaching

In teaching, we can use the constantly resolved scientific problems with multiple explanations and hypotheses to train pupils in reasoning. This is valuable when addressing wicked problems because they experience how science does not produce ready-made answers but is developed through interpretation and iteration between observations and incomplete data. Learning science through an inquiry lesson is an experience that resembles working with a non-ready-made scientific problem because the inquiry is open. The pupils must work through the inquiry and need to be creative and create valid arguments based on the incomplete observation and data to which they have access. In other words, they practice interpretive reasoning and how to address scientific problems without an immediate answer. This prepares and aligns them to be able to address wicked problems, for example, as we have outlined future mass extinction events caused by climate change.

The six-phase inquiry model (6F model) that we have used in this chapter is a model we use in our pre-service teacher education courses at University of Copenhagen (see Fig. 9.3). As described in Madsen et al. (2020), the 6F model is adapted from 'The Biological Science Curriculum Study (BSCS) 5E model' that was developed in the 1980s in the United States (Bybee, 2009; Bybee et al. 2006). The basis of this model came from the work of a German philosopher and educator, Johann Friedrick Hebart, in the early 1900s. He predicated that scientific experiences and social interactions in nature, when related to existing student knowledge, are essential for learning. Consequently, Bybee's 5E model and the 6F model include 'engagement' and 'exploration' with consideration ('elicitation') of previous knowledge as the necessary first three phases in learning science via inquiry. These phases and their sequence can be traced back to Herbart's sequential strategy for facilitating learning (Bybee et al., 2006).

In the early twentieth century, John Dewey described a series of stages of reflexive thinking: defining the problem, making hypotheses, generating ideas for

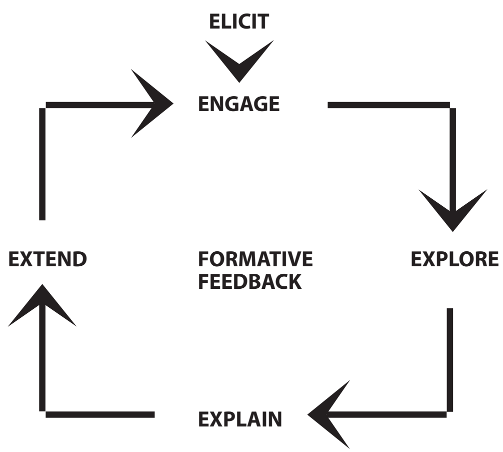

Fig. 9.3 The 6F model used in science teacher education at the University of Copenhagen. It is an adaptation of 'The Biological Science Curriculum Study (BSCS) 5E- model' (Bybee, 2009; Bybee et al. 2006) where we have replaced the Evaluation phase of the BSCS model with continuous FORMATIVE FEEDBACK and added ELICIT at the beginning based on Eisenkraft (2003)

possible explanations, testing and clarification (Dewey, 1997, first published in 1920). This work led to the concepts of learning cycle models (Heiss et al., 1950; Karplus & Thier, 1967). Karplus and Thier's learning cycle contained three successive phases: exploration, invention and discovery corresponding to the 5E and 6F phases of EXPLORE, EXPLAIN and EXTEND (Madsen et al., 2020). Based on this model, the BSCS 5E model has an ENGAGE phase and an EVALUATION in the end of the learning cycle (Bybee et al., 2006).

In the 6F model, we have added Eisenkraft's (2003) suggestion of an ELICIT phase to the model to ensure teachers have knowledge of their pupils' prior knowledge and experiences relevant to an inquiry, before beginning (Madsen et al., 2020). Knowing which pupils share prior understandings, teachers can help them focus on more subtle observations and perhaps even assign them to the same pupil groups with more advanced foci for observation to address their different experiences and knowledge.

We further modified the BSCS 5E model by substituting continuous FORMATIVE FEEDBACK for the evaluation phase of the BSCS 5E-model (Madsen et al., 2020). Our grounds were research that strengthens the value of formative feedback to pupils struggling with inquiry teaching (Evans et al., 2018). Given the sometimes new and challenging experiences of inquiry learning, pupils who may be reluctant to engage fully in inquiry, whether due to unfamiliarity or increased cognitive demands, are encouraged by authentic teacher feedback and constructive peer interactions. When pupils anxieties over not knowing 'how they are doing' receive frequent formative feedback on their progress from peers and teachers, they are more likely to continue to expend the effort necessary for completion (Evans & Dolin, 2018). Concomitantly, teachers who get frequent feedback on pupil progress in inquiry lessons are also more likely to be motivated to continue challenging lessons. Part of this increased motivation is due to increases in self-efficacies resulting from supportive formative assessment (Evans et al., 2014).

How is the 6F model different from the inquiry teaching you know? Try to compare and contrast a concrete experience you have with inquiry either as a teacher or as a student. Are the differences significant for your approach to try out planning and conducting an inquiry – or engaging in an inquiry lesson yourself?

FEEDBACK: Readers' Conclusions

Reflections on How to Use Wicked Problems in Own Teaching

Throughout this chapter, we have provided feedback to you as the reader specifically through four small thinking assignments (indicated by italics in the text) that challenged you to reflect on your own practice in relation to the content and arguments in the chapter. Now – by placing yourself in the position of the high school pupils and their teacher who has been trained in inquiry teaching – you can imagine how well a fieldwork lesson of your own focusing on a wicked problem might fit this milieu. Would your own fieldwork lesson lend itself to genuine inquiry by pupils into a wicked problem or would you need to alter your objectives to accommodate thinking that is more scientific to facilitate a wicked problem? Could a visit you have made before lend itself to an exploration by your pupils before using their findings to create an explanation with multiple outcomes? Many traditional ‘confirmatory’ fieldworks can become more inquiry oriented through the injection of real data collection and hypothesis generation before explanations are approached. Your feedback to yourself about how an inquiry model of teaching and learning in the field might ‘fit’ your circumstances is the ultimate feedback from this chapter.

Discussion and Concluding Comments

This chapter shows that wicked problems can be included in science inquiry for high school pupils within the interpretive and historical science of geology. An exploration of the Cretaceous-Paleogene boundary can become the basis for a wicked problem projected into the future, with many possible answers based on thoughtful analogies with past boundary depositions. There may be no clear solution in hand or in sight for a wicked problem, but there should be some trusted ways to begin the search for answers – such as analogies with past boundary conditions as a strategy for extrapolating the impact of climate change. Through engaging pupils in geology fieldwork, they constantly re-solve scientific problems with multiple explanations and hypotheses. This is valuable when addressing today’s wicked problems because pupils experience how science does not produce ready-made answers but is developed through interpretation and iteration between observations and incomplete data.

There is clearly a need for science instruction that underscores how scientists solve problems in diverse contexts as well as how science contributes to understanding the changes humanity is making to the condition of the world. However, to facilitate the use of wicked problems by high school science teachers in their planning of fieldwork is as demanding as aiding them with inquiry itself. Teaching leading to ‘no correct predictions’ as for a future Holocene-Anthropocene boundary can feel uncomfortable for some teachers and be especially challenging. Here, formative feedback from the pupils on their empirical grounding of predictions, the construction of logically valid inferences and the use of plausible causal reasoning can support teachers in their teaching. Likewise, the sometimes new and challenging experiences of inquiry learning for the pupils together with the demand of using a wicked problem in their learning process also requires frequent formative feedback on their progress from peers and teachers. Hence, designing fieldwork for pupils focusing on a wicked problem needs to have no true or false approaches to learning, but only good or bad ones – in the case of a future Holocene-Anthropocene epoch, approaches that must be based on current scientifically viable reasoning for future predictions.

Acknowledgements This chapter is inspired by and developed in relation to our teaching of future science high school teachers at the University of Copenhagen. First and foremost, we want to thank our students through the years for their energy and active engagement in inquiry practices as well as the high school teachers whose field trips to Stevns Klint we have joined. We would like to extend special gratitude to Charles (Kip) Ault for his engagement in reviewing our chapter, making it much richer and more fluent, and for sharing his deep understanding of inquiry practices. We also wish to thank Salik Anders Rosing for invaluable inputs related to understanding the Anthropocene and the geology of Stevns Klint. Finally, we want to thank the three editors for valuable and constructive comments to improve the chapter. All the usual disclaimers apply.

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Robert Evans is an associate professor in the Department of Science Education at the University of Copenhagen. His interest in this 'wicked problem' can be traced to his educational background in biology and pedagogy as well as his years as a teacher of secondary school biology and in university science teacher preparation. The constructivist approach to this problem using the 'fish clay' is consistent with his own approaches to research and teaching practice. He has extensive personal and developmental experience with the use of the 5E 'inquiry' approach for lesson construction.

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Chapter 10
Connecting with People, Places and Histories Through Archaeology: Youths' Development of Sustain'abilities'

Jrène Rahm

> The world can tell us everything we want to know. The only problem for the world is that it doesn't have a voice. But the world's indicators are there. They are always talking to us. (Quitsak Tarkiasuk, quoted in McDonald et al., 1997, preface)

We seem to slowly appreciate the complexity of environmental issues such as climate change and biodiversity loss, to name two, and the need for action but also collaboration among scientists, citizens, schools and out-of-school settings. We also seem to begin to more seriously engage with the kind of pedagogy needed to address inherent wicked problems that constantly shift and change and as such "resist defining" (Wals, 2015, p. 17) and are never truly solved (Dillon, 2017). We seem to slowly engage in a quest for civic science which is not about doing, talking and being in science, but instead, about using science to promote a better world. Wicked problems have been with us for a long time but gone unnoticed, given our distance from the world and our epistemological footing in anthropocentrism that puts our needs first and attests to a disconnect from place, the land and the voice of the world that Quitsak Tarkiasuk refers to in the citation above. The "coloniality of human exceptionalism", which "asserts the epistemic superiority of Western intellectual traditions granting assimilative authority to the non-Western" (Bang, 2017, p. 122), has marginalized and attempted to erase purposefully Indigenous epistemologies and place-based ways of knowing, being and becoming. It has essentially erased an understanding of relations and collective understandings and actions in light of nature-culture relations. Western science has left us with ideologies steeped in human domination and entitlement that Quitsak Tarkiasuk's comment questions.

I ground this chapter in a vision of science as a tool for action and hence as a process and form of engagement for the common good, and not as an end in itself.

