Patricia G. Patrick *Editor*

How People Learn in Informal Science Environments

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Patricia G. Patrick is a research-focused Fulbright scholar (Sumatra, Indonesia) and an assistant professor in the Department of Counseling, Foundations, and Leadership at Columbus State University, Columbus, Georgia, USA. Her Fulbright project focused on the ways Sumatran (Indonesia) Battra (native healers) passed native medicine, environmental, and ecological knowledge to the next generation. She received her Ph.D. from the University of North Carolina at Greensboro. She is the author of *Zoo Talk* (Springer) and the editor of *Preparing Informal Science Educators* (Springer). She views her research through the lenses of actor network theory, sociocultural theory, and experiential learning theory. These theories well support a qualitative methodology; in which, she focuses on informal science learning with an emphasis on social interactions and cultural perspectives. Her interest is identifying the public's understandings of the natural world through a shared cultural understanding. She studies how people learn science in informal settings—arboretums, aquariums, museums, parks, zoos, etc.

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Chapter 1
Introduction: Learning Theory and Its Relationship to Research in Informal Science Learning Environments

Patricia G. Patrick

1.1 Introduction

This book originates from my desire better to understand learning in informal science environments and my desire to showcase the importance of theory for framing science learning research in out-of-school contexts. The book focus is researchers and graduate students; however, it also provides material of interest to informal science education (ISE) program developers and evaluators. This book is not a first of its kind; it intends to extend the principal work of Bell et al.'s (2009) *Learning Science in Informal Environments: People Places and Pursuits*, Fenichel and Schweingruber's (2010) *Surrounded by Science: Learning Science in Informal Environments,* Beames et al.'s (2011) *Learning Outside the Classroom: Theory and Guidelines for Practice*, and Ash et al.'s (2012) *Putting Theory into Practice: Tools for Research in Informal Settings.*

Below, I define informal science education (ISE), share the difficulty of defining informal science learning (ISL), and explain why learning theories are important to the future of research in defining how people learn in informal science environments. Additionally, I explain how I grouped the chapters to reflect the work of the authors. My thoughts shared below are mine and I do not mean to speak for the chapter authors.

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1.2 Defining Informal Science Education

In 2022, Chazan described the term education as possessing diverse definitions, but offered three: socialization, acculturation, and person-centered. Socialization is a traditional school-based education that provides facts, information, and theories to the next generation with the notion of fostering beliefs and developing skills for living in society (Bruner, 1996; Chazan, 2022; Dewey, 1953). Acculturation is exposing people to skillsets they need to function in contemporary culture with a focus on understanding and practicing the skills (Chazan, 2022; Schumann, 1986). Person-centered education urges self-reflection, supports innate creativity and learning from personal experience, focuses on personal growth, develops feelings about personal existence, and molds learners into contributing members of society (Chazan, 2022; Zucconi, 2015).

Dewey (1953) stated,

> we shall make surer and faster progress when we devote ourselves to finding out just what education is and what conditions have to be satisfied in order that education may be a reality and not a name or a slogan. (p.116)

Though we still may debate what is education and where it takes place, informal science education can draw much from the above definitions. I define informal science education as instruction (including media) that takes place outside the formal classroom, exposes learners to science knowledge and skills as they relate to contemporary culture and society, builds on personal participant experiences, and confronts anti-Semitism, discrimination, genderism, racism, and sexism.

1.3 Defining Informal Science Learning

Semantically, education and learning are not the same. The aim of education is to educate. Below are a few definitions of learning that indicate some commonalities.

> Gagne (1970): A change in human disposition or capability, which persists over a period of time and which is not simply ascribable to processes of growth. (p. 3)

> Bingham and Connor (2010): We define learning as the transformative process of taking in information that—when internalized and mixed with what we have experienced—changes what we know and builds on what we do. It's based on input, process, and reflection. It is what changes us. (p. 19)

> De Houwer et al. (2013): Learning is change in the behavior of an organism that results from regularities in the environment of the organism. (p. 633).

> Brown et al. (2014): …acquiring knowledge and skills and having them readily available from memory so you can make sense of future problems and opportunities. (p. 2)

> Schunk (2020): Learning is an enduring change in behavior, or in the capacity to behave in a given fashion, which results from practice or other forms of experience. (p. 3)

These statements aim to assign meaning to the word "learning". The definitions identify the qualities of what it means to learn. Much like the researchers quoted above, ISE researchers provide definitions of informal science learning (Fenichel & Schweingruber, 2010; Hofstein & Rosenfeld, 1996; Kisiel & Anderson, 2010; Lin & Schunn, 2016), with the most notable being the *Policy Statement of the "Informal Science Education" Ad Hoc Committee* (Dierking et al., 2003). In 2009, Bell et al. posed measurable "science-specific capabilities" across six strands that should result from ISL. While the strands provide measurable outcomes of learning, they do not define learning. I spent many hours attempting to write a definition of ISL. However, I could not settle on "A" definition of learning in informal science settings for the following reasons:

1. ISL may not change opinions or behaviors and may not be internalized. If we think of ISE and ISL as an equation we might consider ISE = IST + ISL (where IST is informal science teaching).
2. People may or may not recall the experience later. Learning may not occur. A memory can fade with no permanent memory or permanent change; thus, no learning. Gagne (1970) says the change should persist over time.
3. If a change does not occur then the lesson must be retaught, and the learning reinforced. ISE usually occurs one time.
4. Learning may take place in school or out of school and with/without an educator.
5. People may participate in out-of-school science experiences because they are fun. They may not possess a desire to learn, but they may unintentionally learn.
6. ISE design is much like formal education design; the "teaching" is predetermined with goals and objectives in mind. This leaves me to question: Is ISE when led by an instructor outside the classroom any different than formal teaching in a classroom? If there are set goals and measurable outcomes, is ISL different from formal classrooms?

The chapters intend to stimulate conversation and thought about what constitutes learning in out-of-school contexts. What is learning? How do we recognize learning? Should ISL simply be the experience instead of a long-term gain in knowledge?

1.4 Learning Theory and Informal Science Education

Education has two essential elements—teaching and learning. Learning theory allows researchers to explain within context how and why knowledge is created and how and why knowledge elucidates behavior. Theory allows for the organization of this information into an explanation about human learning (Bereiter, 1990; Harasim, 2017; Lefrançois, 2019). Beireter (1990) describes three requirements of educational learning theory…

1. to explicate the students' role as intelligent agents in the learning process,
2. to take account of the variety of resources that may come into use in achieving difficult learning objectives,
3. to embed explanations of particular learning processes within larger descriptions of the cognitive structures by which people adapt to various contexts so that they can achieve personal goals within them. (p. 619).

In formal education, learning theory is a way for researchers to define (1) which theoretical perspective best identifies learning, (2) what the implications of the findings are for teaching practice, (3) beliefs, and (4) how educators can reflect on their work (Harasim, 2017; Lefrançois, 2019; Schunk, 2020). However, ISL may take place without ISE and informal science educators. ISL takes place across various formal settings, such as museums, and informal settings, such as homes, backyards, parks, etc. Moreover, people learn about science without the presence of an educator.

Bereiter's (1990) approach to learning theory could be useful in defining ISL. I extrapolate Beireter's learning theory requirements to define the application of learning theory in ISL research. Learning theory in ISL research should,

- recognize, acknowledge, and accept individual knowledge,
- define how knowledge or understanding of concepts changes (or not),
- identify what resources promote (or not) knowledge change,
- explain interactions between organisms (human and nonhuman) and abiotic factors that potentially lead to experiences,
- promote reflective practice (Patrick, 2017).

The application of learning theory in research is an Ouroboros (Fig. 1.1). Theory determines the foundation of the study, meaning theory influences the research questions and drives data collection. The data and findings aid in defining implications for pedagogy, and pedagogy becomes part of the theory.

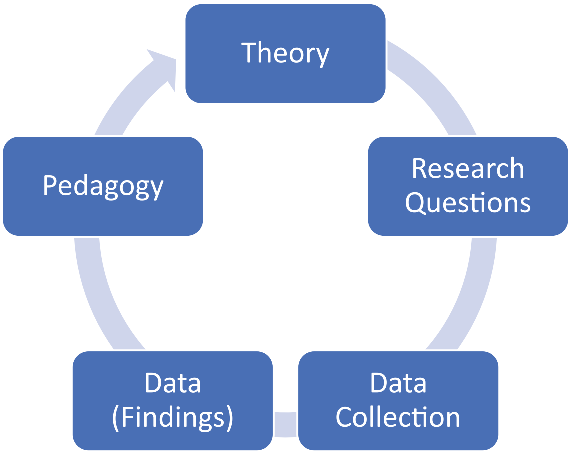

Fig. 1.1 Learning theory ouroboros

When deciding on a learning theory to frame research, the researcher should consider:

- the topic of focus,
- the learning activities or interactions analyzed,
- the type of data collected,
- how a different theory would reframe the focus,
- what is analyzed,
- type of data collected.

For example, in Chap. 16, my colleague and I were interested in how the relationships between zoo educators and classroom educators influenced the zoo's education system. We wanted to describe how the educators' interactions occurred parallel to each other and if interconnectivity existed. We identified zoo educators and formal educators as separate systems that overlap. To understand the two systems, we employed general systems theory.

1.5 Chapters

Numerous learning theories exist that may shape how researchers examine ISL. The goal of research is to shape and reshape learning theory and pedagogy (see Fig. 1.1) and challenge epistemology. The chapters reflect the work of my colleagues who employ various learning theories across diverse contexts. My hope is the chapters become a foundation for future researchers as they question ISE pedagogy and ISL opportunities.

I organize the chapters into seven parts: Part I Community of Practice, Part II Critical Theory, Part III Identity Theory, Part IV Sociocultural, Socioscientific, and Social Entrepreneurship, Part V Systems Theory, Part VI Expeditionary, Place-Based, and Variation, Part VII Theory Development. While the chapters are from various viewpoints, occur across the world, and include diverse experiences and participants, each chapter includes introduction to the theory, example(s) of how the author applied the theory during research, the importance of the theory to the author's research, and implications for future application of the theory. Though the book chapters do not have listed objectives, the material conveys a level of detail for each theory. The overarching objective of the book is clear—to present the scope of learning theory application in out-of-school science learning contexts.

1.5.1 Part I Community of Practice

Chapter 2 (Chaffee, Hammerness, Gupta, Anderson, and Podkul) and Chap. 3 (Pfeiffer and Bradbury) are strikingly similar. In addition to employing a community of practice framework, the authors focus on the interactions of students with science mentors. The students were of similar ages 15–18 years old and 14–16 years old, respectively. Even though the frameworks and the age groups are similar, locations varied. Chaffee et al. completed their work in United States (U.S.) while Pfeiffer and Bradbury's study took place in Australia. My hope is you will read these chapters in tandem. The chapters will be great for doctoral students to read, place the chapters in parallel, and determine how they relate and differ.

1.5.2 Part II Critical Theory

Critical theory recognizes the importance of social, political, and philosophical perspectives, reveals injustice and domination, and confronts, disputes, and disassembles societal related human constraints (Devetak, 2005). Chapters 4–7 address critical theory from various perspectives. Ash and Ward (Chap. 4) employ cultural historical activity in the U.S. to identify the relationship between "family activity, visitor/educator activities and field-based teaching activity". Ash and Ward describe CHAT as an explorative tool organizations may use to determine how power is reflected in their systems due to underlying philosophies. Achiam and Holmegaard (Chap. 5) present a theoretical perspective of how science museum exhibitions exclude and/or include visitors based on gender. Their work culminates in the "hierarchy of levels of didactic co-determination framework". Chapters 4 and 5 apply critical theory in museums while Chaps. 6 and 7 link classrooms and informal science learning. Rajala, Cantell, Haapamäki, Saariaho, Sorri, and Taimela (Chap. 6) confront the ethical and political views of learning. They address linking over-consumption and fossil-fuel-dependent human activities to climate change and environmental degradation. Their study completed in Finland describes students (ages 15–18) working with activist and city authorities and gardening. Guerrero-Hernández, Rojas-Avilez, and González-Weil (Chap. 7) describe critical scientific literacy in Chile. They depict three projects including #1 teacher candidates (pre-service teachers), #2 classroom teachers, and #3 in-service teachers, teacher candidates (pre-service teachers), two park rangers, and two scientists. Their chapter culminates in suggestions for applying critical theory to recognize "connections between individual subjectivities, socio-scientific issues and the social contexts in which they are embedded".

1.5.3 Part III Identity Theory

For a robust description of identity theory see Stets and Serpe's (2013) work where they well explain identity theory and its history. However, below, I share an excerpt from their work in which they describe the primary goals of the theory.

> …is to specify how the meanings attached to various identities are negotiated and managed in interaction. Specifically, identity theorists focus on how identities relate to one another (given their likelihood of being brought into situations and how central or important they

> are to individuals), as well as how identities relate to role performance (or behavior), affect (feelings), physical and mental health (such as stress, anxiety, and depression), the self-concept (such as self-esteem, self-efficacy, and self-authenticity), and social structure. (p. 31)

This excerpt from sets the stage for the chapters in Part III. The chapter authors express these goals through their ideas about the relationship between identity and social interactions.

Katz (Chap. 8) completed her work in the U.S. with four age/grade groupings (Pre-K:4 years old, K-1: 5–6 years old, grades 2–3: 7–8 years old, and grades 4,5,6: 9–11 years old) who participated in out-of-school projects, and her granddaughter (age 5 1/2). She describes the connection between play and the social interactions among science leaders and learners—belonging and participating—as important to developing science identity. In (Chap. 9) Rahm, Fahrni, and Touioui (Canada) describe their work with student immigrants from Bangladesh, Jamaica, Philippines, and Romania, and a family. Their vignettes include a botanical garden, a family discussing a cooking activity, and the maker movement. They suggest mobility is an important aspect of identity, "mobile theory of learning and identity as it also centers intersectionality and local politics and thereby offers a means to attend more deeply to and unpack issues of equity and social justice in informal learning".

Riedinger and Storksdieck (Chap. 10) integrate Falk and Dierking's Contextual Model of Learning and Falk's Situated Identity Model (Falk, 2009, 2010). After collecting data across six U.S. aquariums and zoos, they use the resulting framework to explain "visitors' identity-driven motivations for visits to ISL contexts and how this influenced their resulting visit behaviors and learning outcomes". In (Chap. 11) Scipio employs intersectional identity theory with graduate students (U.S.) to aid them in recognizing the complexity of the relationship among their identities and positionality. Moreover, Scipio urges future environmental educators to acknowledge and appreciate how their identity influences the complexity of nature-culture associations. Vedder-Weiss, Segal, and Shaby (Chap. 12) include three case studies to define their ideas about sociocultural identity theory. They review discourse in three situations: Israeli elementary (ages 6–12) school students during field trips to a science museum, an Israeli family during a year in Australia, and professional development programs for elementary teachers. Their focus is the importance of developing identity through a situative lens.

1.5.4 Part IV Sociocultural, Socioscientific, and Social Entrepreneurship

While many of the chapters in the book derive from cultural theory, social theory, or sociological theory, this section includes theories directly linked to social theories. In (Chap. 13) Patrick employs Rogoff's sociocultural perspective to coin the term sociocultural dialogic patterns and to define how families talk in a stingray exhibit. She defines informal science learning spaces where conversations take place as sociocultural dialogic spaces. She completed her study in a U.S.-based aquarium with intergenerational groups. Idema and Daniel (Chap. 14) examine climate change and water sustainability in U.S.-based aquarium exhibit design through the lens of socioscientific issues (SSI). Their work is one of few studies including SSI as a framework for understanding learning in informal science learning settings. In (Chap. 15) Keyhani and Kim expand social entrepreneurship in STEM education to examine learning at a non-profit STEM centre in Canada. Student (ages 6–9) participants at a non-profit STEM center in Canada completed a game-design course focused on the social entrepreneurship antecedent empathy.

1.5.5 Part V Systems Theory

General systems theory identifies the interdependent parts of a biological, physical, and/or social system (Boulding, 1956) and considers the environmental and social demands placed on the system (Parsons, 1951). GST relies on understanding how the actions of the system cause changes in the environment and vice versa. Sanders and Davies and Patrick and Weinstein include the components of systems theory—boundary and boundary objects—as important aspects of learning in informal science settings. Sanders and Davies (Chap. 16) focus on Barad's material objects and agential cuts as a framework for "moving between the classroom and outdoor settings". Their chapter describes an ecology-focused quadrat (boundary object) activity completed with pre-service biology teachers (teacher candidates) in Sweden and the United Kingdom. Patrick and Weinstein (Chap. 17) examine the system boundary between elementary educators, students (ages 4–11), and informal educators (zoo educators) at a U.S. Zoo. Their work describes the boundary interactions between the groups and defines the importance of boundary crossing for informal science institutions and schools.

1.5.6 Part VI Expeditionary, Place-Based, Variation Theory

This group of chapters is diverse but has a common thread indicating the importance of location in the learning process. I grouped these chapters together because their work depended on the place where learning occurred. Holliday's (Chap. 18) work embraces expeditionary learning. His expeditionary learning *place* is during a 12-day excursion in Germany and Poland. The excursion was meant to develop college students' ideas about scientific concepts through travel and engagement "in a critical analysis of false and doubtful assertions made by Nazi leaders in the name of science before and during WWII". Sedawi, Assaraf, and Reiss (Chap. 19) expound on place-based education by including third-space theory. Their *places* were villages and locations along Hebron stream and other nearby streams in Israel. They explored how Bedouin students (age 10), who completed an education program based on the local river (at school and on field trips), developed a sense of place. Preston's (Chap. 20) *place*, while not outside, is of great interest. Her place is a classroom, but not in the traditional sense. Her study place is a new immersive habitat classroom at a zoo in Australia. She applies variation theory to define the impact of a lesson taught by zoo educators during a student (ages 12–16) field trip.

1.5.7 Part VII Theory Development

While all chapters in this book serve an important purpose in developing our ideas about informal science learning research, the chapters in this section intend to present new ideas about learning theory. The chapters in Part IV present new models or conceptual frameworks of learning that are like a spider web. The theories are meant to be pushed and pulled and questioned and, like a web, they give and take forces. If they break, they are repaired or rebuilt. The ideas in these chapters push us to think and rethink learning in informal settings.

Yeh's (Chap. 21) work links three models as an impetus for informal science educators in a Taiwan natural history museum to reflect on their teaching. Based on the Posner, Strike, Hewson, and Gertzog model of conceptual change, the Personal Awareness of Science and Technology framework, and the Predict-Observe-Explain approach, museum educators refine teaching programs focused on 5th-graders (age 10). Like Yeh, in (Chap. 22) Kapelari, Moussouri, and Alexopoulos illuminate their framework with Big Picnic: Big Questions. During Big Picnic, botanical-garden educators across 12 European countries and one from Uganda, Africa, reflected on their education programs with the goal to address food security and climate change. Their conceptual approach to defining multicultural, multifaceted learning is an amalgamation of Cultural Historical Activity Theory, Organisational Learning Theory, and Communities of Practice. Truong and Patrick (Chap. 23) repurposed Nutbeam's Outcome Model for Health Promotion to develop a Participant Model for Health-Related Cooking Classes. They based their new model on data from 22 children (ages 5–14) who completed a cooking class at a children's museum in the southeast U.S. Striligka, Bliesmer, Sajons, and Komorek (Chap. 24) state, "If using models of general didactics or educational science for subject-related tasks, one must combine them in such a way that they meet the criteria…" In their chapter, they merge the offer-usage model, a design-based research approach, and the Model of Educational Reconstruction to define learning in a science center, national park houses, and out-of-school student laboratories located across Germany. They designate three characteristics of new learning models. Bailey (Chap. 25) desired to answer, "Is learning happening in science museums?". Her quest to satisfy her aspiration led her to develop the Learning Characteristics and Influences on Learning Tool. She fused experiential learning theory, situated learning theory, and sociocultural theory to frame her research across a small children's science center in the U.S. and a large science center in Germany.

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Part I
Community of Practice

Chapter 2
Re-examining Wenger's Community of Practice Theoretical Framework: Exploring Youth Learning in Science Research

Rachel Chaffee, Karen Hammerness, Preeti Gupta, Kea Anderson, and Tim Podkul

2.1 Examining Assumptions in Community of Practice Theory

In this chapter, the authors describe the way community of practice (COP) theory served as a productive framework in a longitudinal study of youth STEM pathways during and following a mentored science research experience. This theory was important in framing the research questions and identifying the constructs—identity, sense of belonging, language, practices, and peer and mentor relationships—and also drove instrument development and analysis. A key component of community of practice theory is a view of learning as a "trajectory of participation" (O'Connor, 2001, p. 228), by which individuals enter a community as newcomers or novices and through guided participation in that community, become full members as they develop and deepen in their practice. Implied in this theory is that newcomers move over time from peripheral forms of participation and membership to more centralized roles, responsibilities, and identities that enable them to develop recognizable expertise in a community. In this chapter, we take a closer look at the assumptions

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embedded in this trajectory of participation by examining the experiences of those who move towards assuming more centralized roles as well as those who remain at the periphery of a science community of practice during the study period. We discuss the potential role of challenges youth encounter in their remaining in more peripheral positions. Below, we provide a short overview of CoP theory and its application in informal learning environments. We then explain the context of our study, mentored science research programs for high school youth ages 15–18 who live in New York City, the largest city in the United States, and share how we drew on the theory to develop instruments and constructs that helped us illuminate features of the mentoring program related to how youth connect and identify with the work of scientists. We conclude with a discussion of how use of this theoretical framework for studying out-of-school contexts may help bring into focus key aspects of youth development and identity, but also may conceal or mask needs for support for youth that remain at the periphery.

2.1.1 Community of Practice as a Learning Theory

We found a community of practice framework helpful in illuminating learner's trajectories and growth with regard to mentors, peers, and the program experience. A CoP is a group of people with an acknowledged shared interest (or shared concern, set of problems), who collaboratively engage in activities and discussions on an ongoing basis with the goal of deepening their knowledge and expertise in this area and collectively learning from each other (Wenger et al., 2002). This mutual engagement includes sets of practices, or what members "do" when they interact. Practices can include shared beliefs, values, ways of acting and interacting, and activities and tasks (Barab et al., 2002; Irving & Sayre, 2016) and are shaped by both individual and collective participation of the group (Dhingra, 2008). Members of a CoP draw on this shared repertoire of resources in order to make meaning together and produce artifacts and processes that reflect their shared domain.

Using CoP theory presented two opportunities in our work: first, to inform out-of-school-time (OST) STEM research questions, and second, to inform instrument design and analysis in a mixed-methods longitudinal study. While studies have utilized CoP theory in examining how learners participate in a science community of practice in the formal contexts of school, including middle and high school (Olitsky et al., 2010) and undergraduate education (Crossard & Pryor, 2008; Hunter et al., 2006), only a few studies employed a CoP framework both quantitatively and qualitatively to illuminate how youth enter into and negotiate their roles, positions, and practices in OST learning contexts. Most of these studies are ethnographic and/or qualitative in approach. For instance, Farland-Smith (2012) utilized a CoP framework to examine how the culture and climate of a girls-only middle-school science camp that provided interactions between youth and scientists provided opportunities for youth to develop a sense of membership in a science community of practice and construct meaningful personal science identities. Verma et al. (2015) drew upon community of practice as a framework to help them describe how the creation of a productive community of practice in the form of an after-school robotics club that culminates in a competition provided an appropriate space for youth engagement in an authentic science community. The organization of engineering mentors, teachers as coaches, and peers who had specific roles and tasks as part of the team created a way for everyday talk to integrate with disciplinary talk and engagement in the authentic activities of constructing/critiquing/building. Similarly, in her analysis of Rahm's (2008) study of youths' dialogue with scientists as part of an OST school/museum partnership program, Dhingra (2008) applied a CoP framework to examine how conversations and engagement in science practices supported youths' identity work across informal and formal learning contexts. CoP frameworks also have been utilized to examine the science-learning opportunities in an after-school youth club (Davis, 2002) and in a retrospective study of the impact of six OST programs on the college and career goals of young women (McCreedy & Dierking, 2013).

Additional studies have drawn on CoP theory in tandem with additional learning theories, including such frameworks as figured worlds (Calabrese Barton et al., 2013; Tan et al., 2013), identity theory (Alhoyokem et al., 2011) and activity theory (Wade-Jaimes et al., 2019), in order to examine how youth author science identities-in-practice and move (or do not move) to more established membership positions within and across multiple communities of practice, including OST science clubs, science classes, and their home and communities.