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M. Achiam et al. (eds.), *Addressing Wicked Problems through Science Education*, Contributions from Science Education Research 8,
https://doi.org/10.1007/978-3-030-74266-9_10

I invoke and build on the civic science lens numerous authors have invoked and developed and to which this book is committed. That vision assumes that we all have an important role to play as social actors in working together for the common good, in challenging science illiteracy, for instance, but also in challenging existing inequity and ignorance that supports policy and action at multiple levels in ways counterproductive to the sustainability of our planet. Taking such a stance to sustainability is necessary in light of the wicked problems that mark our times and that can only be solved through deep and critical ongoing engagement at multiple scales and levels and, even then, will only be "re-solved – over and over again" (Dillon, 2017, p. 2). Hence, the development of *sustain'abilities'* in the plural constitutes critical sustainability literacy. Sustain'abilities' imply a deep questioning yet also understanding of the systemic relations at the heart of a non-anthropocentric view of the world. Those "abilities" can only be developed through "engaged, lived experience of transformative praxis" (Lotz-Sisitka et al., 2015, p. 78). The two projects described in this chapter are understood as examples of transformative praxis of sorts, giving students some of the tools needed to develop a sense of sustain'abilities' and ways to put them into action and thereby contribute to the common good. The two projects engage students in place with history, with the land, with objects, with the past, present, and future in ways supportive of embodied learning. The projects offer students an immersion into multiple timescales, supportive of reconnections with society and culture through objects and dwelling in place. The two projects also offer students the opportunity to experience science as a social, cultural and human process and "deepen the experience of the physical place of which people are part" while simultaneously helping them understand "how science works" (Dillon, 2017, p. 5). Students are offered opportunities to reconnect with their past, with their land, with objects that belong to them. They are offered opportunities to engage in a world that is new to them and that was never made transparent to them. Learning about archaeology and being an archaeologist by doing also invites students to navigate multiple epistemologies of science and of the world (Bang & Medin, 2010) and thereby reconnect with ideas and dispositions that might have been hidden from them given the political work science implies. The two projects invite students to develop the kind of critical dispositions needed to challenge their future as stewards of the artefacts, their land, but also culture, all of which I see as critical to future well-being and constitutive of what I call sustain'abilities'. They are forms of knowing and doing that we take as constitutive of the kind of critical sustainability literacy we believe all of us need to develop in order to be able to tackle wicked problems of our times. Hence, the chapter offers insights into the manner such normative dimensions of sustainability can be developed through either innovative collaborations between formal and informal educational settings or through informal place-based science programming. In doing so, I aim to also begin a conversation about the manner informal STEM education practices, and community-based archaeology in particular (Atalay, 2012), may contribute to the development and practice of a decolonial ethic (Bang, 2017). The first partnership project emerged from an initiative to enrich educational experiences of ethnically diverse urban youth in underserved communities, and the latter emerged from a community-driven need and commitment to engage in the preservation of the land and its artefacts and stories. As will be discussed, activities like these in collaboration with archaeologists, archaeology museums, and local communities, can position youth as agents of socioecological transformation (Bell & Clover, 2017). They also offer rich insights into ways whereby we may engage different actors in challenging existing inequity and ignorance and thereby work towards a practice of civic science in ways the book calls for.

A Word About Archaeology and Informal STEM Education

Archaeology entails the study of the human past, and even though it is part of the human sciences, it implies a dialogue with the natural and physical sciences such as biology, botany, geology, ecology, chemistry and physics, all tools to analyse and interpret the data – artefacts – collected in place (Sutton & Yohe, 2003). As such, the teaching of archaeology has been paired with the teaching of ethics and transdisciplinarity including mathematics, science, and history (Moe et al., 2002). For the most part, archaeology has relied on Western knowledge systems and methodologies despite the fact that it works often on or with Indigenous populations and ways of life. Maybe for this reason, archaeology also privileged for years "the material, scientific, and observable world over the spiritual, experiential, and unquantifiable aspects of archaeological sites, ancient peoples and artifacts" (Atalay, 2006, p. 280). The educational value of archaeology as a basis for culturally relevant science learning in and outside of school has been recognized and has led to multiple outreach projects and programmes, yet few of them have been studied soundly in terms of their educational outcomes in reaching particularly underserved youth in STEM education (see Archaeological Institute of America, 2021; Bureau of Land Management & Montana State University, 2021; Clarke et al., 2008).

Ironically, scientists overlooked the fact that Indigenous communities acted "as stewards over their own cultural resources and history – examining, remembering, teaching, learning and protecting their own heritage" (Atalay, 2006, pp. 280–281) for years, practices that were ignored or side-stepped, yet with the rise of collaborative and community archaeology, they have become recognized anew. That work also makes evident that:

> archaeology is much more than simply a tool for understanding the past: Archaeological practice and the knowledge it produces are part of the history and heritage of living people and have complex contemporary implications and relevance for those people in daily life. (Atalay, 2006, p. 283)

In essence, archaeology can be understood as a pedagogical tool to engage youth with people, places and history but also the future. For that purpose, dwelling in place through field schools may be best understood as a form of place-based learning mediated by key holders of that knowledge such as archaeologists, elders and other community members.

The practice of archaeological fieldwork has also become marked by Indigenous and decolonizing research practices which are driven by the goal to pursue archaeological research in ways that it serves the communities "whose past and heritage is under study" (Atalay, 2006, p. 284). Meaningful archaeological research has to be understood in light of local practices, traditional knowledges and Indigenous epistemologies and worldviews. It led to a call for public archaeology in that its practices and artefacts exhibited in museums should not simply remain a practice of an elite. It resulted in "debates over who owns the past, human remains, and material culture and who has the power to speak for and write the stories of the past" (ibid., p. 289). By applying a postmodern lens to this position, the fact that multiple stories can be told about artefacts and the past is understood as the norm, and hence, as valuable and desirable. That lens helped move the field of archaeology from an objective to a subjective science and the recognition that interpretations of material culture are deeply grounded locally and globally in social and political contexts. An archaeology that matters and that is deeply grounded in decolonizing practices did not simply imply a critique of Western research practices steeped in a positivist epistemology but also called for collaboration and the building of new relations tied to identity and place. For that reason, an Indigenous grounded community-based archaeology is also essential to health and well-being of Indigenous communities. Ideally, "Indigenous forms of science, history and heritage management would be researched and then blended with Western concepts" to arrive at new practices that are "ethical and socially just" (Atalay, 2006, p. 297). Such practices also seem at the heart of a civic science committed to challenge existing inequities and ignorance (Dillon, 2017).

Most pertinent for this chapter is that community-based archaeology calls for an integration of research and education and thereby democratizes knowledge building while making research an emancipatory practice. As such, community-based archaeology is a means "to provide alternative views of the master narrative and to tell histories that might otherwise be silenced" (ibid., p. 301). It can be a tool for marginalized members of society to reconnect with their past and retell stories in ways others have silenced. Hence, community-based archaeology projects are also key tools to engage students in the navigation of multiple worldviews and in the promotion of an ethic of care for each other and our planet. Through engagement with the past by digging but also touching artefacts, youth also can come to story their lives and their relations to place and the earth in new ways, stories that tend to be autobiographical and as such are key to the construction of an identity of self but also collective and cultural identity, grounded in an appreciation of an Indigenous epistemology (Gadoua, 2014). That process can then lead to empowerment and a sense of self and sense of belonging that may reduce feelings of marginalization and lack of voice for youth, at least temporarily. It may also "enable learners to see the world more holistically" (Wals, 2012, p. 17) and think in terms of a system, an important lens to develop for engagement in civic science. To expand on some of these ideas, Case 1 offers an illustration of the educational potential of an archaeology project in an urban centre that implied a partnership between a school, a museum, and an archaeologist.

Case 1: "It's Like Another Planet" – Archaeology in the Classroom and in the Field

> I learned how desperate children are about culture, about getting out of their surroundings… where they live, the gangs and all, it's really like another planet that they visited [through this project]… the thing that surprised me was their level of attention, their questions, their observations. [Teacher 2, Archaeology, Interview, 2007]

"It's like another planet they visited" summarizes well the manner one teacher and her students experienced the archaeology project that was offered to them. It is one example of multiple initiatives developed by the Montreal School Program in existence since 1997 and supported by the Ministry of Education with the goal to enrich the educational opportunities offered to students living in underserved communities. It was initiated as a means to ensure equity and social justice in schools in urban centres that struggle to respond to the needs of their diverse student body. As such, the programme offers rich learning opportunities supportive of academic progress and achievement to all students (Archambault & Richer, 2014).

Description of the Programme

The Montreal School Program consists of seven measures of which we[1] explored the one offering access to cultural resources (Ministère de l'Éducation, du Loisir et du Sport, 2009):

> This measure is intended to instill in students a taste for the arts and sciences and to promote visits to cultural organizations. It is also designed to enrich education by creating ties between classroom teaching, cultural objects and people involved in the arts and sciences. (p. 15)

The measure consists of two components, the first – "*Jeune Public*" – is mandatory and offers financial support to schools to fund one museum visit or participation in some other cultural event per year for all students. The second component of the initiative, the *Innovative Model*, is optional. It consists of a range of activities that promote project-based learning through partnerships between schools, scientists, artists and cultural organizations, while schools are also invited to present their own projects, many of which are later offered as new models.

[1] I thank my research assistants Mathieu Hébert, Audrey Lachaîne and Marie-Paule Martel-Reny with their help in data collection and analysis and use the plural to denote the work we pursued together.

Description of the Activity

In this chapter, I focus on Archaeology, a model that implied four meetings in the classroom, assumed by the archaeologist, spread out over time and ending with a museum visit and mock archaeological dig on the museum grounds outdoor. We followed two sixth grade elementary classrooms' participation in this project (i.e. 45 students, 9–10 years of age, and 2 teachers) (Rahm, 2006).

The Role of Student Questions

A discourse analysis of exchanges between the archaeologist, the teacher and the students, next to interviews, led to interesting insights into the kinds of learning opportunities that emerged naturally, given students' questions and actions during the mock excavation, some of which are listed here:

But how did humans lose their fur?
How do dead people mummify themselves usually?
But an archeologist, what does he do? Is he supposed to find old stuff?
And those objects they find, are they supposed to send them to the museums?

These questions attest to the level of curiosity and engagement we observed among the sixth-grade level elementary school children in two of the six participating schools, as they met with an archaeologist who brought with her images, objects and many stories grounded in and bringing alive her various fieldtrips to different places in the world. The questions also make evident how little students actually knew about the kind of work an archaeologist pursues. Accordingly, the four meetings with the archaeologist in the classroom, followed by a mock excavation and visit of a museum, supported multiple learning goals – the demystification of archaeology and the work of archaeologists, the appropriation of the scientific method through the mock excavation and the development of subject-object relations mediated by the material culture visited and excavated.

A Unique Learning Opportunity

The project became a valuable learning opportunity for the involved students, teachers and archaeologist:

> Working with the students, seeing their thirst to learn, the sparks in their eyes, that's very valuable, it's great to see that the children are still interested in all kinds of things, after all, it's about archaeology and I was amazed to what point that intrigues and interests them, and they knew quite a lot already, yes, I learned a lot from them, their frankness too, it makes you question yourself. [Archaeologist, Interview, 2007]

Most students in this classroom did not have the financial means to visit museums and, according to their teacher, ventured little beyond their classroom and community. The teacher saw these activities as an excellent opportunity to take her students places that were new to them and thereby "visit a new planet". She perceived leaving the community as an important learning opportunity for her students, made possible by the partnership and financial support for such activities in her school system. Yet, she was the only teacher in her school who participated in these activities which other teachers perceived as extra work as she shared with us during an informal conversation.

Struggles Students Experienced

Discourse analysis also made evident the students' struggles with the kind of timeline that the archaeologist and the artefacts brought alive. It makes evident their detachment from place but also the manner whereby the project implied "another planet" in terms of its content. It was challenging for students to distance themselves from the present and their cultural practices and material culture as they engaged in meaning making of the past, as the following dialogue makes evident:

Student 2: But the pyramid that is here?
Scientist: Yes
Student 2: Is it made out of metal?
Scientist: No, it's all made out of rocks, out of blocks of rocks. There was no metal in the constructions of that time period.

It left us wondering about how often material culture actually is engaged with in those ways in classrooms and how often students are offered opportunities to navigate timelines meaningfully, instead of simply remembering factual knowledge tied to specific time periods. The following question about the importance of "knowing about the past" for the present and future by another student further attests to a disconnect with time and place:

Ahlia: My first question is, why is, why is that the past and since it will not really be necessary? It's like...
Jayne: It changed...
Ahlia: It's the past, you cannot change it, it's like now we are not in 2002 [anymore].
Scientist: You cannot change what's in the past, that's right, but in understanding how people lived before, what happened before, you can understand a bit better who you are, or where society is coming from.
Ryan: Really?
Scientist: And you can also, while making sense of the errors that were made in the past, we can try not to reproduce them in the future.
Sue: Oh yes?

Teacher: Yes, but has it brought you something learning about the life of slaves in Haiti? Like, are you now prouder to be Haitian, and of your past? For instance, I give you an example: understanding who your ancestors were, what they knew how to do, how they fought, doesn't that give you something extra as a human being when you say "I am Haitian"?

Ahlia: [I feel] normal.

Sue: Every person is...

Teacher: Shhh... What?

Ahlia: For me, it's like, it's like everybody is transparent, everybody is the same color.

Teacher: No, but I am not talking about color here, I am talking, for instance, in Quebec, we learn about things of the past, we talk about the first World War and how we were involved, but that changes something, it changes, the fact that somebody knows how we got to where we are now today, and that's what she [the archaeologist] is trying to explain.

Ahlia was at ease to challenge the archaeologist about the pertinence of archaeology and "knowing about the past" which had no relevance to her present or future. That link was something both her teacher and the archaeologist tried to make her understand, yet in different ways. Her teacher built on the argument the archaeologist had developed in that knowing about the past and its errors may help us understand the present. Knowing Ahlia, the teacher personalized the argument for the student, referring to the student's past, referring to her roots in Haiti and a family history tied to slavery which may have had an impact on her family and may still have an impact on her today. She assumed that Ahlia identifies as a visible minority and with pride assumes her identity as a descendant of a family that fought against slavery and that despite that history survived given their resilience and activism against an oppressive system and racism. Yet, Ahlia was not ready to take on that positioning, at least not in class, in public. She distanced herself from that history and the positioning by her teacher as a visible minority, noting that for her, "everybody is transparent" and "everybody is the same skin color". Her teacher then offered another explanation that was more locally grounded in that she referred to the history of Quebec, as discussed in class, referring to the war and how understanding that history can help everybody understand the present in Canada. That interesting teachable moment ended after those exchanges, however, as the archaeologist tried to get back to her presentation and cover more content. It was a very complex opportunity for the archaeologist and the teacher to build on and help students understand the role of archaeology as a tool to understand the past, present and future.

Both adults tried to make the case that archaeology helps "put phenomena into perspective" which should result in students' "openness to the world", as emphasized by the school curriculum (Ministère de l'Éducation, du Loisir et du Sport, 2001). In fact, one of the competencies the students are asked to develop in the elementary school system in Quebec is to construct a representation of space, time and society, a competence that could be nurtured through archaeologist-school-museum partnership projects as the one described here. Hence, despite a heavy focus in the social sciences curriculum on relating the present to the past, the students' questions seem to suggest that they struggled with the framing of the present and past. On the other hand, as noted earlier by the archaeologist, she felt "they knew quite a lot already" and, in turn, argued that their "frankness" was actually a valuable means to "question yourself", suggesting that the dialogue grounded in archaeology led to meaningful learning opportunities, at least in the eyes of the archaeologist and teacher.

Getting Out of the Classroom: The Excavation

Once we visited the museum, the students had an opportunity to engage in a mock excavation and become engaged with objects of the past through touch. As the other teacher that we followed noted, her students worked quite diligently, trying to carefully scavenge for artefacts in their squares in ways modelled by the archaeologist:

> What I noticed is that my students, the weakest academically in class, in French, in Math, they were the best in that project. Really, they did their work with much patience, worked slowly and carefully, they were the first to finish with the fewest errors. They were really proud of it and happy. They were applied and for once, they were concentrated on what they were doing. [Teacher 1, Archaeology, Interview, 2007]

As shown in Fig. 10.1, the students' practice of archaeology implied the mapping of the space to be excavated. Students were then given trowels to start to remove layers of the soil. That soil was later passed through a screen to ensure no artefacts were missed. The students then also cleaned the artefacts, labelled them and described them. They were given some prototypes to match them with. The excavation and visit to the museum were the "best parts" for all participants. The activity offered students an opportunity to "put into practice" all the "theory that was presented in class" in the words of the archaeologist, who added, "to really understand the work of archaeologists, they had to have an opportunity to engage in an excavation". She added:

> The excavation, the practical part, they really loved it. There were some students who were less inclined to get dirty while others enjoyed getting their hands in the soil. There was really a role for everybody, some could take notes and measures, and others excavated. There was something to do for everybody, we were meeting their multiple interests and strengths. Some students are more practical than auditory and so they really liked to use their hands, it is a part of the activity that is crucial and should never be removed from this activity, in my opinion. [Teacher 2, Interview, 2007]

To get out of the classroom and to have students manipulate something was also highly valued by both teachers. As one teacher noted, "these activities help children to discover themselves, figure out who they are, [and] live an experience that is different from the rigorous academic work in class" [Teacher 2, Interview, 2007]. Yet, this can also mean for children to discover that they do not enjoy digging in the soil, as was the case for Kevin, one of the participants who was fascinated by the stories about the past in the classroom but felt that the excavation did not mean

Fig. 10.1 Students' practice of archaeology during the mock excavation

anything to him. Other students preferred the excavation while listening to the archaeologist in class felt long. Still others noted how much they "loved learning about the past". Yet another student noted, "I enjoyed digging, and taking the time to dig", while another peer felt that "identifying the object found is difficult". It shows just how diverse students are and how challenging it is to offer them activities that nurture their interests and help them develop to their full potential. As one teacher noted, "teaching and learning really comes from the child who is ready to listen, who wants to learn and who is interested, and then the system has to be able to respond to those interests". She added that projects as these are particularly important for children and youth in underserved communities, so they have the opportunity "to be stimulated, to have positive experiences where they feel good and useful, where they feel they accomplished something, and which leave them with an interest to still learn more". She perceived a tight link between these kinds of projects and her students' perseverance in the educational system. This suggests that partnerships are crucial to support the diverse needs of students. They enrich the standard and often very academically oriented programmes with hands-on activities as described here.

Visiting the Museum

In addition to the mock excavation, students had an opportunity to visit the "Maison le Ber-Le Moyne", a designated historical site that was built between 1669 and 1671 for the fur trade and that now exhibits objects that were used in trading with First Nations at the time, objects tied to agriculture, commerce and navigation. The students visited the museum in two small groups with their guides, listening to stories the objects evoked while asking questions. They were passionate about the past, a way they typically learn about Indigenous populations in Québec. Yet, it can also be understood as a missed opportunity to make connections with current activities and practices of Indigenous peoples in Québec. It would have positioned archaeology as relevant to future generations and our future as a society, a dimension the second case addresses in part. At the same time, the project helped students deepen their experience of a physical place, constitutive of civic science (Dillon, 2017). By doing archaeology work, they also learned first-hand how tedious scientific work can be and the methods it implies. And as also shown in the next example, the experience helped them understand the work of archaeologists.

Case 2. "What I Dug Up in My Community Is Here!" Public Recognition Through Photography and Community-Based Archaeology

> To see them excited, and pointing at pictures, and talking about things, remembering what was going on at the time that the pictures were taken, and telling stories to each other, it was nice for me to see that, because usually, they are so shy about sharing their work. [Interview Amber, 2014]

The photography exhibit the teacher is referring to offered visual depictions of the field school in which 12 Inuit youth participated on *Qikirtajuaq* or Cape Smith island, located close to Akulivik, one of the 14 communities of Nunavik, in Northern Quebec. The exhibit (Fig. 10.2) also showed pictures of the land and the community, taken by different students at the local school later that year.

Description of the Project

The photography project was initiated in the context of a 5-week excavation on the island. The whole team, including 12 youth (ranging in age from 14 to 17 years), 4 archaeologists, 3 geologists, 2 hunters and a cook, camped on the land to pursue a dig of an Inuit sod house or *Inuit Qarmaq* with tunnel entrances. *Qarmaq* is the Inuit term for a single room dwelling. Depending on the season, the lower portion was

Fig. 10.2 Photography exhibit in Montreal and in school in Akulivik

constructed from snow blocks or stone, while the upper layer consisted of skins or canvas. They were used in the cold season and as early as the Thule people period. The *Qarmaq* to be excavated was built on top of a Late Dorset house structure, attesting to the high level of activity on the island. The community asked for an excavation to ensure the documentation of the rich history of the island which was the home of many families during the nomadic lifestyle period of Inuit. In the context of a survey 2 years prior to the excavation, some families were also consulted and stories shared about different activities on the island. That survey also helped confirm that the site was suitable for a field school with youth. The photography project entailed the documentation of the field school, the land and the community (Fig. 10.3). For the latter, the whole school was invited to participate.

Following the field school, two archaeologists and the educator returned to the community together, to share artefacts and stories from the field school with the entire school and to select pictures for the photography exhibit that was planned for the spring (Fig. 10.4).

In the spring the following year, some of the youth from the field school came to Montreal for a week and spent time at the Cultural Institute of Inuit, known as *Avataq Cultural Institute*, the Inuit cultural organization of Nunavik. They learned about what happens to artefacts once excavated, and the actual steps involved in preservation, while they also assisted in the inauguration of the photo exhibit in a local museum. Later, the exhibit was returned to the community and shared through its display in the school.

Fig. 10.3 Visit of the community, selection of pictures for exhibit

Fig. 10.4 Visit of Avataq, the Cultural Institute of Inuit in Montreal

From Dwelling in Place to Public Recognition

I like to summarize the project as follows: From dwelling in place to public recognition – a theme that really came through as I looked over all the data I collected over time as I mediated the photography project on the island and its transformation into an exhibit (Desrosiers & Rahm, 2015; Rahm et al., 2019). In many ways, the field school offered all of us with an opportunity to dwell in place and engage in storytelling, occasioned by objects and landmarks and tied to place. Take, for instance, a walk on the island, at the beginning of the field school. We came upon a place that seemed to depict a Dorset house given the rectangular shape and demarcation still noticeable upon careful observation of the slope, marked by its shallow depression. The *Qarmaq* became alive as the archaeologists with us guided our gaze towards it. Those structures are dug deep into the ground with a tunnel at the entrance and a bed platform in the back. "Inuit usually preferred to dig their houses on the edge of a slope while Dorset people installed their houses on a flat area" according to one of the archaeologists who was with us. Other landmarks in the area were left-over assembled rocks indicative of tent structures, next to secondary structures such as stone caches to store food and fox traps or *Tigiriaq* – an igloo-like structure of carefully assembled rocks with overhanging walls:

> A tigiriaq looks like a small igloo constructed entirely of stone. The only opening is at its top. You throw in through this opening an old hunk of meat unfit for man or dog. The fox smelling a free meal scampers up the side of the tigiriaq pokes his head into the hole and jumps down to get his reward. Later, try as he may, he cannot get out again and dies. Eventually the hunter/trapper comes by, the fox's skin goes south and his remains go to the ravens and dogs. The construction of the tigiriaq amidst the remains of the old houses suggests that it was constructed after the site was abandoned as a place to live.[2] (see Figure 10.5)

These landmarks and objects mediated storytelling on the land in the present while also mediating connections with the past and what came before. Without these stories, these objects and landmarks would have remained meaningless. That challenge is also raised by Myrna Pokiak, an Inuvialuk and now trained and recognized female Inuk archaeologist and educator, who described her learning of archaeology through participating in two different field schools in high school in a story about her educational pathway (Pokiak, 2010). Pokiak (2010) referred to the learning of the methods of excavating and handling of a trowel as tiring and at times boring, until she started to dwell in place and come into contact with objects in a site "full of treasures":

> Until my participation in the dig at Cache Point, I knew little of my ancestor's way of life, even though I grew up practicing traditions passed down from them. I knew the current Inuvialuit culture, at least as I experienced it, but had very little knowledge of earlier times.