While a number of researchers have used community-of-practice frameworks to inform their analytic approach (Smith et al., 2017), our study invoked a CoP framework both conceptually and with attention to the methods as we embarked on instrument design and analysis. We used a CoP framework not only as a way to define and understand youth participation and experience, but we also drew carefully on it to help us identify a series of constructs salient in youth's mentored research experiences and their continued participation in STEM, and in turn, used those constructs to develop instruments such as our surveys and interview protocols. We then used those constructs to help guide and carry out our analysis. Furthermore, the frameworks' emphasis upon different roles and actors in the CoP also shaped our decision to collect data from mentors and other key adults who may play a role in the scientific community of practice.

To complement the theoretical foundation of CoP, our team also grounded much of the methodological approach in social network theory. Social networks are, "a way of thinking about social systems that focus our attention on the relationships among the entities that make up the system, which we call actors or nodes" (Borgatti et al., 2013). Many theories of relations, and the utility of these relationships exist within social network theory, and these are ways to understand and operationalize the concept of social capital (Coleman, 1988; Lin, 1999). In our study, we view social networks as forms of "bridging" (Burt, 1992) and "bonding" (Coleman, 1990). Bridging is the idea that brokerage is possible across otherwise disconnected groups, actors, or opportunities, and this brokerage then becomes the activating agent of social capital (Burt, 2004). Bonding is another way by which actors strengthen their social capital.

This approach emphasizes the strengths of building networks with close and strong bonds between actors (Coleman, 1988, 1990). Because we wanted to understand the value of youths' participation in CoPs for both cohort—and identity—building, as well as brokering opportunities for new learning experiences, we approached the study from a theoretical standpoint that acknowledges both bridging and bonding. Thus, the CoP framework enabled us to study and describe members' positions in a community of practice as a whole, while social network theory enabled us to investigate the specific nature of a member's relationships meaningful in STEM pursuits, both within the community beyond it (such as other peers, family members, and other mentors and role models).

In the sections below, we describe how we utilized a CoP framework to design and implement a longitudinal study of youths' participation in twenty-four science communities of practice and how analyzing our survey data drew our attention to the overwhelmingly positive experiences youth reported having in these spaces. We also bring attention to a smaller but still meaningful pattern of youth who reported substantial disagreement with positive experiences related to features of the COP, and why we posit it is necessary to probe that data with equal attention. Examining the nature of individuals' peripheral positions within a science community of practice provides insights into the affordances and constraints of using a CoP framework.

2.1.1.1 Staying in Science & New York City Science Research Mentoring Consortium: Study Context

Staying in Science was a four-year, longitudinal study funded by the National Science Foundation that investigated how authentic, mentored science research experiences in out of school time settings may support youths' persistence in STEM. The study included 733 high school youth between the ages of 15–18 and 68 scientist mentors. Participants were recruited from 25 science research internship programs at one of 24 institutions who collectively form the New York City Science Research Mentoring Consortium (NYCSRMC). Each institution selected scientists as the mentors who were either graduate students, postdoctoral researchers, professors, or curators. In these programs, youth spend more than 100 h doing research alongside the scientists on existing scientists' projects. (Throughout the remainder of this chapter, we will refer to these mentored research experiences as SRMP for the Science Research Mentoring Program). In addition to the shared principle of having youth engage in authentic research with scientists over time, all sites are required to (a) provide free preparatory coursework to introduce youth to needed scientific concepts, software, and technologies, (b) pay youth a stipend for their time, (c) provide mentor professional development and provide mentors compensation and funds for lab materials, (d) provide youth access to scholarly literature for the area of research of their study, and (e) provide youth guidance and opportunities for communicating their research to peers, adults, and others in a conference-type setting.

While the sites share those principles of youth learning and shared elements of program design and delivery, each site's scientific expertise drives the content at each site. For example, youth working with scientists at the American Museum of Natural History may focus on astrophysics, genomics, or cultural anthropology, while those paired with researchers at the Mt. Sinai School of Medicine may focus on medical topics, and those at Wave Hill Botanical Gardens work in conservation biology. This variation in disciplines and settings (for example, a laboratory or field) leads to varied opportunities to engage in science practices. A site with more field work may have more data collection, background research, and analysis, while a laboratory-based project may involve more analysis and synthesis.

The 25 programs that make up the NYCSRMC annually recruit over 500 New York City youth from all five boroughs to participate in science research mentorships. The demographic makeup of the youth who participate in these programs reflects the diversity of New York City: between 2013 and 2021, the demographic makeup of the youth in these programs included 19% of youth who identify as Black or African American, 23% of youth who identify as Latinx, 18% of youth who identify as White, 19% of youth who identify as East or South Asian, and 15% of youth who identify as multi-racial (24% of youth did not report). The gender breakdown of the programs skews towards female-identifying youth who make up approximately 60% of participating youth, with 33% identifying as male and 1% identifying as gender nonconforming (6% did not report).

In 2017 and 2018, we invited all youth who were participating in research mentorships to participate in the *Staying in Science* study. Youth who consented to the study were sent a survey about their internship experiences and their college and career goals at the completion of their research experiences. In the following discussion, we draw from the survey and case study data of a participant subgroup of N = 353 youth who completed a mentored research program at one of the sites in the consortium in 2017 or 2018 and who consented to the study. Of these youth, 31% identify as Latinx, 14% identify as Black, 33% identify as Asian, 14% identify as White, and 8% identify as "other" or multi-racial. Sixty-six percent identify as female. Nearly two-thirds (63%) are the first in their family to attend college. While the gender makeup of our participant sample is similar the gender makeup of the NYCSRMC youth participants more broadly, the ethno-racial makeup of our subset has higher percentages of Latinx (8% more) and Asian (15% more) youth and a slightly lower percentage of Black or African American (4% less) and White (4% less) youth. Almost one-quarter (23%) are from families with one or more parents born outside of the U.S.; more than half (56%) communicate with their families in languages other than or in addition to English. (Data on youths' first-generation status, immigrant families, and languages spoken was only collected for the *Staying in Science* study, not by the larger NYCSRMC.)

2.2 Communities of Practice Theory in Service of Instrument Development: A Focus on Identity, Practices, and Belonging

In this section, we discuss the ways in which we developed our methods with the aim of measuring the key features of a science community of practice in an OST mentored science research program and how capturing and tracking the movement of these key features (e.g., identity, roles, practices, belonging, tools and artifacts) over time supported our understanding of youth's positionalities with regard to their mentors and peers in the program experience.

We used the following CoP-related constructs in the development of our surveys and interview protocols. The constructs and sample survey items for each are in Table 2.1.

- *Mentoring.* Mentoring relationships between novice/newcomers and experts/insiders in a community of practice are a core component of participation in a community of practice (Wenger et al., 2002). In the case of the SRMP research experience, mentors provide youth with scaffolded opportunities to learn and engage in the practices of science research in a supportive and collaborative environment while providing youth important insights into the life and work of a scientist. Our research instruments aimed at capturing how, and in

Table 2.1 Community of practice constructs and features

CoP construct	CoP features
Mentor/Mentee relationship	Developing a relationship between a novice/newcomer (mentee) and expert/insider (mentor) that supports participation and identity development (Example survey items: My mentor is visible and accessible when I need her; My mentor provides constructive feedback; My mentor shows genuine concern for me and treats me with respect.)
Opportunities for engagement	Authentic forms of collaborative engagement (Example survey items: My peers and I problem solve together; I am part of a community where we all are working on the same goals; My contributions matter.)
Science Practices	Authentic engagement in science practices (Example survey items: I had opportunities to: Design and plan science investigations; Collect data or other materials, or use existing data for analysis; Share my findings with a larger audience (i.e. parents, peers, teachers.))
Science identity	Seeing oneself and believing others recognize oneself as a legitimate participant in science (Example survey items: My (teachers, peers, family) recognize me as someone who likes and knows science; Believe the work done by the scientists at your research site is something someone with your type of background (family, school, etc.) could do.)

what ways, mentors provided these opportunities for youth to develop skills and confidence as a novice researcher while also fostering a relationship that built rapport and genuine connection. Our instruments examined both the practices mentors employed and the nature of the relationships they built. We gathered both mentor perspectives and youth perspectives on mentor roles.

- *Opportunities for engagement in authentic practices.* Legitimate peripheral participation in a community of practice suggests that for youth to shift from novice to expert, they must have opportunities to engage in the community's authentic practices (Lave & Wenger, 1991). In the mentored research programs, youth start at the "periphery"—learning the rationale of the project that the scientist is leading, reading background papers, learning basic lab techniques—and then slowly become more independent with scientific tasks related to data collection and analysis. Youth join lab meetings, ruminate over challenges, contribute to the design of mini-investigations within the project, and share their progress and receive feedback. We wanted to capture the forms of this deep engagement, including the degree to which youth were able to engage in problem-solving, designing and planning investigations, meeting and talking formally and informally about science with their mentoring group, and giving and obtaining feedback from both their mentor and their peers. We also aimed to capture how youth felt about their participation in these collaborative environments, including if they felt supported enough to participate successfully in the program, and if they felt they were a part of the community and their contributions mattered.
- *Opportunities to learn and utilize science practices.* In addition to capturing forms of collaborative engagement in the SRMP mentoring experience, we also designed our instrumentation to capture what types of science practices youth have access to during their program, drawing on the premise of communities of practice participation that the ability to "do" the work of the community, in this case, scientists, is key to developing the competencies and skills that support youth in developing science identities. We developed science practices items based on the *Next Generation Science Standards* (NGSS, 2013) and the six strands, or types of outcomes, associated with informal STEM learning delineated in *Learning Science in Informal Environments* (*LSIE*) (Committee on Successful Out-Of-School STEM Learning, 2009). Using the eight NGSS practices and *LSIE* as our framework, the questions serve as means to understanding if and how the principles of scientific investigation reinforced in the SRMP program are contributing to youth's interest in and pursuit of science.
- *Science identity.* Moving towards membership in a science-related community of practice entails an increased sense of an identity as a practitioner, as learners come to see themselves (and believe that others see them) as legitimate participants in scientific endeavors (Aschbacher et al., 2010). Our aim was to understand the role that recognition plays in youth's ability to access and enact a "science identity" (Carlone & Johnson, 2007) by capturing youth's perceptions of those who recognize them as competent in science, as well as youth's own feelings and perceptions of that recognition by significant adults and peers (e.g. parents,

teachers, friends). We also aimed to capture youth's perceptions of what kind of person is able to do science research.

To help us gauge both youths' program experiences and how the mentoring experience factored into youths' subsequent pursuits, we collected data at specific points in time during and after youths' participation in the mentoring program, including two surveys and interviews with youth. In the first year of the study, we measured how youth felt about the features of the CoP immediately after they completed the program. Findings from this survey (discussed below) suggested that youths' mentored research experiences provided important opportunities for engagement in a science community of practice in their research program. We hypothesized that youths' engagement in these CoPs potentially could support their access to and engagement in other science communities of practice (Tan et al., 2013), including other science research experiences in OST and in-school contexts. In year two of the study, we designed an alumni survey and administered it to all youth who were one year beyond their SRMP experiences. This survey aimed to capture if and in what other contexts youth had opportunities to engage in science communities of practice, including high school courses, additional mentored science research programs, college and college courses, internships and/or research positions, and work. Drawing on the same set of CoP constructs as the current youth survey, the alumni survey asked youth to report on the types of interactions in which they had the most opportunities to engage during their SRMP program and to identify where they had similar opportunities for these forms of engagements (for example, skills development, science practices, relationships with adults and peers, opportunities to collaborate, etc.) in other contexts. In addition, we conducted interviews with a subset of alumni (n26) that enabled us to delve deeper into youth's experiences in their mentored research CoP, particularly regarding the ways in which relationships with mentors and peers formed and were or were not sustained after youths' research programs, and how those relationships shaped youths' perspectives of science research and their interests in pursuing additional science experiences.

To identify the key features of the mentored research experience related to stronger STEM identity and persistence, we began by conducting a descriptive analysis of our survey data, including significance testing of multiple survey variables and constructs specific to youth's participation in a science CoP in their programs. In order to assess whether or not specific constructs are associated with a participant's plans to major in STEM and plans to pursue research opportunities in college, we conducted a latent class analysis of key CoP constructs, including receiving guidance from a scientist mentor; feeling a part of a community of science practice; opportunities to learn and engagement in science practices; and a sense of vision with respect to believing someone like them can pursue research. We analyzed case study qualitative data using a deductive approach to surface themes and coded the data using qualitative analysis software. We used case study data and survey data findings to elaborate and deepen our understanding of our findings, as well as to interrogate findings across the two and to help triangulate emerging findings.

In addition, thanks to a partnership with the City University of New York and their arrangement as a custodian of New York City Department of Education student administrative data, we matched youth in our dataset with student records in the New York City Public Schools dataset. We looked specifically at *Staying in Science* students who participated in the program and also we analyzed descriptive information on 63,500 comparison students who were enrolled in the same schools in the same grade in the same year as *Staying in Science* youth. We analyzed the data on student demographic and baseline characteristics, as well as outcomes of interest.

2.2.1 How a Community of Practice Lens Helped Highlight Important Features of the Mentoring Program

How did this theoretical perspective help us understand and examine key features of the mentoring programs? Analysis of our data allowed us to explore key aspects of the mentored research experience that we suspected might matter substantially to youth program participation, and, ultimately, to their continued pursuit of STEM. Using the CoP framework, we were able to capture and delve into the degree to which youth reported a sense of belonging, increased competence with the practices of science, strong relationships with mentors and peers, and increased identification as someone who can do science and would be recognized by others as being able to succeed with science. Opportunities to acquire these forms of capital through participation in a science CoP are central to youth's ability to be recognized as valued contributors to the production and transformation of these communities and ultimately be seen as valuable contributors to scientific communities of practice they join in other settings, such as summer internships and science-related jobs. This lens enabled us to tease out critical features of these experiences youth were having, and helped us articulate the ways that youth were experiencing the supports, learning, and practices, and how these things enabled them to move from novice to more experienced researchers in their mentored experiences. Across our data, we saw a set of themes consistent with increasing participation in a community of practice: a growing sense of belonging; the ability to learn and use the tools and practices of the community; continued support by more experienced participants; and a deepening identity rooted in the community. Taken together, these themes in our data suggested that youth felt a sense of membership in the community, and, in turn, experienced a confidence in their ability to do meaningful work in that community, to engage in its practices, and a sense of legitimacy in relationship to their identities as scientists—which helped us understand better what combination of features might be supporting youth in their continued persistence in STEM work.

2.2.1.1 Sense of Belonging

We hypothesized that through participating in these mentored experiences, youth would experience a sense of being a 'part' of a team. In this way, functioning as a group of people investigating and exploring something together also might be accompanied by the felt recognition that their participation was important and necessary for the work (Saxe, 1998). In our survey results, youth report very high perceptions of belonging, being part of a team, getting feedback, talking to other members of their team, and—most important—that their contribution matters and that their work is important. For instance, approximately 90% of youth report opportunities to problem solve with mentors and their peers. A high percentage of youth also reported that they had the support they needed to be successful in their mentored research programs, felt part of a community, and believed they were making valuable contributions to the community, suggesting a sense of genuine involvement. These findings surprised us. We had hoped that youth would feel a sense of belonging in their work and in their mentored experiences, but the degree of strong agreement was unexpected.

2.2.1.2 Practices of Science

Critical to the conception of a CoP is the opportunities to learn tools and practices that enable identification with the community, which supports an increasing, gradual ability to engage in the work of the community. We asked youth about their opportunities to engage in fifteen of the NGSS practices (National Research Council, 2015), which ranged from opportunities to design and plan an investigation, to analyze data and to learn to argue from evidence. Youths' reports of opportunities to learn the practices of science showed very little variation across mentoring sites. Uniformly across all sites, youth reported multiple opportunities to learn these key practices and at a high level of frequency. Even practices that are rated 'lowest' in terms of agreement that youth experienced, we find that roughly 70%–76% of youth report agreeing or strongly agreeing that they experienced them. In addition, we found that youth report statistically significantly greater opportunities to engage in science practices at their mentored research programs than in school contexts (Gupta et al., 2020).

Three practices were reported with the most frequency and stand out to us: designing and planning investigations, analyzing data, and using scientific terms. As science educators and scientists ourselves, we believe these are especially important. Being able to design and plan an investigation is a critical 'overview' practice and requires breaking tasks into a set of steps, determining process and sequencing steps appropriately, and considering alternate approaches. As opposed to some of the more specific practices, designing and planning an investigation requires an ability to conceptualize and plan out an entire study, with all the chain of logic that such planning requires. In turn, we see analyzing data and using scientific terms as foundational practices and knowledge for the work of scientists. Additionally, nearly 40% of youth ranked sharing findings with a larger audience at a conference as a high-frequency practice. This practice is especially critical for youths' pursuit of STEM because it knits together the experience of doing science with communication about it, as well as with important networking opportunities. Moreover, clear science communication supports later professional success.

2.2.1.3 Relationships

As the community of practice literature implies, participants learn together in collegial relationships (Wenger et al., 2011). Using that lens, we designed questions that dug into the degree to which youth reported feeling supported, feeling known and heard, and feeling guided by their mentors in their research sites. Youth generally reported strong supportive professional relationships with mentors in our study. Youth generally agreed or strongly agreed that mentors made them feel confident as science researchers, provided guidance/advice about youths' academic plans, and provided information about other science research opportunities. Additionally, a majority of youth viewed mentors' support for their success in the mentored research program in almost equally positive terms, agreeing or strongly agreeing that mentors provided clear guidance for their success in the program, constructive feedback, and adequate support to facilitate their learning. We also found that when youth talked about the science in which they participated with significant people in their lives, those individuals became brokers to additional STEM opportunities. Furthermore, our qualitative research and interviews illuminated the finding that some youth had taken on mentoring roles themselves by providing guidance to peers. They reported seeing mentoring as something they explicitly wanted to do and felt it was important to help support their peers. Of the youth interviewed ($n = 26$), nine had taken on formal and/or informal mentoring roles in STEM and non-STEM contexts, including tutoring other students in campus learning centers and informal study groups. These youth spoke about mentoring their former SRMP peers and friends in seeking STEM opportunities and college degrees, providing guidance on internship and scholarship opportunities, and supporting peers in writing college applications and making decisions about to which colleges to apply and/or major to pursue. Youth also discussed mentoring younger siblings, including sharing information about internship opportunities and encouraging them to pursue STEM-related activities inside and outside of school, including science research mentoring programs.

2.2.1.4 Participants Reported Deepening Identity as a STEM Person

Finally, theories of communities of practice suggest that over time, through participation in the community, members gradually gain expertise, experience, knowledge, and tools and by doing so, begin to develop and deepen their identity as a member in that community (Wenger, 1998). Our data show this development for nearly all youth participants who reported high agreement that they understood key science ideas and were able to imagine that they can do science research in future. Many of our youth also reported agreeing that research was “important to who I am.” Our data suggests that the program supports youth in strengthening their awareness of themselves and of what they are capable (Markus & Nurius, 1986). Also important to the development of their personal identity was the fact that seeing others in the community who shared characteristics with them helped support their own identification with science; many reported that seeing others like me doing science reinforces my feelings about being a science person and a majority of youth reported feeling recognized as someone who likes and does science by their peers, families, and teachers. We also found that youth report what might be the reverse of a stereotype threat condition (Steele, 2002) in the mentoring experience, reporting with high frequency that they can imagine someone of their background doing the work of scientists. Additionally, youth in our study reported that they liked participating in a mentoring program where they see people of similar race and/or ethnicity engaging in and liking science research. These findings are critical for youth historically marginalized in STEM, particularly as they move from the mentored research communities of practice into college and career contexts.

2.3 Interrogating Roles at the Periphery

While we saw uniformly high reports of OST time learning and strong positive reports about the features of the communities of practice across a large majority of youth study participants, we began to wonder about the small number of youth who reported fewer and less positive views of their mentored research experience, a weaker STEM identity, and whose responses would indicate a more peripheral role in their program site’s CoP. Were we ignoring an important signal in the data that was also critical to understand? Could the highly positive reports from youth mean that we were not looking at the experiences of a smaller number of youth who might be ignored because they were not representative of the main findings? As we continued to examine our data, we began to realize that honing in on the experiences of youth who did not take up more centralized positions in their mentored research communities was critical to our research goals—and, in particular, to unearthing potential supports and obstacles to continued participation in STEM. We began to wonder if the theoretical framework’s treatment of peripheral participation as ‘natural’ and part of the community might initially have obscured the need to interrogate that conclusion more carefully.

Wenger (1999) argues that having access to a community of practice does not mean that all community members share common experiences. Was the assumption that members in a community of practice de facto have a range of experiences making it harder for us to see the ways in which a community might, in fact, limit the forms of participation possible for specific individuals, and through established practices and routines, impede participation of some individuals? More specifically, if a community of practice is built upon or reflects a monocultural view of participation, or a set of practices that reflect a singular culture, could that lead to exclusion and lack of connection and belonging for youth who do not feel they align with that culture?

We undertook a series of analyses focused specifically on data from youth who did not report the same high degree of opportunities in their mentored research experiences. We began by examining youth survey responses in order to identify youth who responded less positively and/or had fewer opportunities to engage in their science community of practice than their peers and determine if there was a pattern to these responses; specifically, do these youth participants form a collective group? If so, do negative/less positive responses on CoP survey items correlate across CoP constructs? What might this tell us about the particular factors that influence peripheral participation and outlier positions in a science research mentoring CoP?

To conduct the analysis, we examined the survey responses to the constructs detailed above, including youth's relationship with their mentor (12 items), the features of the CoP that supported participation (13 items), and youth's science identity (12 items). We did not analyze survey responses to youth's opportunities to learn science practices in their program (15 items) because analysis of our larger dataset revealed that patterns related to learning science practices often depends on the specific mentoring program and the ways that program designed and implemented research experiences based on STEM discipline, the scientist mentor's research study, and each program's unique setting.

We grouped participants that responded "strongly disagree" or "disagree" to multiple survey items within and across constructs into a subset of participants with high frequencies of strongly disagree/disagree survey responses. In total, 31 youth fell into this group. Notably, the demographic makeup of this group was not significantly different from the demographic makeup of the larger data set. For example, 70% of the outliers identified as female, whereas 66% of the larger dataset identified as female. The makeup of ethnicity and race categories was similar to the entire participant population with a majority of youth identifying as Latinx (26%), Black (22.5%) or Asian (25.8%); we found no statistically significant differences between the outlier group and the larger youth participant pool. In addition, we did not find that outliers tended to come from particular programs. We found that the youth in the outlier group had participated in eleven of the twenty-four mentoring programs.

We have begun to analyze data specifically from the youth who reported responses that varied from the main patterns of response, and we find a few initial themes that stand out; however, we will be examining this data in more depth over the course of the next iteration of this grant. For instance, an initial analysis suggests that across the three constructs we analyzed, the science identity items had the highest proportion of negative responses (25.8%), followed by mentor relationships (24.4%), and opportunities for engagement (e.g., getting feedback, contributing to a community in tangible ways) that supported participation (17.9%). This initial analysis of survey items suggests there is a proportion of the youth participants may be experiencing their mentored research experiences in very different ways than their peers. At the same time, however, we recognize that while these youth may be reporting a less positive experience for one or more aspects of their mentored research, it may not mean that they were completely negative, or even that youth assessed the experience overall as negative.

A second aspect of our analysis of the experience of youth who fall into this outlier position on some of the features we examined has been to analyze our case study data. Two out of the 31 youth who have reported less positive experiences are among our case study youth. We looked at their data to see if we could further understand some of the experiences and trajectories of those who fall into this category, and to see if data from our extensive examination of youth experience could help reveal any information to help us better understand less positive experiences with the mentored research.

2.3.1 Examining Two Youth Cases from the "Outlier" or "Peripheral Participation" Group

Drawing on our data from our case study youth (which includes social network data, social network maps, interviews, and surveys), we describe the experiences of two youth, Dimira and Luciana.[1] What could their experiences tell us about the experiences of youth who fall into this outlier category? What might we notice about their experiences in the communities of practice, and their discussions of identity within the sites, and mentoring and practices?

Dimira participated in two separate science mentor research programs within the consortium. While she did not intend necessarily to pursue a STEM college major, Dimira reported that she pursued mentored research experiences because she believed she would need them in order to get into a good college and because her family insisted she participate in them. Dimira identifies as female and is Arab-Chinese; her family immigrated to the U.S. in order to find better educational opportunities. While not a first-generation college student, Dimira's parents know less about the educational system in the United States having completed degrees in other countries.