[2] An excerpt from a Geological Survey of Canada, describing a fox trap on Central Baffin Island located on an Inuit site populated 200–300 years ago. http://gsc.nrcan.gc.ca/baffin4d/index_e.php; see also Parent (2012).

Fig. 10.5 Tent structure and stone cache or *tigiriaq*

> I was intrigued by the thought of Inuvialuit living in sod houses and astounded by the huge number of sod houses at Cache Point and in the surrounding Tuk area. I was able to picture the sod house and the setup of the home after each area was uncovered. The midden was interesting, as it contained a lot of bone and broken tools that helped piece the puzzle together. Another student from Tuk uncovered five harpoon-head points in the midden: it was as if someone hid them in a bundle and between the logs in the wall for later use. The whale skulls, which were found in large numbers in and around the houses, were almost eerie. The presence of the whale bone helped me to see the importance of this animal and area to the Inuvialuit, both in the past and today. (p. 253)

It is this kind of weaving together of cultural practices of the past with the present through objects that dwelling in place and a field school support. The educational value of the field school is certainly greatly enhanced by material objects of the past which in turn become important mediational tools for youth to experience pride in their history and in themselves. Yet, the latter became further reinforced in this project through the photography project and exhibit of some of the artefacts the team excavated. They were presented to the public at large, sending a strong message to youth, according to one of the involved teachers:

> What I dug up in my community, it's being shown to other people that I've never seen before and I've never met before. … it's like getting validation for what they actually did, 'cause a lot of the times, they'll be involved in an activity or they'll do something, but they won't really see the outcomes of it, and they don't really see that what they did has an effect on others… so it kind of gives a sense of pride, in their work. [Amber, Interview, 2014]

That resonates with Michael Drew's experiences, summarized in the 2017 winter issue of the Inuit Art Quarterly. Michael Drew, a well-known mask maker in Alaska, briefly speaks about his experience at the Nunalleq archaeological excavation site in Ouinhagak, Alaska, and the manner it helped him reconnect with the past as a Yu'pik and Inupiaq, showing a picture of him with one of the masks that was excavated:

> Being there connected me to my homeland in a way that I have never experienced before, and it affected me profoundly. As I was digging, I felt like I was getting to know the different generations of people who lived on this land. I found a small wooden mask that is probably around 500 years old. As a mask maker, it was surreal. I kept pinching myself because I couldn't believe what I found. The experience has been influencing my work; there is a deeper spiritual connection in the stories that I am telling. (Drew, 2017, p. 14)

Michael Drew's reflections about his experience make evident quite eloquently how he felt "physically, spiritually and culturally" by being on and part of the land and through his contact of a wooden mask of the past. That connection then also fuelled the creation of new knowledge and became embodied and expressed in his current art.

Connecting History and the Past with the Present

Connecting with history and the past while also taking pride in current practices and selves are also dimensions the other teacher noted, who participated in his second trip to Montreal with students from the field school:

> The first time we went, it was the year that Patrick was there, he actually found an artefact that was then at display at Avataq (Inuit cultural organization of Nunavik, in Montreal), they just had a small glass cabinet with it. It was so cool! It was like 'hey, I found that!' … now it's behind a glass and people are not allowed to touch it anymore!" [Randy, Interview, 2014]

The artefacts implicitly positioned youth and their culture and ways of knowing as important given the display in "a small glass cabinet". Having gone through the excavation and then "seeing" the objects on display, all cleaned up, made both the teacher and students take pride in their work but also their history. As Randy added:

> I think they learned that their history is important, and that it's really important to understand your history. And I think that they enjoyed seeing things from the past, what was… important… I think… what they liked a lot is that people had an interest in them, about something that they're doing, or something that is part of their history. [Randy, Interview, 2014]

Not only the artefacts mattered but also the pictures that were on display in Montreal in a public space and that were appreciated by visitors and strangers to youth with whom youth from Nunavik rarely come into contact or conversation otherwise:

> It's empowering. It's kind cool to be able to see those pictures, there are a hundred people here… [they look at] my home, my land, things that are important to me, to us! [Randy, Interview, 2014]

That kind of a dialogue and sharing of worlds with others implied important travel in terms of epistemologies. The material objects and pictures naturally invited exhibit visitors into a dialogue with cultural practices tied to Indigenous ways of knowing and thereby facilitated in certain ways navigations among Indigenous and Western epistemologies in ways central to science education (Bang & Medin, 2010).

Not only did it portray implicitly ways whereby science is a cultural process, but invited the involved teachers and museum visitors to engage in the navigation of epistemologies implicit in the world that was depicted.

Development of Shared Experiences

As both teachers noted, the project also helped them – teachers and students – develop some common ground and knowledge which could then be leveraged in other ways once back in the classroom:

> Through classroom discussions and extracurricular, you start having shared experiences, you start to share your background a little. It gets better because you start to understand, to start sharing experiences that you can then draw on in class. [Randy, Interview, 2014]

The project became a tool to establish shared experiences and form new relationships that could then be leveraged, once back in the classroom, for further learning and teaching. The project also encouraged to renew relationships in place, among youth and elders as well as youth and their parents. The latter became apparent to me as I was packing up artefacts with the curator working with us in town. Two youth were helping us with the task. As we sorted through some of the wood artefacts that were kept moist by packing them in moss, one of the girls found a needle. It was so fragile and beautiful and made us all stop and wonder what stories that artefact embodied and could potentially tell us. The needle eventually became an excuse for Louisa to invite her mother to our house and show her the needle and other artefacts dug up from the land (Fig. 10.6).

Taken together, the dwelling in place made possible through the field school and photography project led to the sharing and appropriation of "the way things are" even though these project dimensions and facets probably worked "pedagogically beneath a conscious level" (Bang et al., 2014, p. 44). It became a way to fully integrate Indigenous knowledge into education and fully "embrace and celebrate" who Indigenous youth are "instead of making them doubt themselves" as is so often the case (Battiste, 2013, p. 180). The fieldschool and photography project also became a means to engage others in a dialogue with Indigenous knowledge and ways on the land, with the past and present, while leaving youth with pride and hopefully new aspirations for the future in ways Pokiak experienced through her involvement in field schools as a youth growing up in Tuktoyaktuk, an Inuvialuit hamlet in the Inuvik Region and part of the Northwest Territories.

Youth Voice

The photography project also gave voice to youth to depict their present in ways meaningful to them. It went beyond the folkloric depiction of their ways and communities so typical of photography projects conducted by Qallunaat (non-Inuit).

Fig. 10.6 Doing archaeology in the field

Pictures of nature, the sky, plants and shells, so typical of their community and often collected, but also country food featured prominently. Megan, one participating youth who was well-known for her photography skills, often caught special cloud formations while playing with contrasts that she picked up on naturally. She also took a picture of country food that she described as tasty, namely, sea urchins and star fish. Pictures of their community depicted everyday ways of life but also places and objects important to the youth. Other pictures depicted the place where the umiuak (a type of open skin boat used by Inuit, resembling a kayak) rested for the winter, a cabin where youth hanged out in the evenings, the water truck, the school bus and the school itself. Left out were pictures from their friends of which there were plenty taken but, in the end, were judged as inappropriate by them for the exhibit (Fig. 10.7).

It was about the development of a work ethic in place in that stories, but also objects of the past had to be handled with great respect (Moe et al., 2002). The storytelling also led to the preservation of a history so many of the participating youth

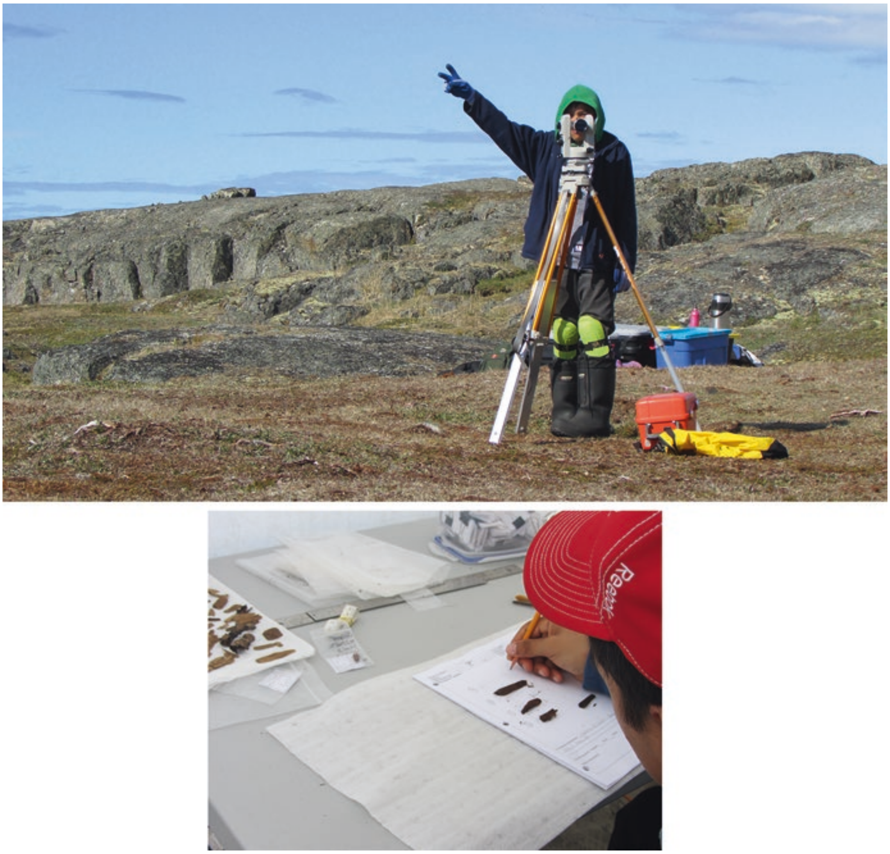

Fig. 10.6 (continued)

knew little about. By exchanging with elders in the context of archival pictures from the island and maps, youth gathered many insights into the dwellings on the island in the past. Yet, that history did not stay in place but travelled with the artefacts to other places and touched the lives of other people.

Implications for Teachers

In terms of the project's implications for teachers and school practices, it is clear that even though the teachers were not involved in the actual field school, they had an opportunity to engage with their students in a new kind of discourse and build meaningful relationships across epistemologies and cultural practices that used to be hidden to them and not understood. The two teachers who were present at the inauguration of the exhibit were struck by the students' affective reactions to the

Fig. 10.7 Youth photography of their community and environment

exhibit. For one, the pictures in the exhibit brought alive many memories the youth had experienced together on the land during the field school. In addition, students who could not travel to Montreal were also present through pictures, sharing pictures of their community and the land with visitors through the exhibit. Hence, teachers and exhibit visitors could engage with the youth in a dialogue across epistemologies.

Discussion

To continue the process of decolonization, Simpson (2014) called for the need to:

> create a generation of land based, community based intellectuals and cultural producers who are accountable to our nations and whose life work is concerned with the regeneration of these systems, rather than the overwhelming needs of the western academic industrial complex. (p. 13)

I argue that youth who engage with archaeology in ways described here, at the elbows of community members and others committed to community-based archaeology, are given an opportunity to then act upon that experience further in their future and become a voice for marginalized stories of the past, present and future. Atalay (2012) calls current moves towards community-based archaeology as a "movement towards inclusivity" (p. 54), which makes it such a powerful pedagogical tool in informal and formal science education committed to civic science. It supports engagement with multiple worldviews and epistemologies in ways most students never experience. In such excursions, material objects serve as pivot points and thereby open up archaeology. As such, archaeology can become a tool for action and transformation, identity work and dialogue, across cultures. It can also become a tool for the process of decolonization and the telling of stories about lives, the land and relationships with the land that have been pushed to the margin. As such, it begs questions about *who can* tell those stories.

The two cases in this chapter also underline that such dispositions – being able to navigate multiple worldviews and epistemologies and tell stories that used to be marginalized given place-based practices and engagement with people, places and histories yet also materials that then become pivot points for action – are essential to and part of the kinds of sustain'abilities' that need to be developed in order to solve and resolve wicked problems or tackle new emergent problems of our times (Dillon, 2017). They are the kinds of praxis we need to encourage through new partnerships between formal and informal education. The two cases underline the role STEM education with an informal content lens can play in supporting the development of youths' critical sustainability literacy. That literacy was developed in Case 1 through a re-storying of the past, present and future in collaboration with youth and by giving them a voice. Engaging with STEM in this manner was initially understood by the youth as "another planet". Yet, the joint creation of a safe space between the teacher, archaeologist and participating youth, the latter had opportunities to voice their struggles in understanding history in place and notions of time, or question the relevance of the work of archaeologists. While Ahlia at the time did not seem to grasp or even oppose the positioning of herself by her teacher, that dialogue might have done some work beyond that moment too, leaving that student with questions about her own history and the manner that history is tied to her identity as a first-generation immigrant living in Canada and identifying as Canadian. It might have helped her develop a new lens, a critical disposition to the world, implying new forms of "learning about, learning to do, and learning to be" (Wals, 2015, p. 22) in STEM, supportive of engagement in civic science – the learning about archaeology in ways that it may transform the present and future.

In contrast, Case 2 makes evident the educational potential of community-based archaeology with Indigenous youth. As the first case, it offers Indigenous youth with opportunities to live the scientific method if you will, through their involvement in all aspects of an archaeological dig, which in this case also implied travel with artefacts from their community in Nunavik to Montreal, which in the end supported a sense of empowerment and pride that youth could experience and bring back with them and share with their community. To what degree that incited an interest in future engagement as stewards of their lands and community is difficult to assess, yet it certainly makes evident the educational potential and value of archaeology and a form of place-based STEM education that was relevant to the participants involved. In particular, we see archaeology as a powerful pedagogical tool to go beyond simply "sprinkling cultural materials into approaches designed for southern systems" (Vick-Westgate, 2002, p. 15). It naturally calls for stepping outside of the Western-based educational system and engaging with multiple epistemologies and epistemology-ideology dimensions (Bang, 2017). It also supports the experience and practice of an ethic in ways described by Bang (2017), tied to the land and relations and to the subjective experiences of artefacts and not simply the objective. It could help erase space-time constructions that have positioned humans at its centre and that resulted in a deep disconnect of humans from the land and each other, leading to a lack of care of the earth in ways discussed at the beginning of this chapter. It helped recentre learning around "culture and dialogic development" (p. 133) as did the photography project and its exhibit which literally got different stakeholders and strangers into conversation. The project also positioned youth as part of that conversation and as stewards of their past, present and future, leaving them with a sense of agency as actors of science driven by a civic goal in ways the book calls for. The project brought together "scientists, educators and the public" and linked "science and society with place and identity" (Dillon, 2017, p. 5). That kind of a science practice can equip youth with the skills, worldviews and dispositions needed to tackle the kind of wicked problems of our times or as I referred to in the beginning, sustain'abilities'. That kind of STEM practice certainly has the potential of moving us beyond "narratives of division, dread and despair" (Bang, 2017, p. 134), towards inclusion, equity, action and transformation (Wals, 2015). The two projects helped students experience, play with, and live a relational approach and feel what a non-anthropocentric worldview implies.

Implications for Out-of-School Science Education

Returning to the theme of this book, namely, the role of STEM education and the informal content lens in addressing wicked problems, we believe that both projects pushed the participating youth towards forms of engagement deeply rooted in place, made possible through people and cross-disciplinary engagements and the sharing of histories through contact with a material and physical world most youth in our sample otherwise never have access to. In light of this, we clearly see the potential of an informal content lens to the practice and development of civic science and the development of sustain'abilities'. As noted, involvement in such projects can be empowering and transformative for all members involved. Involvement in such projects also makes possible an immersion into a decolonial ethic which I take to be at the heart of the kind of civic science wicked problems call for. If we do advocate for a joint learning process around wicked problems, we also need to ground such work in respectful navigations among disciplines, epistemologies and practices, many of which are still Eurocentric and exclusive, and as such, badly equipped to deal with the kind of complex and controversial problems the wicked implies. Returning to the beginning, we have to equip youth and society with the kinds of literacies needed to listen to the world, reconnect with it and work together in ways to eliminate inequity but also ignorance. Archaeology as I lived it with youth through these two projects seems like a promising pedagogical tool to do so. Archaeology does not simply belong into a history or social studies course, but deserves to be developed further through a STEM education and informal content lens.

Maybe most important, building on some words by Atalay (2006), "Indigenous archaeology situates itself to work from the place of the 'local'…" (p. 34). Yet, place-based STEM has become the exception to the rule today. In fact, our engagement with Indigenous archaeology has made quite evident just how disconnected most STEM education has become from place. It has created a disconnect from STEM for many students. It also left us wondering about the relevance of STEM for the kind of wicked problems the youth we work with face daily. Why would they even "dare" look towards STEM when in need for a solution? We used the two case studies in archaeology as tools to unpack issues of STEM while implicitly making the case for the potential of informal science practices to engage learners in place-based STEM practices grounded deeply in a serious and critical unpacking of monologic visions of epistemology and practice and thereby bring into the conversation issues of privilege and power. The two cases also brought together multiple places of learning and diverse communities and essentially engaged both, the formal and informal content lens. Thereby, the chapter makes the case that joint projects of this nature are essential to the building of new narratives of socially just science practices and sustain'abilities' and essentially literacies that are empowering instead of silencing and deeply grounded in respectful relations.

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Chapter 11
School Sliding Doors: Out-of-School Activities and Young People's Engagement with Climate Change

Giuseppe Pellegrini

Addressing climate change remains one of the most pressing challenges that Europe and other continents currently face. Following the Eurobarometer 2017 survey, climate change is perceived to be the fourth most serious problem facing the world after poverty, international terrorism and the economic situation (European Commission [EC], 2017). Despite the fact that there is consensus among the scientific community on the causes and effects of climate change (IPCC, 2019), there is no coordinated action among various stakeholders to limit and mitigate the impact that these changes are having on the environment and health. From a political point of view, this difficulty is due to the fact that climate change cannot be considered in isolation from other important phenomena; it is only one of the factors that condition human health, ecosystems and social well-being.

In this chapter we consider climate change as a broad range of phenomena created by burning fossil fuels, which adds heat-trapping gases to Earth's atmosphere. These phenomena include the increased temperature trend; sea level rise; ice mass loss in the Arctic, Greenland and Antarctica; shifts in flower/plant blooming patterns; and extreme weather events (IPCC, 2015). Following the United Nations (UN) definition, we consider climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods' (UN, 1992, p. 3).

Helping students to understand and respond to these threats is one of the most important challenges for science education in the twenty-first century both in and outside the classroom. A recent survey demonstrates that the majority of young people are keen to take on more responsibility to find solutions with respect to climate change (Masdar, 2016). Rising to this challenge requires schools and

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M. Achiam et al. (eds.), *Addressing Wicked Problems through Science Education*, Contributions from Science Education Research 8,
https://doi.org/10.1007/978-3-030-74266-9_11

communities to work together to deepen and extend our knowledge of how best to support students' learning. In this perspective, out-of-school activities have been carried out in different countries involving young people, associations (e.g. World Organization of the Scout Movement) and institutions (e.g. UNICEF and UNESCO).

In terms of what Dillon, Achiam and Glackin propose in this volume, climate change is a wicked problem. That is, as a wicked problem, climate change has innumerable causes, is tough to describe, does not have a right answer and cannot be resolved by traditional processes. In this perspective climate change is the opposite of hard but common problems, which can be solved within limited time periods by applying standard procedures. Conventional processes do not solve climate change effects easily (if at all), and they may determine situations by generating undesirable consequences as in the case of the production of GMOs to optimize the processing of food, packaging and storage that has produced numerous controversies highlighting the loss of biodiversity and environmental risk (McLean et al., 2012). Science education on climate change can improve knowledge and understanding of the causes and effects of climate change.

Climate change is a complex problem that affects several domains, political, social, economic and administrative, and has been studied under the profile of environmental policies, urban poverty and scientific curricula. The complexity is due also to the involvement of different social actors who often have different and even opposite perspectives. For example, in the formation of urban plans, there can be very different positions. In the case of a coastal area, it may be reasonable to limit urban development to avoid possible negative effects caused by future climate change. From a different point of view, it may be appropriate to urbanize in that area to have a recognizable benefit in the short term by assuming the uncertainty that in the future there may be greater risks (Billé et al., 2013).

The complexity of climate change as a wicked problem highlights that it is often unstructured, transversal and difficult to define. Accordingly, it poses challenging questions to individuals, groups and institutions: what are the causes of climate change? To what extent can individual behaviours limit the effects of climate change? How can science education foster understanding and awareness of climate change effects? What are the effective measures that governments must implement to contain climate change? What are the rules that can facilitate the adoption of virtuous processes by companies?

In this chapter we will examine educational projects that involved young people in out-of-school activities to understand climate change. These projects have been collected, evaluated and selected among those published on the Internet in the last 10 years according to the following three criteria. First, all selected projects needed to have clearly articulated the proposed objectives and methods of implementation. Second, young people were required to be central in the reporting of the project. Third, there was evidence of the impact of the activities within the context where the project was established.

In the first phase of our investigation, 90 projects were collected from different geographical areas through the Internet: 25 from Africa, 24 from Asia, 18 from the Americas, 4 from Australia-Pacific and 19 from Europe. In the second phase, through an analysis of the proponents, the objectives and the contexts, the projects that focused mainly on out-of-school activities were selected, taking into consideration that sometimes projects also included in-school activities. The 37 selected projects have been implemented in the following areas: 12 from Africa, 9 from the Americas, 10 from Asia, 1 from Australia Pacific and 5 from Europe. Finally, the projects selected all included some aspects of the three distinctive characteristics of the wicked problems. That is, 'here and now', 'concrete impacts' and 'citizenship' were directly traceable in the activities considered within climate change. Below we set these out in detail.