Dimira disagreed or even strongly disagreed that she had opportunities to get feedback from others, to problem solve and talk informally about research with her peers and mentors, and participate regularly in research meetings—all aspects that we identified as related to "participation in a joint enterprise." However, case study analysis suggests that despite not having these experiences in her programs, Dimira developed strong relationships with her mentors in both of her programs and felt supported both in her mentored research experiences and in her science pursuits. Dimira also utilized her social network, which included a mentor from one of the programs and peers in the program, family members, and high school teachers and friends, to talk about her science interests and her research, providing her with opportunities to develop a strong science identity that led to the pursuit of additional STEM goals. Dimira has continued to draw on these same resources by staying in

[1] We use pseudonyms for all our participants, including case study participants, to protect their identities, and in some cases have changed specific personal details that could identify them.

contact with a number of her mentors as she moved into her first two years of college and utilizing them to find additional research opportunities, for advice about STEM careers, and for personal support. While not originally intending to pursue STEM or research in college, Dimira selected her university *because* her mentored research experiences provided her with access to scientist mentors and staff at the university, including opportunities to continue pursuing research in her first years of college. In fact, in a later survey, she reported that her mentored research experiences were helpful (or even extremely helpful) in terms of preparing her for college.

A Latina, Luciana is from an immigrant family and reported that she could have not participated in mentored science research programs unless they were paid opportunities. Luciana participated in two different programs within the Consortium, but did so to better prepare herself to pursue a STEM college degree and career. Luciana reported limited opportunities to engage in her program in similar ways to Dimira, including fewer opportunities to problem solve, obtain feedback, and talk informally about science with peers. Notably, Luciana reported that she often did not understand the science language used by her mentor, felt her mentor was not comfortable working with youth, and felt she did not have the support she needed to successfully participate in her program. Luciana explained that she did not feel a part of her mentored research community and rarely encountered others with the same race or ethnicity as her own.

Luciana found her scientist mentor "very intimidating and hard to follow." While she reported that her mentor was knowledgeable about her research area, she felt that her mentor was very formal, used inaccessible language, and made assumptions about her and her peers regarding what they could or should know with respect to algebra and physics prior to beginning their programs. Reflecting on the experience, Luciana stated, "If this was my first research experience, I definitely would have fallen off the edge." Despite this challenging mentoring experience, Luciana was resilient and persisted in completing her program. While Luciana did not stay in touch with her mentor, she did pursue multiple research opportunities, is currently pursuing a degree in computer science, and founded a nonprofit aimed at increasing access in technology education.

Our examination of the experiences of Dimira and Luciana revealed that not all youth were experiencing some of the positive features of participating in a science CoP. While both Dimira and Luciana reported a lack of opportunities for particular forms of engagement and relationships in their program site's CoP, their interview and social network data and analysis revealed the positive experiences that they had in their programs. Both utilized their mentored research experiences to find additional research opportunities and to prepare them to enter new science communities of practice in other research settings at their college institutions, where they are recognized as competent contributors to scientific research and equity in technology education. In addition, both youth possessed a clear and focused sense of what Wenger (1999) would refer to as 'imagination' and what we might call vision. They were aware that participating in a mentored science research program potentially could support their pursuit of their STEM interests and goals and could imagine being welcomed and participating in science CoPs in multiple contexts beyond their SRMP experiences.

2.3.2 Broader Implications for the Field/Next Steps

Drawing on the communities of practice framework has been critical for our research study. It has supported our ability to identify key features that might matter for youth's continued participation in STEM in relationship to their mentored research opportunities, and in particular, for helping us understand better their negotiation of role, practice, and identity at their research sites. It has helped us reveal the ways in which these sites may be helping support youth in their pursuit of science by providing communities in which youth gradually take on more experience and expertise, engage in work that is meaningful and directly related to the work of the research site, and participate in systematic and conceptual work at all levels of scientific inquiry. It has also confirmed a strong sense of belonging, community, and relationships for many—but not all—youth. The framework has helped reveal how these features of their mentored research experiences seem to correlate with continued participation in and pursuit of STEM, as participants move into the early years of college. Many youth in our study report that they are participating in key features of a CoP including: (1) participating in a shared effort and have a collective understanding of their purpose (what Wenger terms "joint enterprise"), (2) participating with a common understanding of norms, expectations, and relationships (what Wenger calls "mutual engagement"), and (3) participating in a shared set of practices that guide their work (or, what Wenger would call "shared repertoire") (Wenger, 2010). As people participate in a community of practice, they reveal a sense of belonging through engagement in shared activity and production of artifacts, imagination of possible self doing this work in the future, and of themselves in that community and alignment with the community. The high numbers of youth in our study who plan to pursue and are pursuing STEM majors in college is heartening and encouraging and further suggests that youth are continuing to carry on this sense of belonging, imagination of self as scientist, and a shared connection. This is especially critical as we recognize the goals of broadening participation and increasing diversity in STEM fields. Aside from an economic argument which has been leading the U.S. for decades (Science Board, 2020), it is clear that the need for creative, committed, innovative, and highly prepared people with STEM expertise who bring diverse voices and standpoints is urgent as we deal with the devastating impacts of public health and climate-related crisis (Achieving the Promise of a Diverse STEM Workforce, 2019).

At the same time, using the framework also has led us to important questions about the assumptions made in the framework; in particular, the notion of peripheral participation. It has surfaced potential gaps in participation that are important for us as both researchers and youth educators interested in and committed to supporting all youth. Even as we are heartened by the strong participation of so many youth, we seek a deeper understanding of how the features of the communities might fall short for some youth and require either refinements or re-envisioning. Therefore, using the CoP framework reveals a set of implications for us not only for our research and how we carry it out, but also for the design of our programs and our work as youth educators. In particular, as we examine and refine our programmatic design, we currently are revisiting the preparation and training we offer mentors.

2.3.2.1 Sense of Identity

Data analysis shows that elements of the programs related to envisioning doing the same work as a mentor, feeling comfortable doing scientific work, and recognition of one who can do scientific research by several types of peers and adults may require more attention to better support some youth who are struggling in deepening their identities as people who can do science. Finding ways to engage program alumni more effectively who as near peer supports could potentially provide youth with opportunities to foster relationships with alumni of similar backgrounds. Finding ways to identify struggles with vocabulary, complex scientific ideas and then re-envisioning the type of support youth need before entering the lab is also an important step. Creating more opportunities for youth to share their science research while on the journey rather than waiting until the research internship is over so that youth can become visible to peers and adults, learn how to share ongoing work, and engage those significant people in conversations about the work is an implication of program design. In terms of research design, an implication to consider is using instruments and techniques to gather data on aspects of science identity that might be masked by surveys and interviews.

2.3.2.2 Mentor Relationships

Some of the themes that surfaced suggest one difference between youth who report lower agreement on many of the features of a community of practice and those who report stronger agreement and more positive experiences—seems to relate to relationships with mentors. While we still are exploring the data from youth, some initial data from mentors suggest a hope for deeper preparation and training. Investing additional learning for mentors that focuses on supporting youth who may have cultural backgrounds that are different from theirs is one early implication we are drawing from this work. The program managers in the consortium are continuing to revise mentor preparation across all the sites in our study. From a researcher-practitioner perspective, an ongoing way for mentors to document successes and challenges as they arise in terms of relationship-building could be used by both program managers but also researchers for examining patterns over time.

2.3.2.3 Opportunities for Engagement

Several youth noted that they did not get opportunities to problem solve with peers, participate in lab meetings, talk informally about science and get feedback from peers. These activities are part of a culture of a scientific lab setting, including "labs" that do field-based research. Some of these are planned activities while other interactions are norms that develop, are produced/reproduced, and transform over time. An important implication for program design is to pay attention to lab settings when selecting scientists for mentoring. Are the lab environments safe and supportive? Do they have activities that foster ongoing formal and informal discussions of the research and related topics? Are they labs concerned with issues of equity and inclusion? Are the PIs of those labs people that understand the value diverse youth bring into the CoP? Conducting observations of the labs during youth experiences would add a layer of documentation about the features of the CoP that are working or need strengthening.

In addition to attending to implications for programmatic work and diversifying tools and strategies for data collection, our examination of the CoP theory also suggests shifts we can make as researchers. No matter how comprehensive a theoretical framework might be, it will spotlight some aspects while pulling attention from others. To help ensure that we continue to account for as many features and aspects of youth development in science as may matter, it will be important for us to widen our theoretical lenses. CoP theory has enabled us to understand, tease apart, and dig into key aspects of the research sites and how they are functioning for our youth to support their learning of scientific practices, to feel a sense of belonging, and to imagine themselves as scientists. Utilizing CoP theory in this research has also made us aware of the way that some of the assumptions of the theoretical perspective may have masked or concealed challenges for youth participants that are important for us to understand and account for in our work.

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Chapter 3
The ‘Science Experience’: Using Situated Learning Theory to Connect Science in Everyday Life for Year 9 and Year 10 Students in Regional Australia Through an Outside-the-Classroom Science Program

Linda Pfeiffer and Ondine Bradbury

3.1 Introduction

The classroom is a social environment where students spend some 20,000 h in 12 years of schooling and go through various experiences (Fraser, 2001). The theory of constructivism that underpins science education concerns with developing teaching approaches that facilitate students’ conceptual development (Treagust et al., 1996). These pedagogical approaches to learning highlight the key role student’s prior knowledge plays in the development of concepts. Vygotsky’s theory describes the importance of both what the student is learning in school and the connections to concepts acquired through everyday experience.

This chapter describes an informal science learning program for Year 9 and Year 10 students, ranging from the ages of 14–16 years old, across Australia. This program uses local and contextual immersive science, technology, engineering, and mathematics (STEM) learning activities created for students by university academics over a three-day period. Each program design provides students with an opportunity to engage in a wide range of science and STEM activities under the guidance of experts in their fields. The program takes place in over 35 universities and tertiary institutions with more than 81,000 students (Year 9 and Year 10) having taken this authentic learning opportunity.

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Situated learning is an appropriate frame for this research as this study incorporates informal or outside-the-classroom science learning experiences that connect scientific concepts and create meaningful learning. The learning theory of situated learning (Lave & Wenger, 1991) draws from Vygotsky's social-constructivist paradigm. This chapter describes a case study of one location that has implemented the informal 'Science Experience' over the past seven years and the basis of situated learning theory underpins the development of the program.

3.2 Introduction to Literature

As outlined in the introduction, the focus of this chapter is in the STEM education context and draws upon a science experience conducted in an informal or outside-the-classroom context. We applied a social constructivist approach to foreground this work. The following section outlines the ontological and theoretical position of social constructivism further and, in addition to Vygotsky's work, outlines the theoretical constructs within the constructivist paradigm of situated and applied learning.

3.2.1 Social Constructivism in Educational Contexts

From an ontological position, a constructivist approach to learning includes the understanding that reality is constructed in relation to the outcomes of individuals interacting with one another rather than being separate from those involved (Bryman, 2016). A constructivist view contends that meaning is not discovered, it is constructed, and individuals construct these meanings as they engage with the world (Crotty, 2020). Additionally, construction of meaning is through engagement with social and cultural products and is not a constraint, but rather an emergent reality in a "continuous state of construct and reconstruction" (Bryman, 2016, p. 30). When approaching learning from within a social constructivist paradigm, the 'self' is not a passive receiver of influences from an external influence. They are instead active in participating, conceiving, and shaping their development by "being actively involved in a constant inter-*action* with the world" (Stetsenko & Arievitch, 1997, p. 160). Further to this, collaboration, co-operation, and social interaction form the foundation of all "mental and personal development" (Stetsenko & Arievitch, 1997, p. 161) as it is within these interactions that learning for the individual can occur.

Vygotsky's (1987) work underpins the theory of social constructivism. Vygotsky outlined that learning includes the relationship between language and social interaction and that this relationship is an important aspect of cognitive and social development. For Vygotsky, language was an "essential component of the human experience" (Vasileva & Balyasnikova, 2019, p. 9). Through his research, Vygotsky suggests that words are cultural tools that relate closely to behaviour and development (Vasileva & Balyasnikova, 2019). Within his work, Vygotsky (1987) outlines that the use of language entails a means to transmit experiences in societal contexts. Within the educational context, learning environments grounded in a social constructionist approach mediate learning in social contexts. This approach to learning denotes a breaking down of boundaries and fixed notions of learning environments, encompassing a variety of contexts in which learning can occur, which includes any situation in which communication can occur, both formally and informally (Hirtle, 1996).

3.2.2 Situated Learning and Communities of Practice

Lave and Wenger (1991) discuss situated activity as having defined characteristics in a process called “legitimate peripheral participation” (p. 27). This term refers to the ways in which learners participate in the collective, social or sociocultural practices of the community; alongside those new to the community of practice and those who may be considered as having mastery of skills and knowledge in the community (Lave & Wenger, 1991). Legitimate peripheral participation arguably was drawn from the notion of apprenticeship and, through an educational, theoretical lens, led to the concept of situated learning (Lave & Wenger, 1991). Influenced by Vygotsky’s social constructivist development theory and Dewey’s instrumentalism, in its design, situated learning suggests the following:

1. Classroom learning by its very nature is out of context and irrelevant.
2. Knowledge presented contextualized in work settings and applications is relevant and effective.
3. Learning is a highly social, interactive activity that involved a considerable level of collaboration and mentoring.

    (Leonard, 2002, p. 174)

From observing various cultural contexts, Lave and Wenger (1991) conclude that close ties can be found between the social situation and the knowledge learned. While within that social situation, conversely, knowledge acquired outside the social situation is meaningless (Leonard, 2002). Within this chapter, the context of the Year 9 and Year 10 ‘Science Experience’ reflects these notions of learning within informal contexts in addition to bridging social experiences to support further the learning within what could be interpreted as a Community of Practice (CoP). Wenger (1998) attests that the primary focus of CoP as a theory is that of learning as social participation. When deconstructing the idea of social participation Wenger discusses how being a participant encompasses both being an active participant in the practice of the community and “constructing identities in relation to these communities” (p. 17). As a result of being a participant in CoP, this should shape what the individual does, contribute to who they are, and impact the interpretation of what the individual does as a result of their participation.

For students, schools and classrooms can form a type of CoP. There are formal components of this context and Wenger (1998) describes that the most transformative aspect of this type of CoP is the “learning that involves membership” (p.19) within this space. We might interpret from Wenger's theory that although there are formal constructs that form certain types of CoP, the informal component of these CoP is often the more transformative and pervasive.

3.2.3 Authentic Learning Experiences in STEM Education

Within Australia and globally, the growth in STEM-related job vacancies and the STEM-related graduate places represents a widening gap reflecting the need for experts in STEM (Mohtar et al., 2019; Vela et al., 2020). This growing need in the STEM space requires a new approach to incentivising and making visible the opportunities for students while still in their secondary school settings. This reflects the time when many students are investigating their opportunities and making plans for future careers (Mohtar et al., 2019). Understating the future direction and career considerations of students in their secondary schooling years has the potential to inform and assist the development of education relating to STEM and STEM-related outreach programs (Vela et al., 2020).

Influences on students taking courses or further educational pathways include peer influence as well as "inherent interest in STEM fields" (Vela et al., 2020). Mohtar et al. (2019) suggest we provide students with realistic and accurate information in relation to STEM careers for them to "make effective decisions about their career choice and path" (p. 405). Possible opportunities for this provision include exposure to real-life STEM workers. This exposure may be achieved by collaboration between universities, industries, and schools (Mohtar et al., 2019). It is through these collaborative networking opportunities that we can design and strategically make available methods and approaches to engaging students in STEM. The application of authentic experiences, Vela et al., (2020) suggest, has potential to increase interest of students in STEM-related fields. As a result of embedding authentic experiences, potential is there to further evolve STEM education broadly as well as "encourage students to pursue careers in the continually expanding scientific fields" (p. 111).

3.3 Application in the Literature

Within this section, we will explore examples of previous research related to studies that incorporate aspects of situated learning, communities of practice, and constructivist approaches in STEM contexts. We selected these studies according to the theoretical constructs that underpin the research, but also as they explore the engagement strategies with middle-years learners to elicit understandings about STEM and STEM learning and to uncover how engagements with informal STEM opportunities inform career pathways.

Mohr-Schroeder et al. (2014) present their research relating to an informal STEM learning experience for middle-years students in the form of a summer camp.

Responding to policy regarding preparation of students for STEM-related professions, in addition to the lack of diverse cultural representation in STEM careers, the summer camp embedded authentic, hands-on experiences from university faculties, teachers, and community professionals. This collaborative approach utilized informal learning environments and social interactions in its design with an aim to “have positive effects on their interest and motivation toward STEM careers” (p. 292). Over a three-year period, the number of participating students increased from eight to 144 and was based in the United Kingdom Colleges of Education and Engineering. Pre and post student surveys were conducted to ascertain the attitudes, perceptions, and efficacy toward STEM fields. Additionally, student survey data was collected relating to their future career aspirations in STEM. By applying informal learning environments, this study indicated an increase in interest pertaining to STEM content and to the field of STEM as a career choice. Significantly, the students particularly enjoyed the authentic collaborative, hands-on experiences, “taught by knowledgeable STEM faculty” (p. 300).

Drawing upon a set of situated learning experiences, Pitt et al. (2019) discuss the findings of embedding the use of digital badges to further support students’ career pathways across multiple STEM workplace settings. This study was conducted with a selection of stakeholder groups including college admissions advisors and personnel from higher education and STEM industry-related fields. The purpose of the badges was to provide a picture of the skills students employed and were achieving to future workplace employers in the STEM career space. The findings within this study showed that the design of digital badges encapsulated broad skill types including soft skills, and embedded authentic experiences. As a result, the application of the badges provided a useful, and informal approach, that allowed for a variety of pathways to enter STEM careers (Pitt et al., 2019). Additionally, the stakeholders within this study reflected that the use of these badges was a positive step in understanding and authenticating skills from a variety of student learning backgrounds.

In response to similar STEM workplace shortages as the Australian context within this chapter, Roberts et al. (2018) discuss the outcomes of their research pertaining to the application of informal STEM experiences to gauge student’s perceptions of STEM and STEM learning. By applying informal approaches to STEM, Roberts et al. argue that students previously disenfranchised with formal STEM learning may display higher interest and motivation “when it is presented on a more engaging, hands-on way” (Roberts et al., 2018, p. 1). Applying their approach within situated-learning theory, the See Blue See STEM model brought together middle-years students and a variety of STEM professionals across a variety of STEM fields. Student participants were provided a pre and post survey that explored not only their attitude toward STEM, but they also were asked about their future STEM careers. By exploring STEM in an outside-the-classroom and authentic setting, students were able to give purpose to and contextualize what they were experiencing in their formal learning (Roberts et al., 2018) and connect this learning to future career considerations. Additionally, these opportunities allowed students to feel connected to a STEM learning community that included their peers and various STEM professionals.

The applications of informal learning experiences coupled with inclusion of experts from the field combine to create authentic experiences for students within the aforementioned examples. These examples provide further context that supports the implementation of educational experiences that take the fundamental aspects of situated learning as the key components of the learning process and design.

3.4 The 'Science Experience' Case Study

3.4.1 Outside-the-Classroom Learning Experiences

Informal or outside-the-classroom learning experiences are an opportunity to provide real-world authentic learning experiences to students. Situated-learning theory allows connections between science theory and content to everyday life. This is particularly important for students in Year 9 and Year 10 in Australia where this age group often are disengaged particularly in STEM subject areas. Outside-the-classroom experiences can increase interest and motivation and provide context and purpose to the learning. These outside-the-classroom learning experiences can allow science concepts to be related to authentic experiences and future career pathways. Regional Australian schools often have less opportunities to engage with STEM and science experts since most of these opportunities are in larger cities.

3.4.1.1 Gladstone

Gladstone region is home to more than 63,000 people and accommodates 21 private and public primary and secondary schools. The regional city of Gladstone is in Central Queensland, situated approximately 550 kms north of Brisbane, the nearest capital city. The region is diverse, containing both seaside rural and urban communities. Gladstone is home to a range of industries, including the world's largest alumina refineries, an alumina smelter, a power station, cement and chemical manufacturers, and three Liquefied National Gas (LNG) plants on nearby Curtis Island. Gladstone is set to become one of the world's largest hydrogen equipment manufacturing hubs with multiple hydrogen industry initiatives recently announced (Queensland Government, 2021). The Gross Regional Product of the area covered by the Gladstone Regional Council is estimated at $4.77 billion, which represents 1.5% of the state's Gross State Product (NIEIR, 2018). As this background would suggest, the Gladstone Region has a strong industrial base, well-developed infrastructure, and services where much of the subsequent employment opportunities are based around STEM careers (Pfeiffer & Tabone, 2020).

Against the backdrop of industry in Gladstone, there coexists many important coastal habitats, such as mangroves, saltmarsh, sand and mud banks, coastal reef, sand dunes, and seagrass. For example, as you fly into Gladstone the viewed landscape is amazing with the shapes and patterns of a World Heritage reef site seen in close proximity to the fifth largest alumina refinery in the world, Queensland Alumina Limited (Holden, et. al., 2017).

The Port of Gladstone, in addition to being Queensland's largest multi-commodity port and the fifth largest multi-commodity port in Australia, is the gateway to the Southern Great Barrier Reef, which brings to the region a strong focus on the environmental sciences. Gladstone has experienced these industrial development cycles over many years and has managed to weather them relatively well (Cameron et. al., 2014). This unique combination of large resource industries and the World Heritage-listed Great Barrier Reef provide a niche context to develop local and contextual science learning experiences.

3.4.2 The Science Experience Gladstone

The 'Science Experience' (formerly The ConocoPhillips Science Experience) is a three-day experience developed by university Academics to immerse Year 9 and Year 10 students in authentic science related to research. There are programs across Australia at many different universities. Each program provides students with an opportunity to participate in a wide range of engaging STEM activities under the guidance of experts in the field who are passionate about their work. The program takes place in over thirty-five universities and tertiary institutions, within many different laboratories and lecture theatres. Participants conduct experiments in the university laboratories, meet and hear senior lecturers in the lecture theatres, attend site visits, and walk around and experience what it is like to be on the campus of a university or other post-secondary tertiary institutions such as colleges and technical training institutes. To date, more than 81,000 students across Australia have taken this rare opportunity. The program provides information about further studies in STEM. It highlights the wide range of careers that allow students to pursue their interest and abilities in the sciences.

In Gladstone, the 'Science Experience' began in 2015 at Central Queensland University Gladstone Marina Campus. The program was developed using the technology, industry, and environmental science focus afforded by the location. Over time, the framework for the program evolved and now is based on the model presented in Fig. 3.1.

This model includes bringing together presenters and sessions that are hands-on for the students. Allowing the students to experience sessions on the university campus allows them to experience "a day in the life of…". Along with the authentic experiences embedded within the sessions, students embark on an excursion in one of the local wildlife rehabilitation centres. The full-day excursion to Quoin Island Turtle Rehabilitation Centre allows the students to experience the work of the scientists and volunteers at the turtle hospital. This outdoor experience also allows for learning to take place within natural habitats rather than sitting at desks in a lecture-style situation. Student-centred learning and outdoor education play a

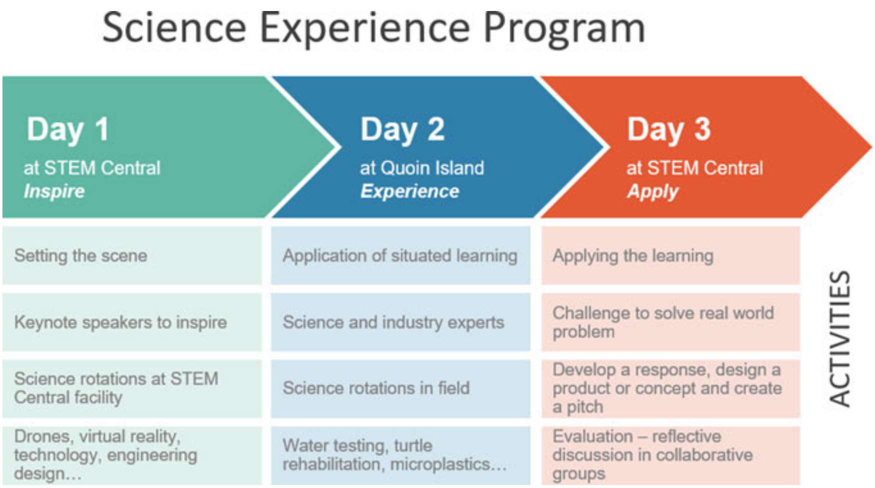

Fig. 3.1 Model for the 'science experience' Gladstone

vital role in the application of situated-learning experiences conducive to science and STEM education. The model developed for this particular location allows for STEM learning while immersed in the action or experience. Figure 3.1 demonstrates how the program allows students to be inspired (through contextual keynote experts), experience and apply the concepts (through authentic experiences in a situated-learning approach), then apply the concepts they are immersed in (in a collaborative, social setting). Pairing outside the classroom learning environments with curriculum-based concepts in this active and collaborative way can increase students understanding of skills for future STEM careers.

A memorable aspect of the program upon which participants often commented and reflected is the opportunity to meet and share ideas with students from different schools. Using the CoP model in the framework with the team of presenters and developers and students allows for reflective discussions, information sharing, and skills development which contribute to belonging in the community. Student collaboration and blending of ideas contribute to learning as social participation.

Inter-disciplinary approaches allow students to combine two or more STEM disciplines from the activity sessions (including but not limited to environmental sciences, biology, ecology, engineering, technology) and conclude with the development of a solution to a real-world problem. The step to trans-disciplinarity involves students exercising more agency in pursuing a meaningful contextual problem. The students develop and share their solutions to a real-world problem that situates the disciplinary knowledge and learning within the authentic, student-agentic contexts (Tytler, 2021).

3.4.3 Science Curriculum

The Australian Curriculum and Assessment Authority (ACARA) leads national collaboration to produce the Foundation to Year 12 Australian Curriculum. The Australian Curriculum sets the expectations for what we should teach all young Australians, regardless of where they live in Australia or their background. The Australian Curriculum includes General Capabilities: Literacy, Numeracy, Information and Communication Technology (ICT), Critical and Creative Thinking, Personal and Social Capability, Ethical Understanding, Intercultural Understanding. The curriculum consists of eight Key Learning Areas (KLAs): English, Mathematics, Science, Humanities and Social Sciences (HASS), The Arts, Technologies, Health and Physical Education, and Languages. The Australian Curriculum Science (ACS) divides into three strands—Science Understanding (SU), Science Inquiry Skills (SIS), Science as a Human Endeavour (SHE).

The Science Understanding strand has four sub-strands: physical sciences, chemical sciences, earth and space sciences, and biological sciences. While the science understanding strand is a major focus for planning learning experiences, educators should consider the science as a human endeavour and science inquiry skills aspects of the Australian Curriculum when planning learning experiences. Science as a human endeavour covers the nature and development of science and the use and influence of science. Inherently, these curriculum areas encompass general inquiry-skills such as observing, asking questions, science in everyday life, including caring for the environment, testing predictions, explaining events, and solving problems to inform community and personal decisions. Further to this, the application of science inquiry skills, including scientific method—predicting, planning, processing, and evaluating and communicating we also can locate and apply in curriculum planning for STEM teaching and learning (see Fig. 3.2).

The program rotations and activities as part of the 'Science Experience' program in Gladstone have included hands-on experiences. These experiences allow the students to contextualise the Australian Curriculum not only in science but by embedding a trans-disciplinary curriculum. Table 3.1 is an example of one of the activities from the program (Harbour Watch) showing the different discipline areas of the Australian Curriculum, called Key Learning Areas. Each Key Learning Areas (or subject) contains curriculum descriptors which describe the content including knowledge, understanding and skills for each subject.

What students learn in school should relate to prior experiences. Through a constructivist lens and situated learning, outside-the-classroom experiences can provide links between prior experiences, real-world contexts, and the school curriculum. Additionally, the experiences, context, and in school curriculum can supply students with knowledge and understanding and access to skills used in various careers. This exposure includes science related values and attitudes which may allow them to make informed decisions as members of society. The marine debris and microplastics sessions in combination with the turtle rehabilitation centre visit provide real-world situations where human impacts directly impact the local fauna.

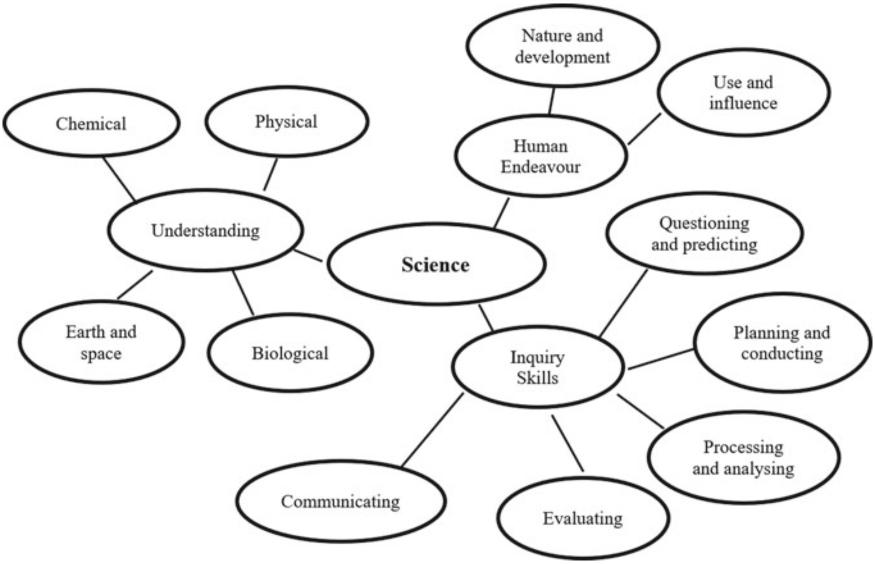

Fig. 3.2 Mind map overview of the Australian Curriculum Science. *Source* Forbes et al., (2021)

Table 3.1 Harbour watch activity

Activity	Description	Curriculum descriptor
Harbour Watch	Human-induced environmental changes that challenge sustainability	Humanities: ACHGK070
	Plan, select, and use appropriate investigation types, including field work and laboratory experimentation, to collect reliable data, assess risk, and address ethical issues associated with these methods	Science: ACSIS165
	Develop techniques for acquiring, storing, and validating quantitative and qualitative data from a range of sources, considering privacy and security requirements	Technologies: ACTDIP036

Source Author

Additionally, opportunities for the students to solve real-world problems further supports this notion.

3.4.4 Data Collection and Analysis

We acquired the data forming the basis of this research from surveys. The survey design included both quantitative Likert-scale responses and qualitative short answer responses. The pre-program survey contained seven Likert-scale questions about science at school and careers in science as well as qualitative short answer responses asking participants to list their favourite subjects at school and career aspirations. The post-survey had the same seven Likert-scale questions about science at school and careers in science, and in addition another six Likert-scale questions about STEM and engagement after participating in the program. The Likert-scale responses were scored from 1 to 5, (1 Strongly Disagree, 2 Disagree, 3 Neither Disagree Nor Agree, 4 Agree, 5 Strongly Agree).

The survey was administered to the participants in the three-day program at the start of the first day (pre-survey) and again at the end of the third day (post-survey). Each year for three years the survey was administered at the start and again at the end of the annual three-day program. The only differences between the survey questions each year was the table asking participants to score each activity rotation out of 10 because each year there were slightly different activities offered. Using a survey as a method of data collection allowed for the identification of beliefs and attitudes of the participants and allowed us to identify any trends in the data (Creswell, 2014).

The quantitative results for the Likert-scale questions were entered into an excel spreadsheet where frequencies and averages were calculated. The qualitative data from the short answer responses were entered into an excel spreadsheet and sorted according to common words, for example responses to favourite subject comments that included the term ‘art’ or ‘arts’ were sorted.

3.4.5 Findings

Table 3.2 displays the average scores for four of the qualitative Likert-scale questions (n = 172) over a 3-year period. The participants were asked these questions post-program only. Not surprisingly, we found an average of 4.87 and 4.68 respectively for students identifying they are engaged more when using hands-on activities in learning and engaged more when STEM has context. We found an average of 4.63 (agree or strongly agree) post-program for students identifying they have more ideas of how to use STEM to solve real-world problems after participating in the program. Student average for being more interested in a career in STEM than they were before post-program was 4.43.

Table 3.3 displays the average scores for some of the responses that were collected pre- and post-program. For most of the questions the results show that there is little

Table 3.2 Post-program average responses

Question	I am engaged more when using hands-on activities in my learning	I am engaged more when STEM has context (where and how to use it)	I have more ideas of how to use STEM to solve real-world issues	I am interested more in a career in STEM than I was before
Average	4.87	4.68	4.63	4.43

Table 3.3 Pre- and post-program responses

Question	I would consider a career in science	I have a good understanding of the types of careers that use science	I like doing hands-on science experiments in class	I am interested in sciences
Pre-average	3.87	3.88	4.44	4.38
Post-average	4.02	3.97	4.53	4.27

change in participants interest in science and doing hands-on experiments pre- and post-program. Participants had some understanding of the types of careers that use science, and they enjoy doing hands-on experiments. Responses for interest in science decreased slightly.

A comparison between pre- and post-program for the question 'I would consider a career in science' changed from 3.87 (n = 135) to 4.02 (n = 172). We found supporting student quotes for these findings in the qualitative section of the survey. For example, students who scored higher after the program stated:

This experience got me extremely inspired and really made me want to consider options in the future than I expected in the first place. Truly blew me away. [2020].

I had a wonderful experience. This excursion has given me a better understanding of the types of careers in STEM. [2020].

In terms of students identifying their favourite subjects at school, 24 out of 135 listed both art and science. This is an interesting find since science and STEM requires critical and creative thinking, yet society generally seems to accept the notion that students are either good at mathematics and sciences or the arts and humanities. Subject selections in secondary school traditionally have students choosing between physics and visual arts on the same subject line. Some of the reasons given for this combination of subjects can be obtained from student responses to their favourite subjects and why:

> Some of my favourite subjects at school are math, science and art. These are very important to me as I wish to go down a STEM pathway and they will play an important role in the future. Art is something I love as I enjoy it. [2019]

Art because you can be creative, science because I love learning new things. [2019].

> Science - I love find out how things work and how they happen, maths - I love being challenged with calculations and interesting topics, art - I love creative things, business - just enjoy it. [2019]

> My favourite subjects at school are art and marine science. These are my favourite subjects because they have areas of creative thinking as well as I love studying animals particular marine animals. [2019]

> Science - chemistry is interesting, art - I like expressing myself and my abilities, English - I enjoy writing stories/essays. [2019]

> Chemistry - I find it interesting and challenging, art - I like to be creative and express my own ideas. [2018]

Fig. 3.3 Photos of students participating in the program

> Although I'm unsure at moment, any career in the fields of art, robotics, or science may interest me. [2018]

Interestingly, trans-disciplinary approach students identified between different subjects and the interest in careers in STEM fields. Figure 3.3 displays some photos of students participating in the 'Science Experience' in Gladstone. The outside-the-classroom experience provides opportunities to solve real-world problems using a trans-disciplinary approach.

3.5 Importance to Research

The 'Science Experience' case study in Gladstone, Queensland, demonstrates the ways in which students can immerse in situated learning to experience real-world applications of science and STEM education in an outside-the-classroom context. The findings of this case study indicate the experiences increased students' interest in STEM careers. The design of the curriculum for this outside-the-classroom experience and student subject choices at school can impact future career choices. The Australian Chief Scientist at the time, Professor Ian Chubb, famously stated that 75%

of the fastest growing jobs require STEM skills (Office of the Chief Scientist, 2014). The model for the program evolved into the current framework: inspire (through contextual keynote experts), experience (through authentic experiences in a situated-learning approach), and apply the concepts (in a collaborative, social setting). With the current framework design in mind, the following section describes how the application of situated learning, social constructivism and CoP can operate as one to inform future designs of similar research and associated experiences.

Upon consideration of the theoretical constructs and conceptual approaches we have outlined in this chapter, the following sections provide suggestions to embedding these multiple lenses to the design and delivery of the current 'Science Experience' and future research and iterations of the same experience.

3.5.1 The Future of the Science Experience

The 'Science Experience' case study for Gladstone demonstrates how an outside-the-classroom experience can use situated-learning theory and authentic STEM contexts to inspire Year 9 and Year 10 students in regional Queensland. Trans-disciplinary aspects that transcend a real-world problem and allow application of inter-disciplinary concepts can enhance students' aspirations for future careers. As reported by Ford Australia (Tytler, 2019), the top 100 jobs of the future will include jobs such as a 'fusionist', which brings art, science, and other aspects of learning together. Teachers need to understand more about what's happening in the world now and in the future. The inter-disciplinary approaches that are authentic and speak to future careers presented in the 'Science Experience' case study validate the important place outside-the-classroom experiences play in the future of the nation. The student survey responses provided interesting insights into favourite subjects at school and future career aspirations. This influenced the iterations of the program over the years, including the integration of the arts. Inclusions moving forward that incorporate the diagram in Fig. 3.4 include accessing feedback relating to work futures from the Year 9 and 10 participants to further inform the experience. Additionally, continuing to access and include industry-specific experts to continue to participate in the experience and perhaps leading from this, influencing formal-classroom environments, bringing the informal and formal contexts together.

3.5.2 Authentic Learning Experiences as a New Learning Model

Foreground this chapter, a series of theoretical constructs were provided and then associated with practical examples of their application, particularly in the 'Science

Fig. 3.4 Associated theories assisting the development of a new framework for designing authentic learning experiences

Experience'. When reflecting on the design of this experience, what became increasingly apparent was that constructing authentic learning opportunities required considerations relating to embedding aspects of situated learning, social constructivism and CoP (see Fig. 3.4).

STEM-related experiences inherently require authentic learning in their design, however, including theoretical aspects similar to those provided within this chapter has the potential to enhance the design and delivery of these experiences. Fundamental to the 'Science Experience' is the incorporation of informal contexts that bring together experts in the field in social situations, sharing knowledge in a learning community. Additionally, the participants (students in this case) who are engaged in this learning experience are concurrently developing their interest in STEM-based careers as well as developing their identity as members of a new learning community that includes industry-based experts. These experiences are generally based in a socially constructed space that encourages collaboration, learning from peers and from experts to further enhance the outcomes for each participant, using this informal framework for formal educational experiences.

3.5.3 Notions of Learning

What has been proposed within this chapter is a new viewpoint and consideration relating to what constitutes learning for all involved in the 'Science Experience'. Outlined within the experience is that localised experts are included within the informal learning context, supporting and mentoring the student participants in STEM-related activities. These experts are not necessarily trained teachers as formally defined, rather, they are practicing engineers, scientists and other STEM-related experts who come from their field into an informal teaching-related context. These informal opportunities, as Wenger (1998) suggests, contain both opportunities for membership and also increased opportunities for a transformative experience for all involved. What is proposed within this chapter is the opportunity to re-think the ways in which formal learning opportunities can include and re-design their approaches to fostering student interest in STEM-related career paths, starting from the invitation to collaborate with STEM experts from the field. This may require a change in mindset for educational contexts, teachers, industry and society in order to see schools begin to partner with industry to provide authentic learning experiences regularly. It is hoped that this chapter begins to develop considerations and questioning relating to the measurements of outside the classroom experiences. This includes looking at STEM subject choices and subsequently the impacts of this on STEM career paths rather than just considering self-efficacy, or increased confidence; or improved self-worth that can impact broader learning. Additionally, the experiences, memories and the critical thinking skills that are often associated with STEM learning are emphasised and central to the learning. In doing so, adjusting assessment-driven approaches and challenging the mindset that learning is only about measuring and increasing knowledge.

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Ondine Bradbury is a teaching scholar who has over 15 years' experience in school and tertiary sectors and the educational policy sector. She is currently completing a Ph.D. at Monash University (Melbourne, Victoria, Australia) in the development of middle leaders in a Learning Specialist role. Her approach includes an authentic inquiry approach that includes teacher self-reflection and reflexive practices. Her recent work includes contributing author on a chapter exploring the impact of Communities of Practice on policy-funded school-university partnerships. Her chapter explores case studies in rural Victoria and rural Queensland. Her current projects include researching the impact of social networks on quality initial teacher education. She has conducted research on the experience of educators who experience cross-sector career changes using autoethnography and self-study approaches. Ondine holds a strong desire to connect teaching and learning communities, and to build and grow collaborative networks across a range of educational settings.

Part II
Critical Theory

Chapter 4
Activity Theory in Informal Contexts: Contradictions Across Learning Contexts

Doris Ash and Sarah Jo Ward

4.1 Introduction

Views of classroom learning have shifted considerably over the past century, from behaviorism to constructivism, the cognitive revolution, sociocultural theory and Vygotsky (1987), community of practice (Lave & Wenger, 1991), and cultural historical activity theory (CHAT) (Engeström, 1987), to name but a few. Over time each has trickled down to informal settings. The above list also signals the important shift from an individual to a social emphasis in learning research. We underscore the need for a rich intertwining of social and cultural processes, using a powerful theoretical frame to cut through the many layers of involvement, and one that uses a unit of analysis large enough to be meaningful; for us, the irreducible minimum is the activity system itself (Foot, 2014). Cultural-Historical Activity Theory (CHAT) keeps entire systems in mind, thus not limiting our analysis. One goal of this chapter is to make CHAT's ideas, tools, and language more accessible, both to museum professionals using it in their everyday teaching and to administrators working to transform how they view learning in their institutions. This chapter provides three everyday examples of CHAT analysis.

We first provide a brief overview of key theoretical aspects of CHAT, then describe how the principles of contradiction and expansive learning can be applied to the work we do in informal settings.

Changing learning perspectives is not easy. Janes (2013) used the terms, complexity, uncertainty, nonlinearity, emergence, chaos, and paradox to characterize museum change. The ways we characterize learning typically reflect our own learning processes, our experiences in formal schooling, and those learning theories we are

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trained to use (Bransford et al., 1999). Learning, for some, focuses on the individual; for others, on behavior; and for others, still on brain function. As informal learning institutions across the world are struggling to adapt to twenty-first century sociopolitical realities, such as shifting demographics and uncertain finances, they are also being challenged to more genuinely embrace socioculturally- and equity-informed learning and teaching practices (Ash, 2022; Dawson, 2014a, 2014b, 2014c). As museums wrestle with financial survival, Covid 19, and shifting demographics, we ask what it means to learn to exist within these new realities and how organizational learning can transform.

Once described by Engeström as 'the best kept secret in academia' (1993, p. 64), CHAT has more recently been applied to informal settings or learning out of school. CHAT is becoming increasingly important in analyses of change, applied to labs, hospitals, libraries, classrooms, and, of course, informal learning spaces (Ash, 2022; deGregoria Kelly, 2009; Yamagata-Lynch, 2010; Ward, 2016). Those who have written about organizational learning in informal learning environments locally, and institutional change more generally (Bennett, 2018; Engeström &; Sannino, 2011; Janes, 2013) argue that transformation must be dynamic, it takes time, history matters; it is hard to recognize barriers; piecemeal change is inadequate, and a comprehensive theoretical grounding is essential.

Increasingly, we are called to critically analyze our conceptions of learning and to reflect on how these ideas and practices uphold systems of oppression in education systems. More importantly, we are asked to develop new conceptions of learning that dismantle systems of oppression. In this sense, we are asked to do what we have not yet done and thus there is no roadmap. CHAT has demonstrated versatility as a theory of becoming that helps us to inform, support, and reciprocally intertwine practice and theory in fundamental and meaningful ways (Engeström, 1987, 1999). We use CHAT to hold and analyze complex systems because of its emphasis on dynamic analysis of how contradictions drive transformation (Engeström, 1987), its focus on dialectical relationships, and its capacity for studying many aspects of systems at once. In terms of museums, CHAT's concept of *expansive learning* becomes central to understanding how change can occur sustainably in the face of mounting pressure to change.

To understand CHAT, we must first dip into sociocultural theory, sometimes known as the first-generation-of-activity theory (Engeström, 1987). Sociocultural theory is a psychology of becoming in which people experience both the social nature of their existence and the collective creative activity that results in the making of new tools for individual and social use (Holzman, 2006). This perspective assumes learners and social organizations exist in recursive and mutually constitutive relation to one another across time.

Founded by Lev Vygotksy, sociocultural theory initially focused on the significance of meaning-making, researching how people use cultural tools, for example shovels and typewriters, and semiotic tools such as language. Vygotsky understood the learning process as inherently social (Wertsch, 2007), whereby what we learn as individuals we internalize from our contexts, thus it first lives outside of us before moving inside. Famously, this occurs in the zone of proximal development (ZPD), which Vygotsky defined as the region of activity learners can navigate with aid from a supporting context, including but not limited to people (Vygotsky, 1987, in Brown et al. 1993), and that mediates between inner and outer worlds.

In addition to these ideas, sociocultural theory has roots in Marxism and thus dialectics become central to any understanding of sociocultural theory and its counterparts. Dialectical thought moves us away from thinking about the subject and the object as their own separate entities and instead makes us understand them as intertwined. It posits that we cannot understand the subject without the object. Engeström noted that struggles and contradictions regarding the object of the activity characterize activity system networks. Power reflects in administrative hierarchies, uneven division of labor, or salaries and roles. The current conception of Activity Theory reminds us to look for power relations in such struggles by analyzing structures and dynamics directly.

If someone were studying us writing this chapter right now, they would get an incomplete picture until they also understood the reader. As writers, we are incomplete without our intended readers. In the case of CHAT, 'working the dialectic' relies on uncovering relationships between activity systems or parts of them. Consistent with other sociocultural perspectives, CHAT allows one to see the world differently from most other learning/teaching theories, because it specifically invites us to see the dialectic within systems and to "grasp the systemic whole of an activity, not just its separate components" (Foot, 2014, p. 3).

Dialectical logic and developmental processes are dynamic, where outcomes are unpredictable, and change is constant. Mahn (2003) suggested that Vygotsky's dialectical approach has four central tenets:

1. We must examine phenomena as a part of a historical, developmental process from their origins to their terminus.
2. We see change, a constant, most clearly at times of qualitative transformation in phenomena.
3. These transformations take place through the unification of contradictory, distinct processes.
4. We must analyze these unifications or unities through aspects that are irreducible and embody the essence of the whole.

CHAT's unit of analysis includes the dynamic interplay of the social, cultural, and historical aspects of development. While Vygotsky's work focused on individual development in context, the contemporary work of Yrgö Engeström describes how collectives and organizations develop through activity in context. CHAT's unit of analysis, the activity system, is a representation of the social and historical organization of "object-oriented, collective, and culturally-mediated human activity" (Engeström & Miettienen, 1999, p. 9).

For CHAT scholars, activity is not simply a behavior; it is a process-as-a-whole, rather than a linear sequence of discrete actions (Foot, 2014). Thus, we must understand activity systems in their completeness as a unit of analysis that we cannot disaggregate (Leont'ev, 1978). This focus on the collective positions the work people do and how they build organizations as greatly affecting how they do the work and how others receive it. CHAT theorists understand the context of the activity system as not a container or shell in which people behave certain ways, instead it is the activity itself.

4.1.1 Activity Systems

The first step in understanding CHAT is to understand the activity system (Fig. 4.1). The activity system is always evolving through learning actions that result as a response to the emergence of systemic contradictions. Five principles guide activity systems (Engeström, 2001):

1. The main *unit of analysis i*s the activity system (See Fig. 4.1).
2. *Multi-voicedness:* Multiple perspectives, interests, and traditions are sources of both conflict and transformation.
3. *Historicity:* The history of a system allows us to understand its problems and its potential.
4. *Contradictions:* Contradictions drive the activity system as old and new come into conflict.
5. *Expansive learning:* Transformations in activity encourage reconceptualization of the object and the motive of activity into something previously unanticipated. (Adapted from Murphy & Rodrigues-Manzanares, 2008.)