The first characteristic is the strategy adopted in activities to be carried out 'here and now'. These activities go beyond the evaluation of past activities or future perspectives. Their educational method is based primarily on knowledge and information gathering rather than on direct experience and the active involvement of young people. The 'here and now' approach builds on the pragmatic attitude of adolescents towards mitigation and resilient actions that starts from personal commitment with results to be obtained in the short term.

The surveys on the public perception of climate change have shown that there is a considerable gap between how the phenomena are felt and the ways of coping that individuals intend to adopt. In the case of young people, over the years there has been an increase in awareness and willingness to engage in low carbon emission behaviour (Pidgeon, 2012). At the same time, some surveys have highlighted the difficulty of perceiving immediate effects in everyday life and the obstacles of sharing values that prompt sustainable lifestyles (Hibberd & Nguyen, 2013). For these reasons, various out-of-school projects focus on the 'here and now' approach to effectively involve young people, encouraging direct contact with experiences that allow the change of attitudes and consequently the adoption of different behaviours. These experiences are possible, thanks to projects that can be realized in the life contexts of young people without particular preparation, and often involve many local actors that allow young people to quickly integrate into the social processes of the communities.

The second characteristic is a broad focus on 'concrete impacts' and a correspondingly narrow focus on ideals or cognitive impacts. From this perspective young people are involved in activities that have a strong social and emotional impact, limiting the rational aspects and the ideal impulses that are found usually in scholastic programmes. 'Climate change is a hybrid theme essentially founded in uncertainty and thus requires the combination of both intuitive and rational understanding' (Lehtonen et al., 2018). The Sandwatch project has sought since 1999 to change the lifestyle and habits of children, young people and adults on a community basis and to develop awareness of the fragile nature of the marine and coastal environment and the need to use it wisely in the Indian Ocean, the Pacific and the Caribbean (Cambers & Diamond, 2010). It is an educational process through which young people and community members learn and work together to critically evaluate the problems and conflicts facing their beach environments and to develop sustainable approaches to address these problems using different disciplines, from biology to poetry.

Projects of this type often use a community-based approach through adaptation actions that emphasize local knowledge; they are usually not based primarily on scientific knowledge. Naturally, in countries where the effects of climate change are very strong and evident, the activities to tackle them are more frequent as populations suffer greater consequences.

Since the 1970s, individual behaviours regarding adaptation actions have been studied with appropriate tools including the NEP: New Environmental Paradigm Scale (Dunlap & Van Liere, 1978). The NEP was used to verify the readiness to change attitudes and behaviours, demonstrating in some studies conducted at the end of the 1990s on energy saving that 'people with higher environmental concerns are generally more willing to actually do something for the environment themselves' (Poortinga et al., 2002, p. 475). Projects that aim at concrete impacts rely on this type of availability of the population and therefore also of young people, enhancing a direct commitment such as conserving electricity, recycling and planting trees. Young people involved in this type of activity experience particular satisfaction by facing immediate challenges that increase their competence (De Young, 1996).

The third characteristic concerns the individual responsibility and the development of actions that have a political value and, in some way, enable young people to ask questions and make claims directly to society and to the decision-makers. This type of activity refers to the development of active citizenship. The projects with this characteristic have been developed with particular attention to the point of view of young people which, as we have seen above, is quite different from that of adult educators who encounter difficulties in interpreting the thoughts, the aspirations and the attitudes of the youngsters. In this perspective, initiatives in which young people are empowered to make their own decisions rooted in local knowledge are more successful (Ashley et al., 2009).

In the following, an analysis of the projects selected through the three different characteristics will be proposed to focus on out-of-school activities. In this way it will be possible to explore how the complexity of the climate change issue has been addressed by organizations and young people.

Here and Now

All the projects identified as 'here and now' were recognized to have a strong adherence to the context in which they have been developed and aimed to mobilize young people with initiatives that are easily achievable. From this perspective, solutions are offered to problems felt by the population to enhance the contribution of young people.

For example, the Ofafa Jericho International Climate Change Club promoted a planting and nurturing trees project in Kenya to limit deforestation. The main objective of the project is to make it clear that planting even one tree is sufficient to have a more sustainable future (Whitehead & Wanjiru, 2011). This is an illustration of short-term action using a single task approach rather than a long-term programme approach using a counter-intuitive strategy. In fact, a common thought of the intensive reforestation supports the need for intervention in the large areas where deforestation has occurred. The project therefore asked individuals to make a small effort to achieve a collective result. In doing so, it carefully avoids sounding the 'biodiversity alarm' and involves neither the problems related to uncontrolled use of wood for cooking nor the larger problem of climate modification. In this way Ofafa Jericho has promoted an extremely effective project that suggests both possible and immediate actions involving the whole population. Young people increased their awareness of the possible activities to be carried out. They activated a biogas generator and started a plastic collection and recycling system to transform it into a usable commodity.

Another interesting case of the 'here and now' approach to climate change is the project 'Water sentinels', a Canadian initiative led by the International Secretariat for Water, EcoMaris and Wapikoni mobile in 2010. The project involves Indigenous youth and adults aged 15–30 living in five different communities in Quebec. Indigenous communities are invited to produce short films on water issues and actions to preserve water. The project has reached hundreds of young Indigenous people with workshops and information kiosks. Active involvement was also achieved by planting white fir trees on the banks of the rivers.

In this case the direct action of the young people was aimed at giving participants an opportunity of simple and immediate commitment. In the case of Quebec, it is particularly relevant from the point of view of out-of-school education given the particular context in which Indigenous peoples can use local tacit knowledge to maintain specific attention to the theme of water (Vincent, 2010).

Other projects mix different purposes such as healthy and non-polluting behaviours addressing climate change reducing environmental degradation and unemployment. The 'Bamboo Bicycle' project has acquired several acres for a bamboo plantation in Ghana. Young people were trained for the planting and maintenance of bamboo. Other young people received a full-time job and training for assembling bamboo bikes (United Nations Joint Framework Initiative on Children, Youth and Climate Change [UNFCCC], 2013). The cultivation of bamboo allows for a complete and sustainable cycle of a plant that produces 35% more oxygen than other trees absorbing as much as 12 tonnes of carbon dioxide per hectare per year, giving a crucial role in stabilizing our planet's atmosphere. The proposal of this project therefore introduces a new element that over time may become habitual for the local population, which again may favour a significant change in behaviour for mobility.

Another example of an out-of-school initiative with immediate effective impact is the Go Green Project which involved young people aged 14–17 with path maintenance activities, census of animals and plants and care of wild animals in three Italian regions: Lombardy, Lazio and Sicily. In the period 2012–2013, participants were involved in outdoor activities alone and in groups with a physical, cognitive and emotional involvement. Young people attended activities focused on individual and group work outdoors, with the opportunity to get closer to the places where the animals live and where they can check the impact of climate change. The project is based on the belief that the most effective way to learn new behaviours concretely is to experience them directly (LIPU, 2013). In this way they were able to experiment with new behaviours in a direct way, with basic theoretical explanation and with a minimum support of educators. In these projects, not only knowledge and technical skills are required to address climate change but also social and emotional learning as important soft skills (Rima et al. 2017).

In a similar way, the project Rainforest Protection and Disaster Risk Reduction has been carried out in Guyana in 2008 with the purpose of ensuring constant protection of the forest as a means of mitigating climate change (UN, 2013). Actions were designed aiming at improving health, hygiene and environmental management among Amerindian populations. A peer-education approach involved children in an educational programme based on practical activities and empowerment. This way, Amerindian children have become environmental stewards of the rainforest region. The activities achieved two important objectives: promoting healthy lifestyles through hygiene education and protecting and preserving the environment through local action. Child-to-child educational programmes between Amerindian children also gave them the opportunity to raise awareness of the importance of protecting standing rainforests.

The development of soft skills is one of the objectives of this type of initiative, starting from the consideration that involvement is not just a question of information but a pragmatic approach to the obvious causes of climate change. Within the 'here and now' projects, young people improve the ability to apply skills to actual situations and develop a mindset that will keep them going through a deeper quality of learning and thinking (Corner et al., 2015). Particularly, self-reliance, understood as the ability to think autonomously and rely on one's own resources, is required to address many of the economic, social and environmental problems they face (Vasiliki & Voulvoulis, 2019).

Concrete Impacts

Faced with obvious threats and dangerous situations, many countries have involved young people in mitigation, adaptation and resilience activities. This is the case of projects aimed at immediately addressing possible disasters, as in the case of the Plan programmes activated in the Philippines and in El Salvador with a community-based approach that sees children under 18 as the true protagonists in the community they belong to (Morrissey et al., 2015).

In the Plan programme project, children were considered as agents of change with respect to their particular perception of the environmental conditions in which they live. Placed at the forefront, the children have realized actions by planting mangroves and building containment walls, thus making visible their commitment. These activities have been carried out in the context of community projects, and due to the firm evidence of their effect on the environment, young people have developed learning and communication processes that have also involved adults. For example, Louisa, a Philippine 15-year-old activist, has been committed to share her knowledge of climate change saying 'We conduct climate change training for our parents, aunties, uncles and neighbours. We also train our fellow children and young people' (Plan International, 2018). Alongside the concrete impacts, including tree planting and solid waste management, expressive moments were developed with theatrical performances that presented the results achieved. These out-of-school activities captured the attention of the involved communities by raising questions and curiosities that have allowed them to face the complexity of the climate change theme in an innovative and extremely grounded manner. The pragmatic approach that guided the activities changed the context of life in the communities by changing the cognitive environment of the residents and placing them in front of unexpected issues (Plan Asia Regional Office, 2015).

Another feature shared in these groups of projects of climate change is that it can be tackled with concrete and specific actions that produce evident results even in the short term while not completely solving the problem. An example of a short-term but incomplete project is the case of an organization operating in Malta, linked to the international Friends of the Earth network, in which affiliates carry out actions that aim to increase their ability to achieve environmental goals' self-efficacy. The group acts to overcome a frequent frustration that often affects those who plan broad initiatives when they require large resources without being able to realize them (Buttigieg & Pace, 2013).

The young people involved in the project recognized the importance of out-of-school activities, thus underlining that informal education allows actions to be carried out in line with local issues, offering young people different perspectives than what they learn at school. Buttigieg and Pace (2013) recorded actions, feelings and happenings of the group through fieldwork using participant observation tools and interviews. They involved activists who were well motivated and engaged in climate change initiatives proposing to young people specific out-of-school activities. In this way, young people open themselves to unexpected perspectives, experimenting with new skills and areas of intervention that they would never have imagined. Thanks to these activities, it was possible for the participants to overcome the sense of helplessness that sometimes hinders people to develop pro-environmental behaviours (Kaplan, 2000) and directly face certain actions gaining confidence and trust in the possibility of changing behaviours. Thus, Malta's experience indicates that climate change can be tackled in its complexity with actions that can effectively motivate and involve young people allowing them to grasp that there are no simple and immediate solutions.

These projects face a small part of the problem, sometimes with a one-shot approach to attempt to solve a specific aspect of the problem. This was also the case with the Clim'act Camp project which involved 30 young people and 11 international experts in Italy with out-of-school activities to develop a campaign of information and denunciation of the causes and effects of climate change (AA.VV., 2018). Youth participants have been gathered to make visible the negative effects of climate change in Italian cities with particular reference to particle pollution (PM10), microparticles harmful to the respiratory tract.