In the diagram (Fig. 4.1) of the activity system (Engeström, 1987) we see the subject, object, motive, division of labor, rules, tools, and community. Each of these six components is in a transactional and dialectical relationship with one another and the relationship between them creates various tensions that affect the system. To illustrate these six components, imagine a teacher leading their class to an aquarium on a field trip. The teacher and the class are the *subject*. The teacher wants to use

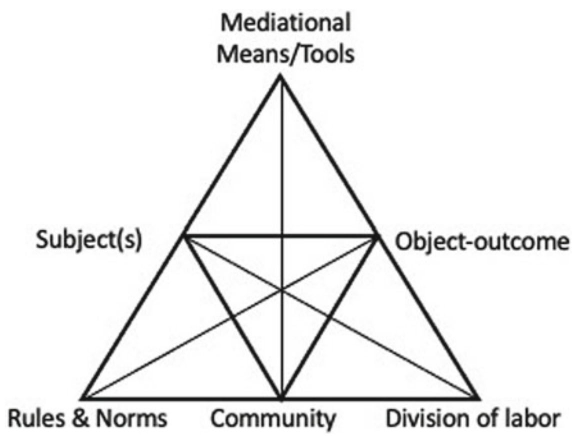

Fig. 4.1 Second generation activity theory

the aquarium as a resource for connecting back to concepts they are teaching in their classroom—this is the *object*. When they get to the aquarium, the teacher uses their curriculum and the objects in the museum as *tools* to mediate student learning. They ask the students to fill out worksheets while they are in the aquarium based on what the museum labels say; these too are tools. Imagine also the class takes a tour with a guide; the guide and everyone in the aquarium are part of the *community*, all of whom engage around the object of teaching the students. Requirements, such as chaperones and a pre-lunch school return time, as well as the directions on the worksheets, all make up the *rules* of the system. Finally, *labor is divided* in this system between the guide giving the tour, the teacher, and the students and what they have been asked to accomplish. If any of these components is disrupted, it affects the entire system.

4.1.2 Contradictions

When we talk about learning in CHAT, we must talk about the concept of contradiction. Theorists situate contradictions (both between and within activity systems) as potential sources of change; they can function as valuable levers of change, rather than disturbances to avoid. Within CHAT, contradictions as they materialize in daily activity spark changes to the system (Foot & Groleau, 2011). Contradictions are systemically, structurally, and personally experienced. They "manifest themselves as problems, ruptures, breakdowns, and clashes" and yet are "sources of development; activities are virtually always in the process of working through contradictions" (Kuutti, 1996, p. 34). Tensions in the system aggravate contradictions and they turn into concrete manifestations that affect the daily work of participants. We can understand contradictions as "places" in the activity system from which innovation is born (Foot, 2014). The extent to which members of the activity system can resolve or transcend the contradictions determines how an expansive cycle will be constrained or flourish. Contradictions are not places of failure; nor are they problems to fix through technical, practical solutions. Foot (2001) describes contradictions as illuminative hinges from which participants can gain new vistas of understanding. She uses the term "hinge" to describe how contradictions link fixed entities to a mobile entity, for example a door (mobile) attached to the frame of a house (fixed) (Foot, 2001, 2014).

There are four types of contradictions; first, all contradictions stem from the primary contradiction that occurs between the use-value and the exchange-value of a system (Engeström, 1987). Marx's ideas about the use-value, that which gives work its inherent worth, versus the exchange-value, that which makes work a commodity, underline the primary contradiction. For example, a doctor provides a service of helping the ill (use-value) but to do so gets paid for that work (exchange-value).

Secondary contradictions exist between the nodes of the system and cause the dormant primary contradiction to emerge, as tension forms between two different parts of the activity system. Tertiary contradictions become apparent when the object of a more "culturally advanced" activity (Engeström, 1987) is introduced to the system. For example, an employee requests that a learning organization puts out a statement in support of Black Lives Matter. Finally, the quaternary contradiction is when two activity systems intersect. The quaternary contradiction arises when neighboring activity systems feel the effect of attempts to resolve a tertiary contradiction (Engeström, 1987; Foot & Groleau, 2011).

By identifying the levels of the contradictions and not treating the contradictions as all the same, we begin to understand how aggravating one level leads to another aggravated level while uncovering some of the interconnectedness of the system in question. To do this kind of work requires two different focuses, one that considers the historicity of a system and another that allows the system a chance to imagine what it can become.

4.2 Expansive Learning

Expansive learning is the process of creating new objects of activity, those as yet undefined. We achieve this kind of learning through specific learning actions:

1. *Questioning, criticizing,* or *rejecting* aspects of the current accepted practice and wisdom
2. *Analyzing* the situation through mental, discursive, or practical transformation to understand what is happening. This occurs through either or both: a historical-genetic analysis that seeks to explain the situation by tracing its origins and evolution, or an actual-empirical empirical analysis that seeks to explain the situation through the representation of the activity system's inner systemic relations.
3. *Modeling* the discovered relationship through some publicly observable and transmittable medium
4. *Examining* and *experimenting* on the model to understand its dynamics, potentials, and limitations
5. *Implementing* the model in practice, enrichments, and conceptual extensions
6. *Reflecting* on and *evaluating* the process
7. *Consolidating* the outcomes into a new and stable form of practice (adapted from Engeström, 2014)

This cycle walks us through the expected stages of change as activity systems encounter contradictions, new goals, mediational means, practices, epistemological views, etc. We note that contradictions in any activity system may be aggravated when participants question the established norm (stage 1), especially if new practices radically deviate from previous activity. By aggravated we mean one of the ways in which conflict occurs, for example, different modalities for teaching, designing an exhibit, how much money to charge, which story to tell, and so on. The expansive cycle works with these aggravated areas.

When we seek to understand situations in which "whole collective activity systems, such as work processes and organizations, need to redefine themselves, [and] traditional modes of learning are not enough" (Engeström, 1999, p. 3), expansive learning becomes a powerful concept. "Nobody knows exactly what needs to be learned. The design of the new activity and the acquisition of the knowledge and skills it requires are increasingly intertwined" (Engeström, 1999, p. 3).

4.3 CHAT in Practice

CHAT has proven to be a powerful theoretical tool in our own work and research. Below we provide three examples that demonstrate some of the ways a CHAT stance toward people, mediational means, object/outcome, rules, division of labor, and community informs how we more flexibly can situate institutional learning in informal learning settings. CHAT provides practical tools for recognizing how components of a system interact and inform each other in dynamic and sometimes unexpected ways. This characteristic of CHAT makes the theoretical eminently personal and practical.

We address three levels of analysis. First, collaborative family learning showcasing the dialectic between individual and the collective in learning activity at a science exhibit. Second, we see the contradiction and the dialectic in teaching ethos, considering teaching as telling versus teaching as scaffolding. We note educators' role in institutional transformation. Last, we discuss equitable teaching in field-based/environmental education, as two activity systems interact when negotiating the meaning of equity for the program. All names in the three cases are pseudonyms.

4.3.1 Case 1: What Are We Supposed to Do Here?

The first example shows how practitioners and researchers can analyze family activity using sociocultural theory/CHAT to interpret collective activity, recognizing the dialectic between the individual and the collective, the inherent role of mediational means in any activity, and different socio-historic roles in the family system. This is an important first step in adopting an activity systems stance.

Observing families as they made sense of science allows us to see the learning activity systems in situ, especially their dynamics and tensions, but also the 'repertoires of practice' the families bring to museums. By 'linguistic and cultural-historical repertoires of practice' Gutierrez and Rogoff refer to moving beyond individual 'styles of learning' toward experience, by focusing researchers' and practitioners' attention on variations in individuals and groups' histories of engagement in cultural practices because the variations reside not as traits of individuals or collections of individuals, but as proclivities of people with certain histories of engagement with specific cultural activities. Thus, individuals' and groups' experience in activities—not their traits—becomes the focus (2003, p.19).

Using experience as focus, we recognize how rules, in this case determining their own 'rules' of engagement' was an essential initial task.

The vignette, a short summary of a digital video-captured segment (1:37 min) of a longer visit at an interactive science exhibit, was captured at an urban museum of science and industry in south central Florida as part of an NSF-funded, equity-oriented, professional development intervention program. The family was audio- and video-taped naturalistically as they visited a subset of four exhibits; here we look at one exhibit, the DINO-Saurus, a large (3 ft × 5ft) dinosaur head with an open mouth and detachable plastic teeth, surrounded by two tables displaying samples of meat-eating and plant-eating animals' teeth. There was minimal signage.

The Aarons family (four children and a mother) initiated their visit with a question concerning how the family might use the exhibit. We now call this specific practice 'figuring out', an activity typically marked discursively by something like the "What are we supposed to be doing?", posed here by Leticia (13-year-old), as they approached the DINO-Saurus exhibit (Mai & Ash, 2012). After a period of uncertainty, and with much discussion and laughter, they collaboratively put the plastic teeth in the Dino mouth. Leticia said very little as she directed her younger brother Pedro (6-year-old), giving him some plastic teeth to place in the spot toward the back of the dinosaur's mouth. At that point Pedro turned to his mother, who stood next to him and also was placing teeth in the dinosaur's mouth, telling her the teeth she was holding were molars.

Mother: How do you know those are the molars?

Pedro: Cause I know.

Mother: Did your teacher tell you?

Pedro: [laughing] Yes.

Soon after that exchange, the youngest brother, "Norman" (5-year-old), jokingly punched the dinosaur with his older brother, "Karl" (12-year-old). His mother directed him to stop and join the others in the teeth placement activity. Norman joined Pedro and started to put the teeth in while Karl watched them from behind.

Pedro: No, look, lookit, lookit, look what I'm, what I'm doing! You twist it in.

Pedro guided Norman to put the teeth in a certain way so they would not easily fall out.

As he watched Pedro, Norman objected.

Norman: No! The sharp teeth ain't supposed to go up there!

Pedro: No, up!"

The two struggled to place the teeth.

At this point, the mother said

Mother: You can put them in any way you want. Let's look at these right here.

She got up and walked over to the other area of display and the boys followed.

(Aarons family at DINO-Saurus, Mai & Ash, 2012, p. 98)

The subjects are the Aaron's family members, while the mediational means are a dinosaur head, sample teeth, dialogue, signs, and gestures. The first object/goal was to 'figure out' how the exhibit was supposed to be used; once that was accomplished the family talked about content, e.g., molars. The rules of 'how to do' the exhibit were not available, nor were there educators to guide them. The family had not been to this museum before, nor were they frequent museumgoers. The surrounding community of other visitors, researchers, and staff were visible, and the division of labor in the family system was fluid, as it often is in social teaching and learning. As Foot and Groleau (2011) describe such an activity system:

> ...the object is both something given and something anticipated.... Subjects are individuals or groups [use tools] striving to attain or engage the object...The concept of tool in CHAT groups together elements of various natures— all of which mediate the subject–object relationship...The community of significant others …[are] multiple individuals and groups who share an orientation to and engagement with a common object…the rules, whether explicit or not, regulate the subject's actions toward the object and relations between members of the community...The division of labor — what is done by whom — describes how the community structures its efforts to engage the object... (pp. 1-2)

We have argued that 'figuring out' is a cultural historical 'repertoire of practice' (Ash, 2022; Gutierrez & Rogoff, 2003; Mai & Ash, 2012) that families new to museums use when faced with the challenge of using exhibits without knowing the language of museums, or the overt and covert rules. Leticia's question externalized what may have been on the minds of all family members. Such scenes, repeated by many other non-dominant families new to museums in our research in other settings, have taught us that families navigate museums in their own way, attempting to understand the explicit and implicit rules (so as not to do it wrong), using sometimes unexpected social, cultural, and historical repertoires and resources (Ash, 2014a, 2014b; Mai & Ash, 2012). This is not surprising.

Returning to Fig. 4.1, we note *division of labor*[2] in the social organization; family members engaged in related but not entirely overlapping actions. Pedro knew things about molars the others did not know. Leticia got the family started and named the activity (figuring out how to do the exhibit). Of the others, the mother, and eventually Norman, were supportive, but Karl was not (punching the head). Knowledge and action were distributed across family members.

This episode and others like it remind us how conceptualizing the ever-shifting landscape, as Vossoughi and Gutierrez (2014) suggest, allows us to "unsettle normative definitions of learning', to move 'beyond reductive dichotomies and… focus on the multiple activity systems in which people develop repertoires of practice" (p. 605). By 'linguistic and cultural-historical repertoires' we mean "the ways of engaging in activities stemming from observing and otherwise participating in cultural practices" (p. 22).

Analyzing the Aarons family interaction helps us move beyond reductive dichotomies. Was the learning individual or collective, both, or neither? Dialectical reciprocal relationships between individual and social, as in this example, are an essential intertwining, or as Mahn (2003) said, "the unification of contradictory, distinct processes" (p. 192), which refers to the way families inform, question, explain, and gesture, often creating events that we may not have expected.

We note the tension between subject(s) and rules, signaling the emergence of a secondary contradiction; for example, what are visitors new to museums supposed to do if the invisible rules of hands-on exhibits, which are so often taken for granted, are not provided? Shall we interpret them as doing it wrong or shall we, instead, search for repertoires we may not have recognized before? We may not 'notice' exactly how and when nontraditional families construct and/or display such repertoires, especially if we are not taught how to spot them (Mai & Ash, 2012). As Bogost (2018) argued, "After all, people have areas in their own lives in which *they* are the experts. Everyone is capable of deep understanding" (p. 2). Beyond an anti-deficit view, this argument asks that we think equitably, that is providing resources according to need. What if norms differed and expectations were not standard European-American? People can and do 'fail' at museums the way they are currently structured.

Dawson noted that European-American epistemologies get in the way of our interpretations of what is happening in museum settings; she fears we are blind to the things we are not in the habit of noticing (). As Dawson argues, we need not view such unknowing as a 'barrier'; such metaphors get in the way of what is happening. This episode is provided to 'open our eyes' to a family activity system in action, meant to counteract *settled expectations*, which Bang and Marin (2015) suggest are: "the set of assumptions, privileges, and benefits that accompany the status…'that whites have come to expect and rely on' (Harris, 1995, p. 277) across the many contexts of daily life" (Bang & Marin, 2015, p. 532).

While we may have been unaware of the embedded *norms* (Moore, 2013) and *settled expectations* (Bang & Marin, 2015; Bang et al., 2012) that have, in the past, and still currently reflect the status and power of in-groups in museums and all informal institutions, we do now know. We use CHAT to look closely at how contradictions between expectations and actuality help us to 'see' such power dynamics more clearly and hold the activity system as the focus.

4.3.2 Case 2: A Tale of Two Shirts

In this second example, we explore contradictions in a years-long research project involving museum educator professional development theory and practice. As educators are often tasked with leading change in museums, this second case highlights their work, but is set within the wider museum system. The contradictions we suggest here are critical to our analysis, as they drive the system of expansive learning.

During this project, we trained a group of intervention educators (*blue* shirts) to question and analyze educator practices, in order to center their new model in equity. One theoretical cornerstone was scaffolding in the zone of proximal development (ZPD) (Vygotsky, 1987). They began by learning and practicing ethnographic watching and notetaking, emphasizing *noticing* visitors' existing resources as visitors interacted on the floor, both with and without educators. One object/goal of their work was "to incorporate the… voices [of those who are] marginalized in research and institutions that make up the informal infrastructure" (Ash & Rahm, 2012, p. 4), to conduct action research on their own practice, to be critically reflective (Ash, 2019), as well as to design and test new teaching/scaffolding practices with visitors (Ash & Lombana, 2012).

While these *blue*-shirted educators were doing this work, another group of regular educators (*purple* shirts) continued to educate visitors using a lecture, showman form of teaching, focusing on content transmission, often using scripts. They had been asked to teach forcefully and to be noticed by visitors (Ash & Lombana, 2012). In this sense, visitors to the museum were seen as “needing to know”, so the work of the educators was to provide that knowledge. Some of the *blues* also worked as *purples*. All educators were paid.

Unsurprisingly, these two different approaches to learning and teaching led to tensions, and thus contradiction between the two groups, which also reverberated in the larger museum. A few *blue* shirt educators had negative experiences with *purple* shirt mid–level administrators and shared their unease with the whole *blue* group. Some *blues* had been hired as *purple educators* during the first year of the project. The *blues* realized just how different the *blues* and *purples* were; they experienced different work expectations, power, agency, and identities concerning their roles as educators. They felt like *purple*-shirt training was asking them to be loud, and to ‘perform’. Sally, a recent college graduate who briefly had been a *purple* shirt, saw that a *purple* shirt mid-level manager was displeased with her work. She took the *purple* shirt job to make extra money. This was short lived, because the following happened.

> I went to one of my (*purple* shirt) bosses and asked, ‘What am I doing wrong that is causing this friction?’ (hand gestures, showing the manager waving her away). I went to another *purple* shirt and asked if that really happened (being waved away). So, they went and tried and said that they got the same response. The person basically told us that we would talk about it later. It was humiliating. It was when I was a *purple* shirt.

Marie, who had never been a *purple* shirt, argued:

> I feel like they [*purple* shirts] are trying to standardize an approach. But what we’ve [*blues*] learned in here is that a standardized approach doesn’t work; it has to be individualized, customized. You have to take cues from the guests. It alienates people when you don’t take their individual style into account.

As the *blue* shirts learned during the first year of the research intervention, changing a ‘teaching system’ is hard. The more powerful *purple* power structure resisted their work. *The intervention* study was well funded and therefore accepted by most administrators, yet mid-level managers resisted. Museums and informal learning settings pour resources and funding into developing new practices, but often without looking at how those practices might impact or be impeded by the already existing systems. This case is one example of what change scholars such as Gutierrez and Barton (2015), and Engeström et al. (1999) mean when they refer to the problems that can arise when attempting to transform work organizations.

To disrupt traditional power structures, we must examine the often-implicit messaging of ‘business as usual’, relative to museum professionals’ work, and then reposition these within both contradictory and dialectical frames. Here the dialectic most directly concerned ‘telling versus scaffolding’ as dominant teaching practice.

Educators tasked with leading transformation efforts, both for themselves and for their institutions, were caught in the contradiction between rules and object/outcome. Historically, socio-politically-formed expectations are appropriated with little understanding of the dialectical nature of systemic change, which incorporates the historicity, intertwined relationships, and contradictions intrinsic to change. CHAT analysis captures all this complexity in analyzing and to some degree anticipating the course of change. Therefore, when planning new interventions, we must anticipate sources of potential resistance within the existing structures and institutional culture, identify them and bring them into the scope of the intervention.

4.3.3 Case 3: Negotiating Equity Across Activity Systems

This third case concerns a research intervention that started with the question: "What is equitable field-based/environmental education (EFBEE)?". This project challenged dominant and normed discourse of equity and asked pre-service science teachers (PSSTs) to conceptualize informal outdoor education as a space of equity and inclusion. We drew data from the pilot year of a professional development program collaboration of an Education Department, Biology Department, the Natural Reserve System of a University system, and the local County Office of Education. Data included pre/post interviews, quarterly reflective journals, ethnographic field notes of workshops, associated MA/C student coursework (including research papers and lesson plans), and reflective presentations (Ash & Race, 2021).

As the program progressed, we noticed that while all partners had the same object/goal of preparing teachers to teach equitable field-based lessons, ideas of how to reach that goal differed, as did the definitions for key concepts, such as *equity* and *resources*. While this is not uncommon in interdisciplinary collaborations, the question became how to attend to competing ideologies without privileging western ways of doing and talking science. As researchers, we needed a way to understand how these differences emerged in the program and how the contradiction impacted pre-service teachers' ability to achieve the program goal.

One place this tension emerged was in the types of mediational means/tools the different partners saw as valuable to achieving the object/goal. For the education department, the tools aimed at social justice and equity, often challenging normative science education. We asked PSSTs to critically reflect on their own identities and those of their students. For the Natural Sciences Department, resources originally focused on examples of successful field-based lessons offered in higher education settings. Already vetted with college students, these activities were scientifically accurate and workable, so why should they not work with the pre-service science teachers (PSST) and their K-12 students? This represented a classic view of providing equal but not equitable resources. The mismatch of meanings emerged most clearly in the quarterly workshops originally led by natural science faculty. The pre-service science teachers, steeped in a social-justice-and-equity stance in their MA/C program, noticed the conflict. Cheyanne said:

> A lot of the kids that they're *(university science professors)* working with, it's not equitable…Let's talk about K-12 when we're working with kids of all levels, all backgrounds. That's where the conversation on equity needs to be happening.

Another PSST Sandy said:

> …I think that [equity] is what the cooperating teachers [CTs] and the student teachers [PSSTs] wanted. I think everyone associated with the master's program, that's what they wanted. But the people that we brought in weren't addressing those issues. And I think just re-aligning what the overarching goal is for everyone, including participants [and] guest speakers about why we are speaking at this specific workshop would be better and put everyone on the same page.

Cheyanne and Sandy recognized that using the same pedagogical approach with K-12 and university students did not consider the many additional and sometimes unknown challenges of equity goals. In short, these activities were not equitable. Near the end of the program, Cheyanne said this about FBEE and equity:

> We can't always take students into the field, but we can always bring the field to them... I think the group needs to spend more time unpacking that. That statement is a statement of equity as we try to compose a method of learning science that can be beneficial to all students across the whole world. And ...not all classrooms have the ability to go to a nature reserve every year. So, I would love to spend more time figuring out tangible ways of bringing the field to my classroom.

This stated tension between program goals and actual new ideas for implementation forced us to step back and systematically analyze the inequity in the essential resources provided to PSSTs. Many program leaders, despite best intentions for equity, often saw resources as generic field-based pedagogical tools, giving little thought to the specific level of instruction. Yet, Cheyanne noted, a key aspect of creating equitable FBEE is understanding how teachers practice equitable pedagogy, expand their local contexts, and use mediational means in new ways.

How does CHAT treat this complex situation? This Field-Based/Environmental Education Project contained multiple activity systems, a network of systems that came together to develop and support this program. We do not analyze the complete network but instead comment on the first-year collaboration between Education and Natural Sciences departments, to clarify how we can use CHAT to understand the contradiction that pushed eventual transformation.

We see in Fig. 4.2 that the triangle on the left has object 1, the second triangle, object 2, and the third new negotiated object will be object 3. The point of this diagram is that more than one activity system can negotiate the meaning of an object; here two University departments are trying to collaborate on what equity-based field/environmental lessons might entail (object 3). This contradiction motivated the PSSTs to advocate for change, which eventuated in a new emphasis for the next year's program, during which negotiating the meaning of equity occurred early and often.

One of the larger lessons of this case involves the tensions created when equity, *not* equality, is the object. First, we saw two activity systems attempt to negotiate common meaning; this is a common but underappreciated activity. Moreover, larger

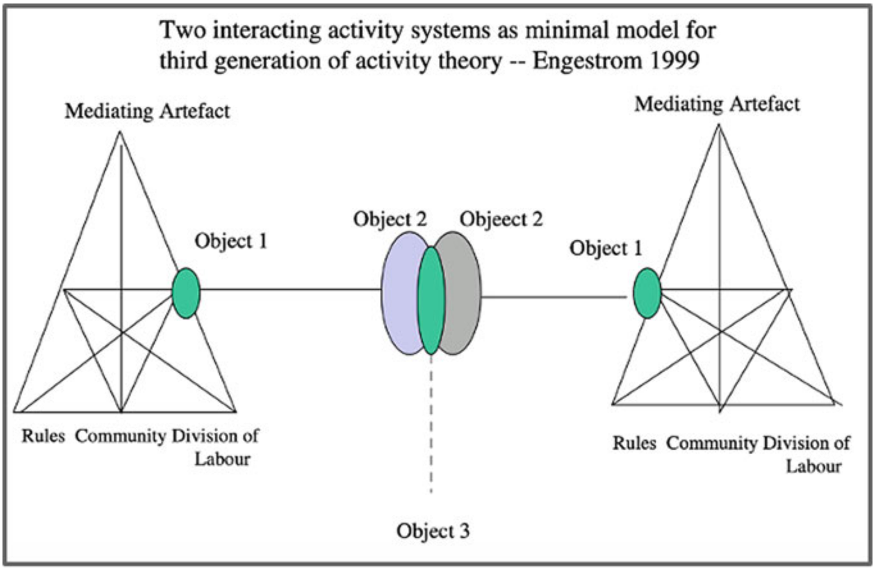

Fig. 4.2 Two interacting activity systems as a minimal model for the third generation of activity theory (adapted from Engeström, 1999)

networks are important. We could have included other systems, for example, the county, the land reserve, or the university administrations, among others, perhaps with varying views of equity. CHAT's principle of multivoicedness can include the voices of many.

The degree of complexity we observed in activity systems of human/natural resources interaction is only one take-home lesson. Because the activity is the unit of analysis, a systemic view frees researchers from isolating single factors and validates what we already know is true—in any classroom, museum, or other workplace setting, there are always multiple competing, socially and historically informed ideological pressures on any one individual, staff, funder, exhibit designer, or member of the board of directors. In other words, viewing different activity systems as they interact is invaluable for equity-oriented, humanist research, making it an effective tool for analyzing power dynamics.

4.3.4 What Do These Three Cases Have in Common; How Do They Work Together?

CHAT is first and foremost a tool for systems analysis informed by seemingly complex notions, such as contradiction and dialectics. But, as we have seen in these three cases, CHAT analyzes at the personal, professional and institutional levels.

We also note that we need not let fear of theory corral us into reverting to known strategies or simplistic practices that seem to 'work'. Simple solutions often miss the mark (Foot, 2014). These three cases: setting agendas for family learning activities; the dialectic between didactic vs. scaffolded teaching; and negotiating the language and meaning of equitable field-based teaching, might seem at first glance to have little in common. Here we tease out some commonalities.

- Each case was complex, involving multiple subjects, desired objects-outcomes, mediational means, community and so on. Such nodes, moreover, often are in tension or conflict. We may consider 'museum curriculum' a form of mediational means or as a negotiated object; further, the 'rule' of using only standard museum or field curriculum as mediational means in each of these three cases, constrained visitors, museum educators and preservice teachers. The subsequent resistance came in various forms, seemingly focused on changing the rules, object and/or the mediational means. When such nodes were challenged or resisted in all three cases, in attempts to change the 'standard curriculum' or the rules surrounding it, then change was hampered, and further tensions and conflict eventuated. Such a questioning of and resistance to what had been considered 'basic teaching and learning content' became essential to any subsequent transformation in each case.
- Each case strongly relied on the cultural historical past, which served as key context and informant to current and 'future repertoires of practice', ideological commitments, as well affordances and limitations to collective agency (see Ash, 2022). The family attempted to create a hybridized curriculum. The museum and the field-based educators attempted to create new tools for teaching. In each case ideological commitments based on long-standing historical conflicts came into play. For example, in museums a deficit views of minoritized learners can eventuate in foisting standard curriculum based on White middle class ideologies on visitors, educators and managers (Ash, 2022; Dawson, 2014a, 2014b, 2014c).
- By using sociocultural/CHAT theory to explore each case, new and generative questions arose: Case 1. Sociocultural/CHAT-How to do exhibits?; Case 2. CHAT-How to teach at an exhibit?; 3. CHAT- How to hybridize ideological differences?. Core ideological positions informed these three cases, for example resource vs. deficit views of minoritized learners. Theory both informed these new questions but also was informed by them. We used different aspects of CHAT to unpack the internal working of each system, yet underlying principles such as dialectical relationships between agency/structural constraints informed each case. Moreover, we witnessed inequality and contradictions of power reflected in competing ways of being, doing and thinking, and reflected in the discourse surrounding these efforts.

4.4 Discussion/Importance to the Field

Which learning theories do we rely on in informal and field-based settings? Will these theories suffice to inform our examination of equity in the face of current demographics? Informal learning environments are caught in a moment of unprecedented change and upheaval; using CHAT as a theoretical tool helps us remember that all the tensions and contradictions we are experiencing are an inherent part of activity systems. Our job is to work with them. Moreover, while we personally and individually may not feel the impacts, a systemic view orients us toward the real need, rather than any perceived need**.**

Most learning theorists now view learning as a fundamental intertwining of social and cultural. Cultural-historical activity theory or CHAT does that, and also adds historicity and the dialectic (Barton & Tan, 2009; Rahm, 2012). CHAT provides a comprehensive *theory* that can integrate many complex aspects of learning, as well as many and different levels of analysis.

CHAT seeks out and traces 'contradictions', understanding they are the persistent historical tensions that accumulate over time. When contradictions are noticeable in the system, they are emergent opportunities for change and fundamental components of the system that drive 'expansive learning' cycles (Engeström, 1997). In the cases in this chapter, we traced three such pathways that may inform practice.

Museums and other informal contexts are looking for systemic insights, pursuing a better understanding of teaching practices that reflect learning theories, yet museums are rarely reflective or critical of their practices (Janes, 2009, 2013). This inhibits their ability to organize toward meaningful and lasting change. CHAT design provides scaffolding for museums and other informal institutions to organize toward lasting change. To change, institutions first need to recognize accurately what must change and where within the organization.

CHAT provides useful tools for institutional critical reflection for change. For example, CHAT provides a way to explore dialectics of power (Dubin, 2014; Roth et al., 2012). By this we mean that power is involved in the inner workings of any activity system, where rules, hierarchies, and competing ideologies are involved, often resulting in dynamic and unpredictable outcomes. This sets the stage for dialogue concerning power differentials as they manifest at all levels of function.

CHAT allows us to examine multi-layered, contradictory events like the equity-based field/environmental education intervention, the intervention for training educators to work with equity, and the creation of a new lens for understanding cooperative family learning activity. Such examination reveals underlying philosophies, the roles and creation of mediational means, rules, communities, as well as hierarchies and goals. It is useful to frame contradictions in more practical terms, to make it easier to deal with often gnarly issues that arise in the course of change.

We are challenged to recognize the hidden ideologies and power dynamics underlying and affecting such events. CHAT allows us great freedom to explore how informal institutions work as systems, including identifying the sources and influence of power within the system and acting upon the system. CHAT provides scaffolding for museums to do that reflective work as they engage in the creative production of new ways of being in the world. This chapter informs our research community by demonstrating how CHAT can be a helpful tool to analyze learning and systemic change.

Given that informal learning environments are caught in a moment of unprecedented change and upheaval, using CHAT as a theoretical tool will help researchers and museum personnel understand change processes and will guide their experience as they promote change. Though we are each personally and individually caught within our own frames of reference, CHAT's systemic view orients us toward the obvious and the real needs of all involved, including those new to the existing systems.

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Chapter 5
Gender Inclusion/Exclusion in Science Exhibitions: Theoretical Framework and Practical Implications

Marianne Achiam and Henriette Tolstrup Holmegaard

5.1 Introduction

When entering a science centre gallery with all its hands-on exhibits featuring scientific principles just waiting for discovery, it is tantalisingly easy to think these spaces extend the same open invitation to everyone. However, it is becoming clear that science and technology museums, natural history museums, science centres, and related institutions (in the following: 'science museums') do not afford discovery and engagement on the same terms to everyone. In fact, many members of the public experience exclusion from participating in science museums before they even reach the entrance.

Among the many mechanisms that may exclude people from visiting science museums are distance of travel (for those living in rural areas), entrance fees (for lower-income members of the public), or topic (for those uninterested in science). Yet more subtle exclusion mechanisms are also at stake, as shown for instance by Sandell (1998), who points to non-representation of minority groups within collections and exhibitions, or Dawson (2014a), who demonstrates how use of culturally specific codes in museums can exclude culturally diverse visitors from participating because they are unable to decipher these codes. As these brief examples illustrate, exclusion mechanisms may be embedded in the way science museums represent science, all the way from the mission statements to the opportunities for participation and interaction in individual exhibits.

In recent decades, research on inclusion in science museums focused on interaction between gender and science. In particular, this research considered gender to be a strong determining factor for what, how, and why visitors to science museums acquire

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science, and studies do indeed show girls and boys may have quite disparate museum experiences (for instance Archer et al., 2016a; Borun & Chambers, 1999; Crowley et al., 2001; Ramey-Gassert, 1996; Wöhrer & Harrasser, 2011). One important cause for such gender-specific experiences is the gendering mechanisms designers may build directly into the design of science museum exhibits and environments (Dancu, 2010). For example, the discovery pedagogy that is the original *raison d'être* of many science centres (see for instance Oppenheimer, 1968) may have particular appeal to extrovert personalities who enjoy experimentation, competition, and risk-taking—traits we often associate with masculinity. In other words, discovery pedagogy may imply a certain kind of (masculine-gendered) visitor and exclude others. This implication is important, because even if visitors who feel excluded manage to somehow overcome the difficulties they encounter, they still may walk away from their museum experience with a reinforced belief that science museums are "not for them" (cf. Dawson, 2014a).

Museums and science centres are, above all, *for the public*. For this reason, many of these institutions are in the process of renewing their perspective on what it means to be (gender) inclusive (Achiam & Sølberg, 2017; Bandelli et al., 2009). Our objective with this text is to present and discuss a framework to guide such initiatives. First, we describe the notion of gender as we employ it. We then show how gender (and sometimes, gender exclusion) is present at various levels of social life, and how this presence translates to the science museum environment encountered by visitors. Based on these discussions, we synthesise a gender-inclusion framework to analyse existing science museum practices and experiences, and to guide efforts to establish new practices.

5.2 Gender and Gendered Contexts

The term gender refers to "social differences between women and men that have been learned, are changeable over time and have wide variations both within and between cultures" (European Commission, 1998, p. 18). Study of masculinities in a subculture in Mexico City portrays one example of variation of gender. In this subculture, the dualism masculine/feminine expands, and biological males perform a range of gendered positions, including "mayates" who are men who have sex with other men but do not see themselves as homosexual, "jotas" who perform femininity without positioning themselves as woman or man, and "exoticos" who use feminine symbols (for example, dress codes) but identify as male (Prieur, 2007).

As this example illustrates, rather than simple translation of biological difference, gender is a complex spectrum through which individuals make themselves recognizable and perform in various ways (Butler, 1990). We can think of the performance of gender as the adaptation of the individual to the cultural context in which they participate. Such contexts may impose differential constraints on individuals' performance of gender. For instance, Francis (2000) provides a number of examples of secondary school teachers' disciplinarian and confrontational approach in the classroom to boys and much more lenient and gentle approach to girls. Francis argues that such differential treatment perpetuates the polarised performance of gender by prompting boys to be outspoken and bold (but also sometimes to feel excluded and "picked upon"), and girls to be passive and compliant. In summary, culture alone does not determine gender performance; however, it does set the scene for how we negotiate and perform gender.

The adjective "gendered" describes situations or contexts we structure in ways that reflect implicit or explicit assumptions about the gender of the participants. For example, Faulkner (2000) illustrated how the construction of computer engineering is in terms of the technical, specialist, and abstract; in a similar way, Hughes (2001, p. 435) found an "abstract-rational and frequently mathematical version of science" to pervade many school curricula. We often connect these characteristics symbolically with masculinity (Due, 2014; Faulkner, 2000; Phipps, 2007), meaning that for individuals (female *or* male) who do not identify with such characteristics, a position within those contexts is unavailable to them on the same terms as for those who do identify with such characteristics (Due, 2014). As a result, these contexts force these individuals either to reject science completely, or to downplay their gender identity if they choose to participate in spite of the poor fit (Faulkner, 2000, 2014; Hughes, 2001).

5.3 Gender in Science Museums

We already offered some general examples of how science museum exhibition design effectively may include and exclude visitors based on gender. To achieve a more fine-grained and systematic understanding of the origins and manifestations of gendering mechanisms in exhibition design, we turn now to the hierarchy of levels of didactical co-determination (Achiam & Marandino, 2014). With this hierarchy (Fig. 5.1) we can map and analyse the multitude of conditions and constraints that affect (or co-determine) the way visitors realise and experience science in museum institutions. For example, Achiam and Marandino (2014) used the framework to observe systematically the conditions and constraints for development of an exhibition in a natural history museum. These conditions and constraints ranged from macro-level influences such as the influence of national cultural events on the topic of the exhibition, all the way to micro-level considerations of prospective interactions between visitors and specific exhibit components. In a subsequent study, Achiam and Marandino (2019) used the framework to compare conditions and constraints, across Brazil and Denmark, for the realisation and experience of science content in two museum exhibits.

In the present text, we use the hierarchy of levels of didactical co-determination to structure our discussion of potential gendering mechanisms in museum exhibition design. In doing so, we argue that we can see notions of gender, and gendering mechanisms, as a specific subset of the multitude of conditions and constraints that co-determine the design and realisation of science exhibitions. Risman (2004) points

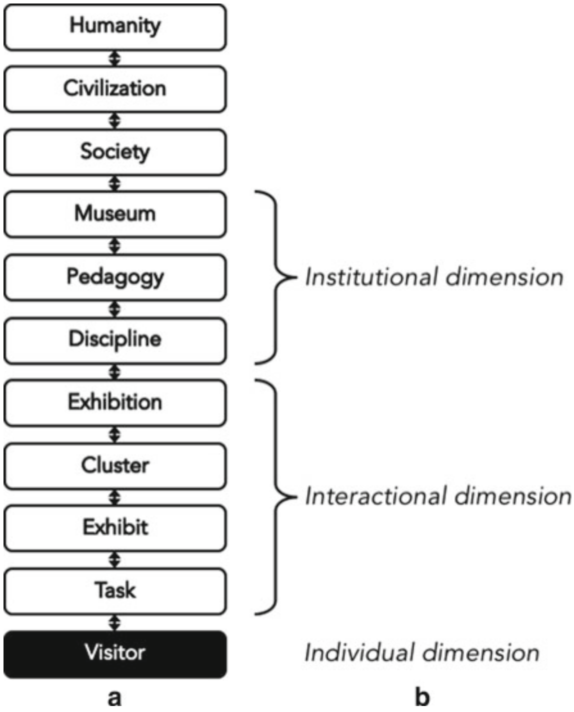

Fig. 5.1 The hierarchy of levels of didactical co-determination. *Note* **a** organises the levels at which conditions and constraints for exhibition design and experience originate and manifest themselves (Achiam & Marandino, 2014). These levels include the three dimensions of gender **b** described by Risman (2004); in addition, the present text designates the upper three levels (humanity, civilization, and society) collectively as the cultural/societal dimension

to three dimensions: individual, interactional, and institutional, where in various ways we co-produce, negotiate, and maintain gender, in our lives. By enriching Risman's concept of gender dimensions with the levels of didactical co-determination, we create a more detailed framework for understanding where and how gendering mechanisms originate and where and how they manifest in museum work.

5.3.1 *The Cultural/Societal Dimension*

The cultural/societal dimension encompasses political, economic, and, indeed, gender discourses that exist outside individual desires or motives and that influence and interact with human action (Risman & Davis, 2013). Analytically, we may think of these discourses as originating and/or manifesting themselves at the levels of humanity, civilisation, and society (Achiam & Marandino, 2019). Humanity refers to our shared human heritage, while civilisation denotes political systems, social norms, and ethical values that transcend nations in the region(s) in question. We can understand society as relationships and institutions (for instance, educational structures or labour markets) that groups of individuals within a nation share.

5.3.1.1 Humanity

Researchers have well documented the deep embedding in humanity of gender and ideas about gender difference. Indeed, Harding (1986) suggests gender difference may be the most ancient, universal, and powerful origin of our conceptualisations of the world that surrounds us. In a study of sex segregation in 44 countries and territories, Charles and Bradley (2009) found evidence of a widespread gender-essentialist ideology that persisted across time and space, even in those nations most liberal-egalitarian. Across humanity, our shared conceptualisation of gender difference leads to legitimisation of male dominance in the form of legal rights, duties, and liberties (Smith & Weisstub, 2016), but also to tolerance of persistent patterns of discrimination such as gender-based violence (Wylie & Greaves, 1995), the gendered nature of poverty across the world, and the differential impact of development policies on women (cf. Crasnow et al., 2015).

5.3.1.2 Civilisation

At the level of civilisation, ideas about gender difference are important as well. Limiting focus here to western culture, Lloyd (1984) discusses how western philosophers throughout history constructed dualized images of knowledge that portray women as less rational than men, thereby excluding them from the world of rationality. Schiebinger (1989) further argues that the definition western science has constructed of itself serves to position women as less capable.

5.3.1.3 Society

At the societal level, gender essentialist ideas about how women and men behave, or ought to behave, become embodied gradually in patterns and processes that define a given society (Elam & Terjesen, 2010). For example, society may incorporate gendered ideas into policies that consider the nuclear family as the ideal, thus supporting families of the single-earner type (Korpi, 2000; Sjöberg, 2004), or into traffic planning initiatives that ignore needs of minorities and prioritise traditional households (Knoll, 2017).

These conditions and constraints form an important part of the complex societal and cultural fabric within which science museum practices take place. Although these conditions do not result necessarily from an intention to exclude or disadvantage individuals or groups on the basis of gender, still they contribute to and co-determine gendered norms, habits, and assumptions that may embed in institutions such as science museums (Dawson, 2014b).

5.3.2 The Institutional Dimension

Subjacent to the cultural/societal dimension is the institutional dimension. We consider the term institution to include the formal organisation—the science museum—explicitly set forth by relevant authorities as well as unwritten, informal norms and rules that exist within this organisation. Research shows gender is an inherent feature of both formal and informal aspects of institutions and permeates the experiences of women and men *within* the organisation, the relationship *between* the organisation and its actors, and the *outputs* of the organisation (Thomson, 2018; Weiner & MacRae, 2014). We may subdivide the institutional dimension into the levels of museum, pedagogy, and discipline (Fig. 5.1). Museum refers to the type of formal organisation (that is, science centre, science and technology museum, natural history museum, etc.), while pedagogy refers to the enacted institutional principles for dissemination that transcend particular subjects within that organisation. Discipline refers to the subject or subjects, for example, physics or palaeontology, from which the organisation draws exhibition content (Achiam & Marandino, 2014).

5.3.2.1 Museum

Often, public discourse conceptualises organisations and institutions as gender neutral (Acker, 1990). However, organisational structures may prompt gendered division of labour (Gardner, 2013) and co-construct and reproduce gender segregation and inequality (Britton, 2000). It seems museums are no different from other institutions in this respect. In a survey of US museums across disciplines, Schwarzer (2010, p. 43) found that, "men dominate museums in two critical areas: power and money", and suggests this pattern influences not only the content of collections, exhibitions, and programmes, but, ultimately, the gender composition of visitors (see also Christensen, 2016; Hein, 2010).

Evidence supports this conjecture. In their study of fifteen museums and science centres in the US, Feinstein and Meshoulam (2014) observed instances of institutional logics that perpetuated a white, male, and middle-class culture. Ash and Lombana (2013) reported a similar pattern. Staff members may ingrain and take for granted such institutional logics so that they hinder the staff members from acknowledging or even perceiving embedded gender-excluding practices (cf. Machin, 2008). Even among museums with explicitly inclusive institutional cultures, research shows social inclusion ideologies can be difficult to implement. For instance, staff members might have diverging understandings of what it means to be inclusive and how to achieve it (Kinsley, 2016; Tlili, 2008). Such issues may cause museums to constitute or perpetuate gender-exclusionary practices, for instance, in the institution's marketing strategies or staff recruitment policies (cf. Dawson, 2014b).

5.3.2.2 Pedagogy

Several studies have examined pedagogy in museums. Crain et al. (2013) discuss science museum pedagogy in terms of "cultural scripts", in other words, the ideas that museum staff members share and that inform their "popular, educational, and political notions about science teaching, learning, and practice" (p. 265). These cultural scripts are often idiosyncratic to the institutions within which they exist. For example, the cultural script of "hands-on" is ubiquitous in science centres because it makes manifest Oppenheimer's (1968) original vision of providing visitors with "apparatus which [they] can see and handle and which display phenomena which [they] can turn on and off and vary at will" (p. 206). However, Crain et al. (2013) argue that the cultural script of hands-on effectively limits what counts as science by reinforcing the notion of science as practical, disinterested, straightforward, and rational. Other research suggests that hands-on pedagogy may privilege masculinity by affording physical, assertive, and competitive performances of identity whilst excluding individuals (girls or boys) who cannot perform such actions in an authentic way (Archer et al., 2016a).

Natural history museums, on the other hand, typically organise their educational activities around objects from their collections. The pedagogy of natural history museums thus descends from nineteenth century object-centred epistemology (Conn, 1998), in which we find assumptions that "the meanings held within objects would yield themselves up to anyone who studied and observed the objects carefully enough" (p. 4). Although contemporary natural history museums resituate objects to promote affective outcomes as well as more individualised meaning-making (Tran & King, 2007), natural history museum pedagogy remains essentially object-based, visual, and contemplative. These features may appeal in different ways to different learners. Indeed, Bitgood and Bishop (1991) found that female visitors had a more positive response than male visitors to four object-based natural history exhibitions. Whilst, Tunnicliffe (2017) observed significant differences, between girls and boys, in the content of the conversations natural history objects elicit. These studies may suggest that the contemplative pedagogy of natural history museums privileges ways of performing gender that often connect to the symbolic feminine.

5.3.2.3 Discipline

Finally, it is becoming increasingly clear that natural science disciplines themselves are not gender neutral. Rather, we can understand each scientific discipline as a particular constellation of culturally and historically situated human practices; as such, "scientific knowledge, like other forms of knowledge, is gendered. Science cannot produce culture-free, gender-neutral knowledge" (Brickhouse, 2001, p. 283). In fact, the sciences are both a source and a locus of gender inequality (Crasnow et al., 2015), for example, exclusion of women as practitioners (Wylie et al., 2008), marginalisation of women and gender as subjects of scientific inquiry (Lerner, 2001), and gendering of scientific practices themselves (Due, 2014; Faulkner, 2014; Martin, 1991; Spanier, 1995). To the extent gendered patterns routinely go unquestioned within disciplines, it is reasonable to assume they persist when scientific knowledge, values, and practices transpose from their locus of production to their locus of dissemination in science museums (cf. Nicolaisen & Achiam, 2020).

5.3.3 The Interactional Dimension

The interactional dimension of gender refers to the way gender influences and shapes expectations and behaviours in social interactions (Risman, 2004). In science museums, social interactions of visitors primarily take place within, and as a response to, exhibitions. This means with respect to science museums, we can understand the interactional dimension as the way museums prompt, afford, or promote gendered and gendering visitor interactions by the exhibition and its constituent parts: clusters, exhibits, and tasks (Fig. 5.1).

5.3.3.1 Exhibition

Science exhibitions consist of scientific objects, phenomena, visualisations, and other installations arranged in dedicated spaces. From a curatorial point of view, specific arrangement of these items in exhibitions often reflects a kind of language that requires visitors to have a level of exhibition literacy (Bain & Ellenbogen, 2002), as suggested by, for instance, the systematic exhibition, where the exhibit presents a collection of objects spatially according to a taxonomy or biographical documentation, or the narrative exhibition, where the intention is to engage the visitor in some form of story-telling (Ågren, 1995). Levin (2010) argues this exhibition language is always temporally and societally constructed; thus, exhibition spaces are defined not just by their physical affordances and constraints. Rather, they constitute complex social and material assemblages in which visitors, curators, scientific discourse, and material objects and installations intertwine. This means the visitor's decoding of the exhibition may differ considerably from the curator's encoding of it. Although studies do suggest sex-specific patterns of circulation behaviour in museum exhibitions (Imamoğlu & Yılmazsoy, 2009; Tröndle et al., 2014), no one yet has studied in depth the gendered construction of science exhibition time and space by visitors.

5.3.3.2 Cluster

Many exhibitions parse their content into clusters, that is, conceptual or thematic groupings of exhibits. Clusters break down the exhibition's overall content to a higher level of resolution, assumably to offer visitors a structure to handle the range of available material (Falk, 1997; Miles, 1988). Although these subdivisions often inherit the classification system of the scientific content on display (for instance, chronology, geography, or taxonomy), Hein (2010) cautions such categorisation schemes may reinforce gendered hierarchies because they reproduce (perceived) universalism and objectivism we associate with masculinity.

5.3.3.3 Exhibit

We understand exhibits to be the basic units of the exhibition. They represent the highest level of resolution of exhibition content, embodied in a range of physical forms, for example models, instruments, taxidermied animals and plants, dioramas, replicas, graphics, or interactives. Analytically, exhibits may be subdivided further into their constituent tasks, which are the opportunities for action the exhibit offers, for instance, finding, identifying, manipulating, navigating, etc. (Mortensen, 2011). When visitors accomplish an exhibit's tasks, the tasks together carry the exhibit's intended meanings.

Although it is easy to assume exhibits are gender neutral, research shows museum objects and their staging in fact may contribute to creating or maintaining gendered social relations (Oudshoorn et al., 2002; Patrick & Moormann, 2021). Dioramas are a well-known example; in several cases, they reflect gendered socio-political ideology rather than animal ecology (Asma, 2001; Haraway, 1984; Wonders, 2003). But other exhibit forms also may circumscribe gendered ways of interacting and understanding. For example, technological artefacts can embody traits that function as "rules" for the gendered behaviour of users (Berg & Lie, 1995). Such rules are in play in examples Archer et al. (2016a) provide, demonstrating how interactive and competition-based exhibit forms serve to include those learners who are comfortable with being dominant, physical, and active, while effectively limiting the availability of alternative gender identities.

5.3.4 The Individual Dimension

We turn now to the individual dimension (Fig. 5.1) as the locus of co-determinants of gendered and gendering mechanisms. The individuals we consider in the present text are the female and male members of the public who arrive at the museum with different experiences, preferences, backgrounds, and aspirations. These characteristics set the scene for encounters and interactions between visitor and science museum; in the following, we explore some of the implications.