The young people involved also noticed obvious changes in the landscape as in the case of the reduction of the glaciers or the devastation caused by floods. The project makes it possible for the participants to verify for themselves that in every part of the planet, climate change has more or less dramatic consequences and demands an explicit and immediate denunciation of national governments and international institutions that do not do enough to limit the damage.

The activities based on direct experience make it possible to increase the self-efficacy and pro-environmental attitudes required to develop attention to the causes and impact of climate change in the lives of young people (Kenis & Mathijs, 2012). This kind of process will allow many young people to develop single and collective actions of commitment to mitigation, adaptation and resilience towards climate change.

By making evident the effects of climate change, young people are allowed to face the various levels of uncertainty that characterize these phenomena. The young people are thus offered the opportunity to concretely verify how to tackle a wicked problem (Tauritz, 2016), and due to these experiences, the participants will therefore have the chance to experience seemingly irresolvable challenges facing the concreteness of the problems and developing problem-solving skills to manage the complexity of the climate change. In other words, these activities contribute to addressing a wicked problem such as climate change by managing the unavoidable level of uncertainty.

Citizenship

Projects devoted to young people in out-of-school activities help to raise awareness and willingness to act on climate change; in specific cases young people can even gain a role in the public debate. The critical thinking of young people has been disseminated through communication initiatives such as Voices of Youth, a project by UNICEF that has enabled thousands of young people in various parts of the world to offer their critical thinking on issues concerning climate change.

In a fully connected world, this project has provided communication tools that have opened spaces for participation and leadership. In this way young people could get personally involved, developing a greater sense of responsibility by offering concrete proposals to stimulate public decision-makers. Voices of Youth is a programme that gives voice to many young people from various countries through a dedicated website where many posts are published. A post proposed on the site of Voices of Youth calls into question the politicians: ‘Today we are much more aware of environmental problems. Even though governments often ignore warnings given by environmental scientists. The question we need to ask is what actions the government can take to protect the environment’ (UNICEF, 2018). This criticism does not develop only to assign to other responsibilities but to make visible an individual position that enhances the commitment to change attitudes and behaviour. This type of position arises as an alternative to other approaches principally centred on denunciation, protest and ideological opposition.

Many posts are dedicated to climate change, with particular attention to the personal commitment that emphasizes what each person can do to counteract the effects of climate change. Among the proposed testimonies, we can mention the post You Count: 'More often than not, we believe that we are too small to bring about change or that what we do does not make a difference. That is simply not true. Every single action has a consequence, and, because of that, we should choose carefully' (UNICEF, 2018). In a clear and immediate way, the site presents testimonies of young people who describe their efforts in opposing climate change, but it also presents proposals for commitment that involve them directly without referring their responsibilities to others. This type of commitment is particularly relevant and widespread as it develops on the Web, offering young people all over the world the opportunity to declare their willingness to address and attempt to mitigate the effects of global warming.

The 'Butterfly Effect' project also aims to support advocacy actions at the local level. Groups made up of young people aged from 13 to 25, local partners and involved citizens participated in this network to improve access to water and sanitation services in a sustainable way, as well as the management of water resources. The Butterfly Effect encourages the development of joint actions, without the desire to take control or conflict with other international, regional or local initiatives.

The project strengthened the international connection of young people, the mobilization for events and mitigation actions. Progressively, this network has expanded its range of action by offering young people the opportunity to participate in the International Secretariat for Water Solidarity. Since 1998, the ISW fostered good citizenship and direct democracy (Berger et al., 2012).

The attempt of these experiences and projects is not to develop processes of institutionalization but rather a mobilization of local resources connected to a wider international movement. These actions which are not to be routinized are in fact innovative and context sensitive. At the same time, these activities are configured as advocacy programmes with a strong attention to the public good and protecting people against climate change. The reference to individual responsibility thus allows young people to grasp the complexity of the topic as a multifaceted problem, and that necessitates a holistic approach (Elias et al., 2009).

Conclusions

The complexity of wicked problems, as in the case of climate change, calls for activities that can interest young people by approaching them in their learning processes through situations close to their lives. Civil society organizations and institutions promoted the analysed projects involving young people giving them the opportunity to be involved directly in concrete actions. This is one of the main strategies used by the out-of-school activities in the projects examined. It is a matter of using an inductive method in order to allow new generations to progressively deal with the complexity of the wicked problems.

In general, young people's knowledge of the causes and consequences of climate change is limited; at the same time, however, scepticism towards climate change is also modest as reported in the recent 2017 Eurobarometer on climate change (EC, 2017). More concerning is young people's lack of confidence in governments and these governments' ability to cope with the negative effects of climate change. This has led to young people, on the one hand, feeling a sense of impotence and helplessness but, on the other hand, offering the possibility of active involvement and an increased sense of responsibility and willingness to take opportunities of commitment (World Economic Forum [WEF], 2017).

Here and now, *concrete impacts* and *citizenship* are features that may overcome some of the unconstructive rhetoric linked to the need to educate and inform without the concreteness and incisiveness necessary to promote changes in attitudes and behaviours. In this regard, the final document of the Paris conference suggests planning educational initiatives in an organic way with attention to elements of public awareness and public participation (UN, 2015; UNFCCC, 2015). The projects proposed in this chapter therefore aim to produce small but evident changes in the contexts in which they are made.

Dealing with climate change as a wicked problem points to the need to influence traditional school curricula by proposing a multidisciplinary approach that addresses the climate change issue in an organic and complex way. This approach makes it possible to develop an awareness that is appropriate to this theme by considering social, economic and technical aspects by activating spontaneous critical thinking.

The projects described and analysed here do not claim to resolve the causes of climate change nor to limit the obvious impact on the environment and people's lives. Rather, these projects have the common objective of making the experiences of young people significant in order to involve those young people emotionally and practically.

The out-of-school activities described here attempt to activate the protagonism of youth and avoid the exploitation that can sometimes be found in citizen science projects (Follett & Strezov, 2015). Young people are not passive actors to be involved in propaganda actions; rather, they are capable of detecting contradictions and manifesting – with concrete commitment – their desire for change.

The out-of-school experiences described here as ways to treat climate change as a wicked problem make it possible to find new methods of facing the world and its environmental emergencies. Such experiences go beyond the apocalyptic visions or the excessive optimism that is often proposed by the world of science and technology and by public institutions (Asadollahi & Ospina, 2017; Salawitch et al., 2017). These activities are a response to national and international policies that often prove to be inadequate despite the fact that there is sufficient scientific evidence and evidence to understand processes linked to climate change.

The young people's involvement through informal settings makes it possible to tackle wicked problems in an unusual way, encouraging awareness, learning and acquisition of skills and helping young people to understand the world in which they live 'facing the world and to frame these in the context of their own lives' (Francique, 2007, p. 12). For this reason, the commitment in out-of-school activities makes it possible to deal with an apparently irresolvable theme such as climate changes, learning to manage the uncertainty and the sense of impotence that characterize all the complex phenomena.

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Chapter 12
Wicked Problems and Out-of-School Science Education: Implications for Practice and Research

Marianne Achiam, Melissa Glackin, and Justin Dillon

In their explorations of how out-of-school experiences can help prepare learners for an uncertain future, the authors of this volume collectively sketch out a new role for out-of-school science educators and institutions. It is often the case that out-of-school science experiences are lauded for their ability to promote general interest in, and motivation for, science and nature. However, in this volume we find support for the idea that out-of-school science has more content- and practice-specific contributions to make to public understanding of contemporary wicked problems such as biodiversity loss and global climate change. Even though the chapters explore wicked problems across a broad range of settings and diversity of situations, there are several coherent themes that collectively characterise how out-of-school science experiences can *critically* and *uniquely* engage learners with wicked problems.

Science Alone Cannot Provide the Answer

As we mentioned in the Introduction to this volume, one important area in which wicked problems do not fit comfortably within mainstream science is the idea that science can provide the right or the definitive answer. Because wicked problems are systemic, and located at the intersection between science and society, science and technology alone cannot solve them (Dillon, 2017). Instead, proposals for

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M. Achiam et al. (eds.), *Addressing Wicked Problems through Science Education*, Contributions from Science Education Research 8,
https://doi.org/10.1007/978-3-030-74266-9_12

addressing them must be evaluated against a range of different, and sometimes contradictory, scales (Rittel & Webber, 1973), by stakeholders who operate with different analytical paradigms (Garvin, 2001). As a result, the proposals often involve significant trade-offs or even conflict (Roberts, 2000).

The ambiguity of addressing wicked problems was observed and discussed by several of the chapter authors. In their detailed exposition of the collaborative design of a science centre programme, Ingrid Eikeland and Dagny Stuedahl note that among the expected dynamics, they found a particular subset of tensions related to understanding and generating ideas for engaging learners in the wicked problem of bacterial resistance. Eikeland and Stuedahl describe how the complexity of the problem seemed to 'infect' the collaborative process of designing an education programme, causing it to become equally ambiguous and conflicted. In other words, the lack of a right answer, which is of course a characteristic of wicked problems, resulted in a significant challenge to traditional science centre pedagogy. Catharina Thiel Sandholdt reports on a similar struggle in which science centre professionals expected science to provide the correct answers for them to transpose into exhibition activities, even though progressive health promotion theory holds that there is no such thing as a definitive answer. Ultimately, in these two cases, the difficulties were resolved, illustrating the utility of participatory design but also the necessity of having adequate institutional backing in terms of time and space for such experiments. This is a key point that we return to later.

The angst caused by attempting to deal with problems without definite answers also characterised the reactions to the programme developed by Jung Hua Yeh. She presents an innovative use of dioramas as representations of biomes, engaging learners in evaluating the environmental trade-offs involved in placing energy production facilities in different ecological settings. Whilst frustration could, perhaps, be expected of the learners in the programme over the lack of a clear 'right answer', Yeh also observes a similar frustration among teachers. Hagit Shasha-Sharf and Tali Tal offer an important counterexample in their description of how teachers gradually became proficient in discussing and evaluating trade-offs in a learning unit about sustainable energy production. Taken together, these studies show that when science teachers are tasked with confronting youth with transdisciplinary, real-life learning situations to prepare them for an uncertain future, out-of-school science experiences can play an important role.

A related facet of many of the out-of-school experiences described in this volume is the shift of authority away from canonical science (cf. Kaufman, 2009), towards more interrelated and locally grounded ways of knowing. This shift may be an indication of a larger transition underway within out-of-school science education, a transition that acknowledges the gendered, raced and classed aspects of Western science (Archer et al., 2016; Dawson, 2014; Nicolaisen & Achiam, 2020) and provides space, if not equity, for other voices and ways of doing. As we argue in the Introduction to this volume, given how slowly school science evolves, out-of-school science education has a unique opportunity to be a frontrunner in validating alternative voices and stories in science. We develop this theme in the following section.

A Multitude of Voices

As we have previously discussed, wicked problems are located at the intersection of science and society and cannot be addressed with reference to a purely scientific epistemology. Instead, different forms of rationality including multiple versions of evidence and knowledge are at play among the stakeholders, leading to mitigating efforts that are mutually constructed (Garvin, 2001). In these co-construction processes, there is a growing acknowledgement of the significance of lay, practical and Indigenous knowledge (Messerli et al., 2019). A similar acknowledgment, or validation, of a diversity of voices characterises a number of initiatives described in this volume.