First, the individual visitor meets the science museum with a range of prior experiences, including those that involve science. These experiences strongly co-determine what is recognisable as science and scientific culture by the visitor, and what constitutes legitimate ways of interacting with it across different settings. Because the rules for appropriate behaviour in exhibitions are often culturally specific and implicit (Rees Leahy, 2010), not all visitors are able to recognise or decipher them. Dawson offered an illustrative example, observing a group of Sierra Leonean visitors who, upon seeing a diorama with a particular bird species in a science museum, performed a singing and dancing ritual they associated with that species in Sierra Leone. From the experience of these visitors, this was an appropriate way of interacting with the content of the exhibit. It contrasted, however, with the quieter and more contemplative behaviour the museum expected, resulting in feelings of non-belonging and exclusion among the Sierra Leonean visitors (Dawson, 2014a).

An important aspect of prior experience has to do with socio-material dispositions. From the perspective of post-humanist performativity theory, matter and bodies have an on-going and interactive construction (Barad, 2003). Matter therefore neither is fixed nor open for any discursive interpretation. Instead, research must seek to understand how the "boundaries and properties of the 'components' of phenomena become determinate" and "particular embodied concepts become meaningful" (Barad, 2003, p. 815). Researchers have examined performativity and socio-materiality within museology in general (Bergsdóttir, 2016; Dudley, 2013); however, so far studies of materiality in *science* museums have taken a more one-sided approach. For example, in a study of "female-friendly" design features of science exhibits, Dancu (2010) considered biological sex to be a proxy for gender, thereby analytically reducing the diversity of the population of female museum visitors. This approach allowed Dancu to make suggestions for exhibit alterations that proved effective in including a larger diversity of visitors; in contrast, approaches based on socio-materiality would emphasise the on-going interactions between the material experiences embodied in visitors and the materiality visitors encounter in science exhibitions (Barad, 2003). In other words, …

> The meaning of the object lies not wholly in the piece itself, nor wholly in its realization [by the viewer], but somewhere between the two. The object only takes on life or significance when the viewer carries out his realization, and this is dependent partly upon his disposition and experience, and partly upon the content of the object which works upon him (Pearce, 1990, p. 135).

Another aspect of the individual dimension involves visitors' socio-economic background. Through their background, individuals internalise a matrix of dispositions—the "matrix of perceptions" (Bourdieu & Wacquant, 1992)—that shape their way of making sense of the world (Archer et al., 2016b). When they visit science museums, individuals therefore will approach and make sense of exhibitions and exhibits in many ways. This emphasises the importance of designing these environments to offer a diversity of possibilities for visitors to relate themselves to science, ultimately making a larger section of science relevant to more people (Archer et al., 2016b). On the other hand, the influence of the visitor's background means their encounters with the science museum can be a risky affair. Museums often implicitly require visitors from working-class or unprivileged backgrounds to take up identities or perform in ways foreign to their everyday world, which may leave scant room for them to access or activate the resources they bring to their encounter with science (cf. Tan & Calabrese Barton, 2010). Indeed, some visitors may consider engaging with science to be in contradiction to or even undesirable for their sense of selves, as for instance observed by Jackson (2002) in a classroom-based study of working-class boys. These boys performed their masculinity in a "laddish" way as a strategy to conceal their lacking ability to align with the culture and requirements of the classroom as well as to avoid the risk of being seen as "feminine". Similarly, museum visitors unable to engage with science in accordance with the museum's expectations may feel compelled to perform in ways that shift the focus for their inability from a lack of capability to a lack of effort (cf. Jackson, 2002).

Godec (2017) demonstrates this point in her observations of how various ways of performing gender enable different forms of engagement with science in museums. For instance, the performance of hyper-hetero femininity by a group of girls from a working-class background caused a perception by their teachers—as well as by the girls themselves—to be in tension with doing science. Performances of restrained hetero femininity appeared to better support the girls' engagement with science; yet, hard work, obedience, and being quiet raised the risk of invisibility. Godec showed how for girls, science museums afforded few, narrowly defined ways of performing gender, requiring the girls thus to negotiate either their definition of science or their gendered identity to fit in.

5.4 Summary

In the preceding, we argued that rather than taking place in a vacuum, science museum practice and the resulting visitor experience conform to conditions and constraints that originate and manifest themselves at various levels of co-determination. We showed how the individual, interactional, institutional, and societal/cultural dimensions can circumscribe these levels of co-determination. Finally, we argued that in museums, we can consider gendering mechanisms, that is, the mechanisms that prompt us to perform our identity in certain prescribed and sanctioned ways, to be a subset of the conditions and constraints that co-determine science museum practice and experience.

Gendering mechanisms likely often result from interactions between conditions at several levels. To illustrate this point, we draw on Archer et al. (2016a), who studied teenage boys and girls from two schools during a visit to a science museum in London. These researchers describe how…

> Hegemonic forms of masculinity were privileged and normalized by the museum field in various ways within the visits, for instance, through the physical environment and exhibits, the focus of the intervention activities [...], and the competitive and physical nature of some of the hands-on interactive exhibits (p. 476).

> Boys' performances of laddishness and muscular intellect appeared to silence or marginalize other students (p. 471).

> Whereas a couple of girls were reprimanded by staff for being too 'bossy' (dominant), throughout all three visits there were no recorded instances of boys being reprimanded by adults or other students for comparable performances (p. 471).

Even though these brief excerpts obviously do not allow for a thorough analysis of the observations of Archer et al. (2016a), they do permit us to form hypotheses about the mechanisms behind the observations. First, we might consider the competitive and physical nature of museum exhibits as a manifestation of an institutional preference for discovery pedagogy. Further, the hands-on and competitive nature of the exhibits, when encountered by some of the visiting boys, manifested itself in dominant and hegemonic behaviour that marginalised and oppressed other visitors during the visit. Finally, we might hypothesise that the gendered nature of staff members' reprimands to girls performing dominant behaviours (whilst ignoring boys behaving similarly) could be indicative of a general societal perception of what constitutes appropriate behaviour in female (in contrast to male) visitors (see Fig. 5.2).

Although we cannot make claims about the generality of the gendered and gendering events Archer et al. (2016a) observed, we do suggest that the brief breakdown we presented in the preceding illustrates the broader utility of the hierarchy of levels of didactic co-determination. Consequently, we argue that the hierarchy

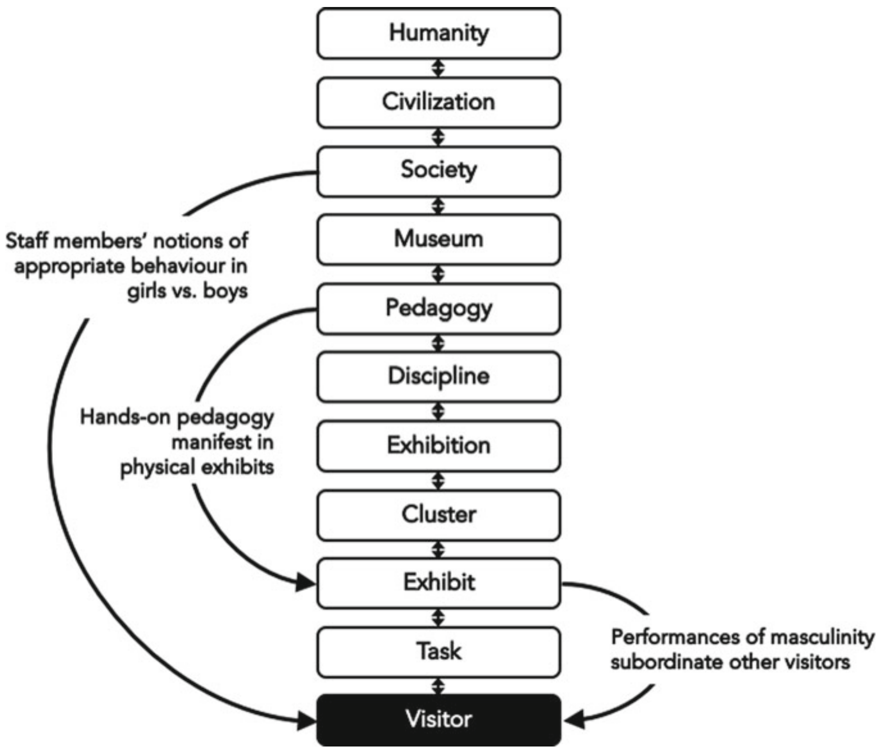

Fig. 5.2 The hierarchy of levels of didactical co-determination. *Note* The hierarchy of levels of didactical co-determination offers a framework for hypotheses about the origins and manifestations (arrows) of gendering mechanisms in museums, such as those Archer et al. (2016a) observed during the visits of two secondary school classes to a science museum in London

as adapted here to science museums and gender emphasises how gender not just is constructed by individual museum visitors or negotiated in their interactions, but how it also is conditioned and constrained by science museum space and culture as well as the surrounding society from the micro to the macro level. In addition to pointing out the pervasiveness of potentially gendered and gendering mechanisms in science museum practice and experience, we thus suggest that the hierarchy provides us with the means to frame precise investigations into the interaction between gender, science, and museums.

5.5 Discussion

The adaptation of the hierarchy of levels of didactic co-determination to the case of gender, science, and museums we presented here has several implications for museum inclusion practice and research. First, our contribution emphasises that gender-related conditions and constraints exist outside the confines of the institution, making them impossible for museum professionals to affect and difficult for researchers to discover. Second, our contribution points to the (sometimes implicit) role of institutional culture in the design and provision of science education experiences. Third, our contribution emphasises the importance of the specific configuration of the interface between museum and public—the exhibition—for gender inclusion. In the following, we discuss these implications in turn.

5.5.1 Conditions and Constraints Outside the Science Museum

The most immediate implication of our contribution is that although societal norms and cultural discourses that surround science museums are strong co-determinants of science museum practice and experience, they are at the same time beyond the direct control of science museum professionals. In other words, we observe that despite strong and earnest efforts to build their institution's gender inclusion capacity, museum educators and management alike are limited to acting *within* the confines of that institution while they are relatively powerless to control gendered and gendering discourses that surround it. At face value, this seems a discouraging (if unsurprising) state of affairs for science museum professionals who wish to build their institution's capacity for gender inclusion. However, research shows that stakeholders and decision-makers outside the institutions in question may have an important role to play with respect to the internal workings of those institutions. Although they have been shown in some cases to stall or hinder gender equitable practices in institutions (Thomson, 2018; Waylen, 2014), stakeholders and decision-makers outside institutions in other cases positively can affect efforts to promote gender inclusion. These so-called "critical actors" are individuals or groups who consciously act from their external vantage point to encourage or lend critical momentum to gendered institutional change (Childs & Krook, 2009). Even though they are studied mainly in political contexts, we hypothesise that such critical actors could have an important role to play in transforming museums' capacity for gender inclusion.

5.5.2 Conditions and Constraints Inside the Science Museum

Turning our attention now to the institutions themselves, our contribution implies that science museums' efforts to provide experiences truly gender inclusive should go beyond just adjusting exhibitions and programmes. As we discussed in the preceding, science museum practice is subject to the constraints of the museum's own histories, traditions, and ideals (Feinstein & Meshoulam, 2014) that may confound even the sincerest attempts at inclusion. For instance, Robinson (2017) describes how the exhibition *Encounters* at the National Museum of Australia developed as a collaboration with Australian Indigenous people and the British Museum to promote reconciliation and a sense of shared history between Indigenous people, non-Indigenous Australian people, and museums. Despite these intentions, Robinson (2017) demonstrates how conventional institutional practices ultimately hindered sharing of authority with the Indigenous people, privileging instead established Eurocentric museum approaches in the final exhibition. In a similar way, we might imagine instances where science museums ally so completely to (western, masculinized) science and scientific culture (cf. Cole, 2009) that efforts to promote an explicit gender inclusion agenda may fail because long-established and implicit institutional cultures and ways of doing override or subvert them (Mackay, 2014; Waylen, 2014).

The solution to this problem may be to address it on more than one front. In other words, building an institution's gender inclusion capacity should address several levels of organization simultaneously to build a collective understanding of gender inclusion. Equity advocates suggest management efforts not only should support initiatives to build gender inclusion capacity, but also should ensure and demand such initiatives take place (European Institute for Gender Equity, 2016). At the same time, research shows individual educators have potential to work for institutional transformation through bottom-up actions, provided they consistently pursue these actions (Fraser & Honneth, 2003). In fact, Ash and Lombana (2013) observe how museum education professionals "occupy an intermediate institutional level, ideally positioned to impact both administration and visitors" (p. 70). In summary, simultaneous top-down and bottom-up initiatives may be a viable way to address entrenched, non-inclusive institutional practices after discovery.

5.5.3 Conditions and Constraints in Interactions Between Exhibitions and Visitors

Finally, our contribution implies that for science museums to be gender inclusive, they must ensure their public face—their exhibitions—presents diverse and many-faceted versions of the sciences to the public. Although some researchers have presented suggestions and guidelines for the design of inclusive science exhibitions, these suggestions and guidelines have for the main part targeted the way design embodies content in physical or virtual space rather than critically interrogating content itself to question its status as (gender) neutral. For example, family-friendly guidelines presented by Borun and Dritsas (1997) suggest that to be including, exhibits should be multi-sided, multi-user, and multi-outcome. Ash (2004) suggests that exhibits that provide several different entry points can serve to include learners with different levels of expertise. According to Dancu (2010), female-friendly exhibit features are those that encourage social interaction and collaboration, connect to social and contextualized applications of science, and seek more balanced representations of female and male scientists (see also Dancstep & Sindorf, 2016). Although we certainly agree with these suggestions, we suggest that exhibition design could take more radical steps to present science in an inclusive way. In the present text, we hinted at ways of creating more gender-inclusive exhibitions (for example, thinking carefully about the spatial language of the exhibition, questioning the categorisation schemes of science, considering the gendered messages that objects and constellations of objects may potentially impart); however, ultimately, we see the need for a more profound change. Accordingly, we suggest that rather than accepting the (gendered) organisation of scientific knowledge, values, and practices as it exists among the practitioners of the disciplines (cf. Chevallard & Bosch, 2014), science museum professionals should focus their efforts on creating new and inclusive organisations of science in close collaboration with their target audiences, new organisations that have the power to disrupt the hegemony of the established ways of organising science.

5.6 Final Words

In our discussion of the hierarchy of levels of didactic co-determination in terms of gender, science, and museums, we made several suggestions for change. We are not alone in advocating for radical changes to the way we deconstruct, reconstruct, and disseminate science in museums. Dawson (2014b), Feinstein and Meshoulam (2014), Kinsley (2016), and Ash and Lombana (2013), made similar calls for institutional transformation. These voices all point to the need for museums to reimagine science "in the image of the underserved and invest in new programs that are grounded in the cultures and concerns of the very people who currently avoid science museums" (Feinstein, 2017, p. 536). What we hope to offer here is a framework that can contribute to this reimagining by qualifying and nuancing understandings of where and how (gender) exclusion mechanisms originate and manifest themselves in science exhibition design and its subsequent experience by visitors. We suggest that the framework may be useful not only to museum staff members, to discover and understand the many different mechanisms that influence their practice, but also to researchers, to qualify and frame research questions into gender inclusion in science museums.

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Chapter 6
Engaging with the Political in Learning: Possible Futures, Learning and Agency in the Anthropocene

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All designs and theories of learning are implicit theories of society.
(Philip & Sengupta, 2021)

6.1 Introduction

In this chapter,[1] our aim is to discuss the application of recently emergent critical theories of learning (Philip et al., 2018; The Politics of Learning Writing Collective, 2017). These theories have emerged in response to and as a critique of the neutrality of the field of learning sciences, including its inability to engage with

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the ethical and political dimensions of learning (see also Biesta, 2010). In other words, advocates of these critical approaches argue that "all education research is intended to inform social change … it is not possible, then, to engage in education research and argue neutrality" (de Royston & Sengupta-Irving, 2019, p. 278–279). Although this should be obvious for any informed reader and has been thoroughly addressed by critical scholars of education (Freire, 1970; Hooks, 1994), the field of learning sciences appears to have been mostly preoccupied with the question of *how* to promote learning and design effective learning environments. The more political questions of *for what* we learn and teach something, *to whom* it is useful and *with whom* we produce knowledge or scholarship of learning is relatively neglected (Philip et al., 2018). Recent reviews of learning sciences programs (Nathan et al., 2016; Packer & Maddox, 2016; Sommerhoff et al., 2018) and international handbooks (Fischer et al., 2018; Sawyer, 2014), in which socio-political themes are either absent or only nominally included, confirm the relative lack of engagement with the political contexts and consequences of this scholarship (see also Philip & Sengupta, 2018).

Why, then, are critical theories of learning relevant now? The global rise of nationalism in general and the election of Donald Trump as President of the United States in 2016 in particular have been key triggers for the organization of critical learning scientists around these topics (Jornet et al., 2020; The Politics of Learning Writing Collective, 2017). Furthermore, the ecological crisis has inspired critical researchers to re-theorize learning and education (Curnow, 2017; Lehtonen et al., 2018; Rajala & Jornet, 2021). As its consumption and pollution habits have become a global geological force, humanity is entering a new geological epoch: Anthropocene (Steffen et al., 2011). The age of the Anthropocene calls for a political effort to negotiate the role of education in the face of conflicting interests and demands (Zylinska, 2014). Research on learning and education should contribute to an understanding of what we need in the necessary transition to carbon–neutral societies. Overall, these societal challenges interconnect and reflect deep contradictions of modernity manifested as aggravating political, economic and social crises of the current times (Bauman, 2017; Malm, 2014).

Advances in the critical learning sciences often reflect the practical struggles faced by researchers and their research participants. For example, the revolutionary spirit of building a socially just society motivated the pioneering work of Russian scholar Lev Vygotsky. Although Vygotsky's work has become hugely influential in the educational field (Roth & Lee, 2007), the uptake of his work has recently been critiqued for domesticating its critical, transformative aspects and reducing his work to a form of social engineering effective learning outcomes without critically investigating the purposes for which something is learned (Cole et al., 2019; Jornet et al., 2020; Stetsenko, 2016). In recent decades, critical theories of learning have been most salient in attempts to challenge racialized premises on how learning and cognition are theorized in a way that disproportionately benefits some students over others (Cole & Bruner, 1971; Gutiérrez et al., 1999; Lee, 2001). An early precursor of this line of work is the research by Mike Cole and his colleagues at the Laboratory of Comparative Human Cognition (Scribner & Cole, 1978), which questioned implicit assumptions underlying the assessment of learning and cognition that implicitly characterize non-White students as deficient and proposed alternative arrangements to help these students thrive. The first edition of *The Cambridge Handbook of the Learning Sciences* included a chapter by Nasir and colleagues (2006), who argued culture and diversity are inherent aspects of the fundamental processes of learning and that we should consider diversity as a pedagogical asset instead of a problem. More recent research in the emerging field of critical learning sciences has addressed a wide range of topics, such as inequity and dehumanization (Booker et al., 2014), imperialism and the role of US military interests in science learning (Philip & Sengupta, 2018), the decolonization of science and science learning (Bang et al., 2012), food activism (Jurow & Shea, 2015), animal rights activism (Vea, 2020) and the youth climate movement (Curnow, 2017).

Often underpinning critical theories of learning is a sociocultural view that conceptualizes learning as situated in social, historical and cultural contexts (Lave & Wenger, 1991; Vygotsky, 1978). This view regards learning as a component of living in different sociocultural contexts that extends over a wide range of settings in the student's life—not as taking place exclusively within formal education (Akkerman & Van Eijck, 2013; Rajala et al., 2016a, 2016b). However, the critical approaches add to the sociocultural theories of learning ways to unpack how these so-called "real-world" settings are thoroughly political and embedded in hierarchies of power.

In the following sections, we first give an overview of applications of critical theories of learning in the research literature, focusing specifically on out-of-school settings. We then illustrate our theoretical argument with examples from our own research on youth climate actions. We close the chapter with reflections on why critical theories are essential in research on learning in the current era of social and ecological crises.

6.2 Application in the Literature

Despite their relevance, critical perspectives appear to be uncommon in research on science learning. Takeuchi et al. (2020) reviewed 154 studies on STEM learning and education, including studies in out-of-school settings, and noted only a handful of these studies adopted a critical stance, while a much larger portion took for granted the discourse on human capital without examining its connections to the ideological notions of economic growth and global competitiveness. Their review showed that the lack of critical investigation of capitalist, nationalist and militarist ideologies appeared to orient STEM learning toward instrumentalist purposes. Similarly, Vossoughi and Vakil (2018) unpacked the political contexts and consequences of STEM learning by tracing its explicit and implicit connections with militarism and US foreign policy. They analyzed a design competition organized in partnership between Maker Media—a major actor in the maker movement—and the US Department of Defense, in which high-school-age youth competed to design new combat vehicles. Their analysis showed how this kind of partnership easily results in the overdetermination of pedagogical contents (such as using science for surveillance and control) and practices (such as emphasizing technological innovation and de-emphasizing critical thinking and social analysis) based on business and military interests rather than visions of public good.

Critical research on everyday science learning has also shown how established expectations in science education can restrict the content and form of science valued and communicated through science education and create obstacles to meaningful science learning for some students—particularly those from nondominant communities (Bang et al., 2012)—thus reproducing unsustainable assumptions about nature–culture relationships (Bang & Marin, 2015). Bang and Marin's (2015) study examined video-recorded interactions in summer programs focused on middle-school-age Indigenous children as well as parent–child interactions during forest walks among urban Native American families. They drew from Gidden's (1984) structuration theory and decolonizing methodologies (Smith, 2012) to examine established expectations regarding nature–culture relationships in these interactions. They argued nature–culture relations as manifested in science education often focus on settled phenomena and perspectives instead of the most crucial scientific questions or the lived socio-scientific challenges faced by students and their families. The study shed light on emergent structural principles, such as acknowledging non-human agency and developing an alternative time–space framing to counter the erasure and absence of an Indigenous presence and Indigenous places. These emerging principles helped to de-settle normative time–space and nature–culture relations and generate transformative science learning in a productive interaction between Western science and Indigenous ways of knowing.

Another application of critical theories in research on out-of-school learning concerns research on learning in activist movements. This research stream has mostly examined adult learning contexts, such as animal rights activism (Vea, 2020), food activism (Jurow & Shea, 2015) and environmental activism (Boyer & Roth, 2006; Curnow, 2017). Taylor and Hall's (2013) study is an example of research on learning in an activist setting involving young people. The authors designed and examined an after-school bicycle building and riding workshop in a US city, with non-driving teenagers as the participants. Specifically, the researchers conducted the study in a neighborhood that lacked the infrastructure for mobility without cars. The study focused on the concept of counter-mapping, which refers to practices of re-imagining a city through:

– "collecting information about community assets,
– making maps or new map layers that reflect these assets and aspects of personal use or mobility, and
– using these maps to make and justify claims for use and development of assets in the future." (p. 66)

The authors viewed counter-mapping as a form of "thirdspace" practice (Lefebre, 1996) whereby youth can make personally relevant claims to contest professional conceptions of space and ultimately change the relationship between public activity and the built environment. The study showed that counter-mapping promoted the youth's transformative sensemaking and engagement with new ways of experiencing, representing and reflecting on mobility in the city. After the study, the maps designed by the participants had material consequences, as the city planners took up the students' ideas.

6.3 Envisioning and Building Concrete Utopias to Promote Student Learning and Agency

In this section, we illustrate the application of critical theories of learning with examples from our own research, all of which addresses learning in the current epoch of Anthropocene, a new geological epoch, in which over-consumptive and fossil-fuel-dependent human activities have already made a fundamental, permanent change on the planet's climate and environment (Rajala & Jornet, 2021; Taylor & Pacini-Ketchabaw, 2015). We argue science learning should foster students' civic action and learning of crucial skills and dispositions needed for generating novel solutions to challenges of sustainability and human wellbeing in the Anthropocene (Cook, 2019). However, being knowledgeable about climate change is insufficient for fostering actions for a sustainable future; if schools are to raise active citizens, they must provide their students with involvement in the transformative activity of envisioning and enacting sustainable futures (see also McNeill & Vaughn, 2012).

In our work, we build on and develop a positive critical theory that differs from critical approaches that denounce concrete and positive suggestions for social change as inevitably subject to domestication by the status quo (Brown & Cole, 2001). To these ends, we draw on utopian methodology research (Brown & Cole, 2001; Levitas, 2013; Rajala, 2021; Rajala et al., 2020). Utopian methodology refers to the re-imagining and building of alternative futures and ways of social organizing as well as the prefigurative enactment of these visions and futures in the present (Levitas, 2013). The utopian methodology challenges the ethos of a lack of alternatives and "end of history" characterizing the present day (Fukuyama, 1989; for a critical discussion, see Stetsenko, 2016).