One important problem facing global society today is that of excess sedentary behaviour. Catharina Thiel Sandholdt explains how previous attempts to address this problem using scientific epistemology have failed and shows how the participatory approach used in the PULSE project allowed publics from across the socio-economic range to co-construct aspects of health in ways that were meaningful to them. In another example, Giuseppe Pellegrini reminds us that personal and societal reluctance to assume responsibility for climate change creates significant uncertainty and therefore calls for both rational and intuitive ways of knowing. His survey of climate change education projects from around the world illustrates how community-based approaches integrated local knowledge and experience with the pragmatic attitude of youth towards climate change mitigation. These projects resulted in social and emotional outcomes, potentially offering nuance and depth to the more idealised or canonical science presented in school programmes.

Finally, Jrène Rahm explores this theme in depth in her analysis of two partnership projects in archaeology. Rahm argues that beyond the Western knowledge systems and methodologies that govern traditional archaeology, *community-based* archaeology (archaeology 'at the elbows' of members of Indigenous communities) has the potential to engage youth in navigating multiple voices and worldviews. She demonstrates how the projects promoted new relationships across epistemologies and practices, not just for the participating students but also for their teachers. Collectively, these studies show us how out-of-school science promotes the inclusive mindset and the alternative and transdisciplinary ways of thinking that are necessary to meet the wicked problems facing us.

The Importance of Time

Many wicked problems raise questions about time. For example, climate change poses questions about human time versus geological time, biodiversity loss poses questions about historical time versus evolutionary time, and issues of sustainability are fundamentally issues of resource distribution in the past, present and future. Our ability to grapple with many wicked problems, then, is in part a function of particular ways of perceiving time (Jasanoff, 2010; Markley, 2012). Whilst scientists capture the vastly different registers of time involved using records such as sediment layers, ice cores or specimens, school science does not usually have access to this kind of evidence.

The theme of time cuts across a number of the chapters in this volume. Annette Scheersoi hints at the historical significance of natural history museums when she discusses them as inventories of the diversity of life, and this point is alluded to by Patrick and Moormann in their chapter, too. Natural history collections have played a crucial role in scientific studies of biodiversity and its decline over time (Suarez & Tsutsui, 2004). In Scheersoi's study, visitors are prompted to observe changes in local biodiversity over time by engaging with dioramas. Similarly, Lene Møller Madsen, Bob Evans and Rie Hjørnegaard Malm draw a parallel between the ways scientists use the past to understand the present and the ways that learners might emulate these techniques. They describe how a geological locality, famous for its evidence of the Cretaceous-Paleogene mass extinction, can serve as a *milieu*[1] for scientific inquiry about the events that caused the extinction as well as the nature of possible future mass extinctions. For both scientists and learners, this type of inquiry establishes coherence between present-day evidence and past events (cf. Estrup & Achiam, 2019), thereby linking the past with the present and possible futures in ways that would be difficult to orchestrate in the classroom.

Different registers of time are also invoked by Hagit Shasha-Sharf and Tali Tal, who discuss how sustainable energy use and distribution create a dilemma between (among other things) long-term and short-term objectives and *inter*generational and *intra*generational considerations. This dilemma embodies the broader importance of the temporal point of view in discussing wicked problems. That is, how should the trade-off between current and future generations be valued (Cavender-Bares et al., 2015)? Juanita Schläpfer-Miller tackles this question head-on, as she confronts learners with the consequences of climate change. To help learners grasp the notion of a long-term future, the Climate Garden 2085 *localises* and *materialises* climate change in a public experiment. As learners immerse themselves in the climate scenarios of the year 2085, Schläpfer-Miller observes how they gain an almost visceral knowledge of the timescale represented by the project – again, in a way that cannot be easily replicated in a school setting. And finally, Giuseppe Pellegrini's chapter offers a number of examples of climate change education projects that successfully bridge the divide between intangible long-term effects and 'here and now' actions which might have immediate and concrete benefits.

[1] We refer to milieu here in the sense of the material and immaterial affordances of the geological locality that frame the possible trajectories of inquiry (cf. Achiam et al., 2013).

Place-Based Perspectives

A final theme that plays out across the chapters in this volume is that of place-based education. Although many wicked problems are located at a global scale, a slogan of the sustainability movement, 'think globally, act locally', reminds us that remedies must somehow translate or operationalise these abstract problems to specific, meaningful actions in order to be effective (Jasanoff, 2010). This point is illustrated in Annette Scheersoi's study, where the concrete reality of local habitat dioramas prompted visitors to reflect about specific species of plants and animals that are gradually disappearing.

Many of the chapters in this volume offer learners direct and concrete experiences of wicked problems on a local scale. Perhaps the most obvious examples are those linked to specific field localities such as the geological evidence of the Cretaceous-Paleogene extinction at Stevns Klint (Lene Møller Madsen, Robert Evans and Rie Hjørnegaard Malm) or the archaeological excavation sites on *Qikirtajuaq* on Cape Smith island (Jrène Rahm). In the former case, Madsen, Evans and Malm propose that the observable evidence of the Cretaceous-Paleogene extinction event adds substance to the abstract notions of anthropogenic climate change, substance that can catalyse the kind of inquiry necessary to create meaningful understandings. In the latter case, learners indirectly grapple with problems of inequity and marginalisation of minorities through grappling with concrete evidence of their cultural heritage. Rahm describes how the tangible material culture of the excavation activities became a means for youth to 'experience pride in their history and in themselves' and to help them, ultimately, to build new and more equitable narratives of STEM.

A final compelling example of place-based education is offered by Juanita Schläpfer-Miller's *Climate Garden 2085*. Schläpfer-Miller discusses how the project embodied the abstract notion of climate in concrete experiences. *Climate Garden 2085* offered visitors a tangible and relevant narrative about climate change and its consequences by inviting them into immersive future scenarios of familiar north-east Switzerland ecosystems. Visitors were able to sense the increased air temperature, lower humidity and unfamiliar agricultural and horticultural plants that might emerge as the climate continues to change.

And so...

To summarise, we found four central themes across the diverse accounts of wicked problems in this volume: science alone cannot provide the answer; a multitude of voices matter; the value of time; and the importance of place-based perspectives. In different ways, these themes reflect the changes occurring in science itself, namely, a shift towards more transdisciplinary approaches, the extension of peer communities to include policy-makers and the public, increased attention to the temporal aspect of sustainability problems and an increased focus on the interaction between global and local perspectives (Fang et al., 2018; Jasanoff, 2010; Markley, 2012; Spangenberg, 2011).

This alignment with science underscores an important point about out-of-school science education experiences which is that they are not bound by the hierarchy of disciplinary, pedagogical, institutional and societal conditions that co-determine what goes on in school science, but can and do draw more directly on the science of scientists to create opportunities for learners to grapple with wicked problems. Due to this emancipation from the constraints of school, out-of-school science can offer powerful *alternative* learning experiences that do not suffer from the time lag between scientific knowledge production and its uptake in school curricula. Emancipation from school in the ways described in this volume thus goes beyond simply leaving the four walls of the classroom or crossing the well-rehearsed boundary between formal and 'informal' education.

Messages for Education Professionals

A collective effort is required if we are to educate effectively about wicked problems across out-of-classroom settings. Whilst this goes for all partnership programmes, the authors in this volume clearly bring home the need for creating times when people's personal beliefs concerning a controversial issue can be explored. In doing so collectively, there is an opportunity for educators to consider a range of perspectives on these complex and complicated issues. What we understand from the studies included here is that creating time for exploring beliefs can offer an opportunity for people to broaden their views, or in some instances change their opinions, about an issue. That is, time is needed to collectively relearn and re-understand the complexity underpinning wicked problems. Importantly, educators have the capacity to ensure that the resulting programme or exhibition is truly comprehensive in reflecting the multiple perspectives and the slipperiness of as many perspectives and viewpoints on an issue as possible.

However, more time for collective reflection is not enough in itself. As the authors in this volume have indicated, there is a great deal that can be learnt from the use of structured activities that allows educators to think deeply, as well as broadly, about controversial issues. As we saw, whilst focused on energy resources in Israel, Shasha-Sharf and Tal found that role-play enabled a range of perspectives to be openly discussed resulting in many teachers changing their stance. What we learnt from this study is that if we are serious about teaching about wicked problems, all educators, and in this we include ourselves, need to have access to relevant professional development opportunities. We also acknowledge that these opportunities cannot just be one-offs but, rather, must be continual. Again, whilst continuity is frequently stressed as a necessity for professional development programmes, it is particularly vital in this context where educators require a safe and supportive environment, so that they feel able to express their opinion without feeling judged.

Finally, alongside belief change, the design of education programmes or exhibitions related to wicked problems in out-of-classroom settings demands a significant amount of understanding and patience. This point was particularly clear in the Eikeland and Stuedahl study which documented the surprising extent of detailed negotiations required between scientists, programme developers, programme deliverers, funders, etc. before the end result was achieved. The detailed meeting notes and post-meeting action points are a useful reminder to us all – that a record of decisions made can prevent misunderstandings and keep everyone focused on their shared goals.

Implications for Researchers

In 2016, Dillon et al. described how natural history institutions, even though their collections contain critical evidence about wicked problems, still 'struggle with creating learning experiences beyond [their] traditional comfort zones of systematics, evolution, and general science education' (p. 2), a state of affairs that probably extended to other kinds of out-of-school science education providers. Since then, out-of-school science education institutions and their interest organisations have increased their attention to wicked problems, for example, through increased uptake of the UN sustainable development goals (International Council of Museums, 2020; Science Centre World Summit, 2017). However, it seems to us that the field of out-of-school science education has still not addressed this challenge head-on. Whilst the studies in this volume offer us tantalising glimpses of how out-of-school science education professionals have been able to craft powerful learning situations that address wicked problems in ways that seem difficult to achieve in school, we suggest that more *systematic* studies are needed of the translation of complex wicked problems into meaningful education situations.

Such systematic studies would benefit from considering the specific hierarchy of conditions and constraints (cf. Achiam & Marandino, 2014) that shape the opportunities for potential teaching-learning situations about wicked problems. This hierarchy includes, at least, the following: *society*, for example, how does governmental funding provide for education activities; *institution*, for example, what are the specific strengths and expertises of the institution in question; *pedagogy*, for example, what are the pros and cons of the employed principles of teaching; and *discipline*, for example, what are the specific disciplinary 'alliances' of the institution and how do they relate to wicked problems? In fact, we would argue that the examples provided in this volume of effective education for wicked problems are successful exactly *because* they fit optimally in the space available to them. Accordingly, we suggest that researchers who wish to build on and extend the findings reported here might benefit by attending to the specific conditions and constraints that govern their particular cases.

Systematic studies of how to transform wicked problems into effective education opportunities would also do well to consider the still-emerging domain of *science* *for sustainability*. As we briefly mentioned earlier, science for sustainability transcends earlier attempts by scientists to address wicked problems, due to Einstein's Dictum: The problems of sustainability cannot be solved by the same mindset that helped create them (cf. Spangenberg, 2011). What has emerged is a research domain that offers new approaches to doing science, new approaches that might well be better suited to out-of-school experiences than to the strictly mono-disciplinary, authoritative versions of science still mandated by school science curricula. Accordingly, we suggest that another promising avenue of research, tentatively pioneered by the authors of this volume, is the study of science for sustainability and its specific affordances for out-of-school science education.

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