Our work examines the pedagogical potential of the concept of "concrete utopia" (Bloch, 1986), the meaning of which differs sharply from the common understanding of utopias as an impractical imagination of alternative worlds (such as abstract utopias). The idea of concrete utopias is to leverage actual potentials for change in an existing activity (Levitas, 1990). An excerpt from Stetsenko (2016) further captures the essence of this distinction:

> This future society cannot be charted nor predicted in full detail in advance, that is, it cannot be construed as a utopia in the sense of an abstract idea—imagined as something one can simply await in hopes that someday it might arrive. Instead, this society is imagined through actively carrying out practical steps toward its realization already in the present, if even only in nascent and modest forms. (p. 91)

Critical pedagogy has understood utopia as a radical orientation toward the future that develops a pedagogy of hope (Webb, 2009).

In this chapter, the term concrete utopia refers to projects planned and implemented by youth in collaboration with—and sometimes in opposition to—their teachers, civil society organizations and local decision- and policymakers. We can characterize these projects as concrete utopias if they involve an orientation to re-imagine and make a transformative change in the existing ways of living and organizing activity.

We draw from a transformative approach to learning that views human learning as well as the development of knowledge and skills as co-constructed by individuals understood to be agentive actors of social practices as well as their own lives, identities, experiences and common history. Within this perspective, learning—as the development of competences— occurs as a result of contributing to collaborative transformative practices, implicating a "sought-after future" and a commitment to realizing it (Stetsenko, 2016). Through these experiences, citizens and their communities become active agents for sustainable futures. Agency accounts for the opportunity, will and skill of people to act upon, influence and transform activities and circumstances in their lives and in society (Rajala et al., 2016b).

We also draw from a learning-ecology perspective (Barron, 2006; Rajala et al., 2016a) to foreground youth agency formation across a range of meaningful contexts throughout their lives, including, for example, school, family activity and civic actions. This conceptualization challenges the simple separation between informal and formal learning. By limiting a view of learning to a single setting—whether formal or informal—ignores significant inter-dependencies between multiple settings of learning. Learning happens as individuals move in and through sites of learning seen "less as parking lots and more as intersections" (Leander et al., 2010, p. 336; see also, Erstad, 2012).

Dealing with politically sensitive topics, such as climate activism, is risky and likely creates tensions and conflicts (Gutiérrez et al., 1999; Rajala et al., 2016a). For example, in many countries, nationalist politicians seek to politicize the topic of climate action and question the legitimacy of how schools and other everyday settings of learning teach this subject. Presently, we do not have sufficient knowledge on how to reconcile such tensions in an educationally meaningful manner and understand the consequences for pedagogy and students' learning and agency. In contrast with a common way of framing learning as simply a technical matter of effectiveness and efficiency, this chapter foregrounds tensions and conflicts related to ethical, political and institutional aspects of teaching and learning as objects of empirical analysis. How teachers, students and other stakeholders address these tensions and conflicts is related to discussions on the viability and achievability (Wright, 2010) of the youth's utopias.

6.3.1 *Bicycles on the Move! Changing the Paradigm of City Planning*

Our first example discusses a Finnish upper secondary school (ages 15–18 years) elective project called "Bicycles on the Move!" Two teachers, Mikael Sorri (a co-author of this chapter) and Pentti Heikkinen, started the project with the aim of taking learning to "authentic environments." During the project, the students cooperated with cycling activists and city authorities to influence the decision-making of the City Council concerning cycling. The course involved the use of an interactive digital map in which the students added photographs of their cycling experiences, details on places where cycling conditions needed improvement and suggestions for new or alternative cycling routes. These photographs then provided opportunities for the students to share their experiences and observations during in-classroom discussions. In addition, the students—together with their teachers—filed official complaints about city plans, wrote opinion pieces, contacted the city planners and decision makers, and participated in city planning competitions.

We collected data by observing and video-recording the activity and by interviewing the students and teachers. Furthermore, we collected various project-related documents, including a public talk, newspaper articles and a television program. The interpretive analysis of the data focused on how temporality and spatiality were produced in the pedagogical activity and negotiated in the social interactions.

The following excerpt (reproduced from Rajala et al., 2013) exemplifies a typical task in the Bicycles on the Move! project. The teacher introduces the students to an assignment related to the construction of a new pedestrian and bicycle path near the school as part of a city plan. To accomplish the task, the students took photographs of problem areas for cyclists in the neighborhood.

Excerpt 1

Teacher: The most urgent issue would be... right now, they [the city authorities] are really starting to ponder and think about... whether Tapiolan Raitti is a functional main route for cyclists or whether it should be arranged in some other way.... It is likely that we'll get an audience with the big bosses in January; so, before that, we should have something of an idea and we should have already checked every corner there and we should have an idea. So, would you possibly feel up to going through those corners, especially from the Sokos Hotel heading east, and think about it? What would be a functional route?

In the example, the teacher reminds the students of an upcoming meeting with a top city official, framing the students' contributions as consequential beyond the classroom. During the project, the students collaborated with and needed to convince a wide range of stakeholders, including city officials, cycling activists and newspaper readers, when co-authoring opinion pieces with their teachers. By contributing to local political debate, the students had the opportunity to learn to question assumptions and contest decisions about cycling issues. Thus, the learning environments outside of school were not only regarded as places where students could visit, make observations and learn science, but the project also provided the students with opportunities for exercising political influence and active citizenship, positioning them as historical actors capable of contributing to a change in their neighborhood (see also Gutiérrez et al., 2019).

The next excerpt (reproduced from Rajala et al., 2021) is from an email one of the students sent to the City Council of Espoo:

Excerpt 2

Dear City Council.... In particular, such solutions as combined pedestrian and cycling avenues are already outdated models. In a route with little traffic, the combined model could work well, [as] there is little traffic in very few routes in the partial centers of the City of Espoo. Separate cycling and pedestrian avenues are the future. This has been understood in Amsterdam, Copenhagen and even Helsinki.

In filing the complaint mentioned above, the project collaborated with a local cycling association to influence traffic plans near a railway station. The complaint first resulted in tabling of the city planners' traffic plan during a technical committee meeting. Eventually, the city planners decided the matter in the project's favor and implemented the traffic solution in a way that resembled the students' suggestion. The idea behind the suggestion was inspired from the students' experiences on a trip the project made to the cities of Amsterdam and Rotterdam in the Netherlands.

The Bicycles on the Move! project made visible the students' agency in envisioning and building concrete utopias—that is, proposing alternative futures regarding traffic solutions to reimagine their city. The motivation behind the project was a utopian vision of what one of the teachers called a "paradigmatic shift" toward a cycling-friendly Espoo. Overall, the project aimed for a fundamental change in ways of thinking, social practices and traffic infrastructure. During the project, the students learned to contribute to a historical change in their neighborhood, changing themselves in the process. The surrounding environment was not perceived by the students unchangeable, but as historical, political and co-emergent with the students (see also Stetsenko, 2016). In fact, the students reported that the project had made them view their surroundings more critically; bumps and cracks in the road, previously unnoticed, were now viewed as something to change through collective action (see also Rajala et al., 2013).

The transformative learning and building of concrete utopias often requires questioning existing practices, which, in turn, leads to tensions and conflicts. This was also the case in the Bicycles on the Move! project. At best, the city officials welcomed the suggestions made by the students and invited the project to conduct traffic calculations together with a city traffic engineer. However, some of the city officials considered the project to be "utopistic" in the pejorative meaning of the term and even accused the teachers of brainwashing the students. It is important to note that dealing with these kinds of contradictions is an inherent aspect of the expansive process of reconfiguring existing practices (Engeström, 2015). In line with Levitas (2013), we posit that we should consider concrete utopias not as monological blueprints imposed on others but rather as dialogical, provisional and always subject to exhaustive self-criticism (see also Brown & Cole, 2001). In the Bicycles on the Move! project, negotiating and sometimes disagreeing with the city officials helped the students better understand their perspectives and build a shared understanding for collaboration. These negotiations provided opportunities to learn a crucial civic disposition: what Anne Edwards (2007) calls "relational agency", which indicates a capability to act in relation to and in collaboration with others (see also Rajala et al., 2013). However, it is equally important to acknowledge that flexibility in these negotiations risks domesticating the radical content of utopias and assimilating the transformative actions within the boundaries of existing practices (see also Rajala et al., 2021).

Finally, in the Bicycles on the Move! project, the students' agency was not restricted within a single setting but extended across a range of formal and informal settings, as the students and their teachers interacted and collaborated with—and sometimes opposed—different social actors outside the school, such as cycling activists, researchers and city officials. Jurow and Shea (2015), in their study on consequential learning in hydro farming activism, used the notion of scale-making to describe a similar process of the reorganization of the temporal, social and spatial relations through which people acting within arenas of limited influence could exert a more profound influence over their lives.

6.3.2 Designing Alternative Forms of Food Production

Next, we discuss examples from our ongoing research project based on a design-based research methodology that examines the pedagogical potential of the concept of concrete utopia in promoting youth agency and climate activism in educational settings. The methodology of social design experiments (Gutiérrez & Jurow, 2016) informed our research approach. Accordingly, we sought a design process that promotes social transformation and positions the participants as historical actors capable of designing social futures (see also Espinoza, 2003; Gutiérrez et al., 2019). The differing factor in regard to more conventional design-based research is that the latter often seeks change and improvement within the confines of the existing institutions instead of seeking to change the institutions and their relations to the wider society. In line with these considerations, we grounded the methodological approach in collaborative partnerships between researchers, teachers, youth activists, non-governmental organizations and other stakeholders (Coburn & Penuel, 2016). Based on collaboration between researchers and practitioners, the use of this approach should result in design principles, pedagogical models, theories and empirical findings about youth learning and agency. It should also lead to processes of social transformation as a result of youth agency. To support the envisioning and building of concrete utopias, we organized four preparatory workshops with the teachers. These workshops included NGOs and youth climate activists as well as expert lectures based on the above-outlined theoretical framework and collective design of the pedagogical approaches and tools.

In this chapter, we focus our discussion on urban gardening projects in the Otaniemi Upper Secondary School in Finland. Two of the co-authors of this chapter, Kirsi Haapamäki and Aki Saariaho, designed and implemented these projects, basing the documentation and analysis of the project and preparatory workshops on an ethnographic research approach and data collection. Ethnography is understood as both a research methodology and research product; it is a reflexive account of social life that prioritizes participants' perspectives (Hammersley & Atkinson, 2007). The data collection methods included interviews, participant observations and field notes (supported by video recordings and photography as well as document analysis).

The two teachers designed and implemented a project motivated by a utopian vision of promoting a circular economy and alternative forms of food production in their school. In the following excerpt, Kirsi Haapamäki reflects on their vision:

Excerpt 3

Our dream is to create a learning environment of these growing methods mentioned, such as aeroponic, hydroponic and aquaponic, but also meadows, insect hotels, a real greenhouse, an instant house for growing oyster mushrooms, cell pods for cell cultivation producing berries or potato saplings, making biocarbon for cultivation and using bokashi liquid absorbed into it at school. We already have bees. This allows us to get concrete experiences about food production and all the things related to it. In this mini environment, we try to tackle challenges created by the accelerating greenhouse effect and loss of biodiversity. Hands-on doing gives us power and hope. What should be done on a big scale in the world is done on a little scale at our school.

This excerpt illustrates how the utopian vision did not remain at the level of abstract ideals, but took steps toward concrete action to realize the vision in practice. Implementing a form of circular economy in the students' lives, the students re-used materials in their everyday lived environments to cultivate food, such as using leftover food from the school and their homes to create soil in the bokashi compost or collecting sticks from the school yard to create biocarbon. The products created during the project, such as aeroponic potatoes or plants cultivated with the help of bokashi composting, were intended to be highly visible in the school building (see Figs. 6.1 and 6.2) to attract the attention of those who were not part of the projects. The creation of these material products also helped facilitate cooperation between the different student groups, each of which conducted their own components of the whole project. For example, the project culminated in a terrace designed and constructed by the students that hosted the plants they had cultivated. Specifically, one group studied the bokashi composting method and created do-it-yourself composts, while another group made the z; then, both were used to cultivate plants in the terrace. During the interviews, the students reported that they felt a sense of belonging to a community of practice established through this cooperation. This creative way of distributing the work across several youth groups also helped realize the utopian vision within the institutional time constraints of the school.

The following excerpt from a student project plan illustrates a youth perspective on enacting the utopian vision:

Fig. 6.1 The different groups of students created the cultivation terrace and opened it for all. The students decided to place signs from climate action demonstrations on the door (the photos were taken by the authors)

Fig. 6.2 The students created biocarbon in the school yard (left). The students cultivated aeroponic potatoes, which they set up in the school dining hall (the photos were taken by the authors)

Excerpt 4

In a world in which food waste is a huge problem and landfills are filling up with waste that clearly doesn't belong there, our group wanted to see if we could get alternative composting methods to work while also maybe learning something about microbes and how they can be used to our advantage in composting.

Our school building also has a public library and they have been experimenting with bokashi composting for the last year or so. Our wonderful librarians were kind enough to introduce us to the world of bokashis, and we were immediately interested in this new and innovative way of turning your food scraps into nutrient-dense fertilizer that can be used, for example, in your garden. However, the bokashi composter in the library was quite pricey and, therefore, possibly something not everyone can consider buying.

After a little research, our group decided to expand our project a little bit more and see if we could possibly also build our very own bokashi composter out of everyday materials that everyone already has somewhere lying around. We also wanted to buy an actual bokashi set that could be used outside of this project too to show people how bokashis work and how they can be stored almost anywhere—for example, in a corner of our school cafeteria!

The project plan showed how science learning about microbes and composting was functionalized to address crucial issues of ecological sustainability through envisioning alternative ways of organizing food production. This excerpt further illustrates how the students could exercise their agency across a range of informal and formal contexts of learning: They first learned the basics of bokashi composting from the staff of the local city library and decided to save money by building their own do-it-yourself bokashi composters and re-using left-over materials from their homes. In the following interview excerpt, one of the students participating in the project explains how the idea was not to complete a school task, but to make a change in the world.

Excerpt 5

Yeah so one of the goals of this bokashi thing was that we wanted to spread the word— to make an impact so that this would not be a mere school project that molders away in some corner; so, we started to think about different alternatives of how can we push this forward. Can we advertise it on YouTube? Can we advertise this on Facebook? So, in this way, this was quite different... here, we had to think [about] how we can make this make a difference so that this can make an impact.

As intended by the teachers, the students viewed the material presence of their products in the school building as a form of change-making. One of the students elaborated on this idea in the following interview excerpt:

Except 6

It is very good to have the terrace for everyone's use in the school.... There, the other students can see what we have done and they could start to do something like that themselves. It's not very difficult, really, and the social media posts have been seen by many people and it has made them think like... like it makes them think how they could also make an impact.... [Regarding the activist signs that were laid out at the terrace entrance] They are very relevant for this topic, and, when people see them, it makes them think too and... hopefully, it makes them think. And, in that way, information is shared and hopefully also desired—like, hopefully for some, it engenders a desire to participate in activism. It would be the best situation.

It was a design intention of the teachers that the project would extend across informal and formal contexts of learning and that the students could exercise their agency in envisioning and building the concrete utopia in collaboration with their teachers and social actors outside of school, as reported by teacher Kirsi Haapamäki:

Excerpt 7

In this future-oriented urban gardening project, students are seen as active citizens learning new things together with adults who can be their teachers, university students or other collaborators, such as librarians from the local city library or a company related to the topic. Teachers are seen more as co-learners, providing the equipment and using their knowledge for the coordination of the project.

Both teachers reported that dilemmas arising when their work challenged the status quo of the school, as reflected on by teacher Aki Saariaho:

Excerpt 8

The role of a teacher contains many paradoxes. Our curricula give us the possibility to raise students to be empowered citizens in society, yet the school as an organizational structure is very much top-down and regulated. Teachers are given the position of societal educators of active citizens, but they are also required to be wary of what they can actually do in the tight hierarchical nature of school.

Although transformative approaches to researching and promoting learning, such as those we examined in this chapter, make the political aspects of learning more salient, learning environments—whether formal or informal—are never neutral. However, the above excerpt demonstrates that taking on a transformative activist stance in learning is a daring act that requires courage and the questioning of existing practices (see also Stetsenko, 2016).

6.4 Importance to Research

In this chapter, we discuss the emerging critical theories of learning that challenge the politically neutral stance of the learning sciences and underline that all educational research is intended to inform social change (de Royston & Sengupta-Irving, 2019; The Politics of Learning Writing Collective, 2017; Philip et al., 2018). Research on learning and education needs to make more explicit assumptions about the desirable social change and social futures that underlie claims about knowledge and learning.

The magnitude of the multiple interconnected social, political and ecological crises faced by humanity perpetuate the importance of critical approaches in research on learning and education. We argue that the pragmatic concerns and design of relatively small educational improvements that often characterize the design of and research on learning environments (Andersson & Schattuck, 2012) may be of limited usefulness in addressing racial inequities and oppressive power relations in learning (Espinoza et al., 2020; Ladson-Billings, 2006) or contributing to the ecological reconstruction and green transition of societies (Curnow, 2017; Rajala & Jornet, 2021). Education can no longer emphasize enculturation into an existing, unsustainable culture.

Based on our own previous as well as ongoing research, in this chapter, we discussed the pedagogical potential of the notion of concrete utopias for researching and designing possible futures as well as consequential and transformative learning and agency in educational settings. The motivation for our research stemmed from the dire situation faced by humanity in the age of Anthropocene, in which "the power to shape the earth system, including planetary climate, has passed from the realm of nature into the realm of humans" (Ritchie & Knight, 2016, p. 2). The IPCC Working Group I report (Arias et al., 2021) estimated the chances of surpassing the global warming level of 1.5 °C in the next few decades and found that, unless we make immediate, rapid and large-scale reductions in greenhouse gas emissions, there will be catastrophic consequences. Climate change is already affecting every region on Earth in multiple ways. However, this report also shows that human action still has the potential to determine the future course of the climate. This requires rapid political action all over the world, and need to change our behavior and economics immediately.

It is clear that governments play the main role in limiting cumulative CO_2 emissions. In addition, we discussed the role of private citizens. All actions we perform are political, because they are reflections of our understanding of the climate crisis and its causes throughout the world. Notably, the two cases from our research discussed in this chapter showed we can take important climate and environmental action in settings of everyday learning and education. We discussed school projects in which students' learning and agency extended across a wide range of informal and formal settings when the projects interacted and collaborated with other social actors in society. We argue our approach for designing and researching the production of possible futures can be applied in a wide range of settings of everyday learning. NGOs, recreation forums and associations, such as nature clubs or choirs, are important settings of learning to promote sustainable futures. For instance, a choir can choose their repertory in a way that shows an ethical interest in making a statement on the global crisis. However, as we argued in this chapter, there is a need for research approaches not limited to the examination of single settings of learning (whether formal or informal) (see also Barron, 2006; Jurow & Shea, 2015; Rajala et al., 2016a, 2016b). Overall, effective climate action often requires the pursuit of courses of action in and across multiple settings of learning.

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Chapter 7
Critical Scientific Literacy Approach and Critical Theories in the Learning of Science Outside the Classroom

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7.1 Introduction

In 2020, August 22nd marked the "Earth Overshoot Day", or "Ecological Debt Day", as the date when humanity's demand for ecological resources and services exceeds what Earth can regenerate in a year (Global Footprint Network, 2020). In the last 50 years, we increased our use of resources from consuming one whole planet Earth to 1.6 Earths in a year. Each year, the Global Footprint Network calculates this day based on changes in carbon emissions, forest harvest, food demand, and other factors that could affect global biocapacity or the ecological footprint.

Since the origin of life and for millions of years, our planet has behaved as a harmonic system of energy flow and matter circulation. Solar energy enters biological systems and matter circulates, which, in constant recycling processes, has generated the most diverse forms of life. In contrast, in the current global industrial economy, the flow of energy and matter goes practically in only one direction: we extract energy by burning fossil fuels to produce, maintain, or transport everything we use. At the same time, we deplete "renewable" resources, such as fishing, soil fertility, biodiversity, or water, and all matter that enters the economy (fossil fuels, construction materials, metallic minerals, biomass), and we recycle few amounts, going from 4.5% in Latin America and Caribbean to 20% in Europe and Central Asia (Kaza et al., 2018). As a result, each year, we consume the planet's resources faster than replacement can

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occur. At the same time, climate change increases due to the burning of fossil fuels, overexploitation and destruction of resources, loss of biodiversity, hyper urbanisation expansion, and desertification (Gudynas, 2018).

The above describes the planetary emergency we currently are experiencing, which is rooted in our current socio-economic system and favours the increasing accumulation of capital and growth to the detriment of the common good and care of the environment (Foster, 2017). This context generates race inequality and increases extreme poverty, conflict, and violence (Benzce et al., 2012). Moreover, the impact of extractivism is generating conflict zones with indigenous communities fighting for human rights and collective tribal ownership of their ancestral lands.

From our local context in Chile and Latin America, the dynamics of resource extraction to feed the global industrialised economy has consolidated our continent in its role as a producer of raw materials (Gudynas, 2018; Lander, 2014), reaching an extraction level of 10 tons per person/per year (Martínez-Alier & O'Connor, 1996), and we export most of it. The overexploitation of natural resources and the accumulation of waste seriously have worsened the environmental situation, resulting in high loss of biodiversity and natural habitats, excessive use of fertilisers, and water and air pollution (Acosta & Machado, 2012). Under this scenario, socio-environmental conflicts have increased, which governments tend to repress strongly and criminalise (Svampa, 2011).

We describe socio-environmental conflicts as "Ecological Distribution Conflicts" (EDCs), a term Martínez-Alier and O'Connor (1996) coined to describe the social conflicts that arise as a consequence of the unequal distribution of environmental benefits. Examples are access to natural resources, fertile lands, or ecosystem services, and adverse environmental effects, such as pollution or waste (Scheidel et al., 2018). The Environmental Justice Atlas registers a total of 960 socio-environmental conflicts in Latin America; that is an average of 48 conflicts for each country. In contrast, the same map records 533 conflicts for Europe; that is 14 on average for each country.

In this scenario, where a climate emergency strains nature and humanity, traditional educational structures and specifically learning and curriculum theories are held in check. In this line, education and specifically the role of science and environmental education might be fundamental to promote skills, aptitudes, and competencies to empower individuals to become critical about knowledge and thinking. Activities outside the classroom might offer real opportunities to connect teaching and learning with real-world contexts. Moreover, a proper theory of learning according to the times we live is imperative. Thus, in this chapter, we propose applications of critical and post-critical theories to support the teaching and learning of science teaching outside the classroom.

7.1.1 Critical and Post-critical Theories

A theory of learning should offer an image of the real world. A theory, in principle, should serve as a mirror to discover reality, to reflect it, to represent it. However, theories in education not only describe the world. Instead, by describing it ontologically, they re-create and produce the reality with which they were dealing. According to Da Silva (1999), there is a paradox in this process because a theory first creates and then discovers, but, by a rhetorical device, what it creates ends up appearing as a discovery.

In education, the theory selected to analyse, describe, and discover the world is relevant. For instance, a central question for any curriculum or pedagogical theory is what knowledge we should teach at schools. Hence, this process demands critical reflexivity and drives us to the question about what students need to know. What is valid, necessary, or essential knowledge to consider part of the curriculum in science education?

In a context of climate emergency, the learning and teaching of science have been tensioned by challenges and new interpretations about the aims of scientific literacy. Several questions have been raised to address interrogations about what contents, attitudes, and skills we should consider within the science curriculum, such as the aim of science education. How should we (re)organise the different disciplines and scientific areas to promote an environmental responsibility? How can we connect science with real-world scenarios and balance it with other areas of knowledge? Consequently, what do we understand as scientific literacy within the context of the climate crisis? To tackle all the previous questions, this chapter proposes a questioning approach in science education and specifically in the context of activities outside the classroom from critical and post-critical theory.

According to Da Silva (1999), critical theories distrust the status quo, holding it responsible for social inequalities and injustices. Traditional theories are theories of agreement, tolerance, adjustment, and adaptation. The critical theory derives from a vision to address domination and social inequity from mistrust, questioning, and radical transformation (Hayward, 2007). For critical theorists, the important thing is not to develop techniques for the curriculum but to develop concepts that allow us to understand what the curriculum does.

Critical theory refers to the theoretical and analytical perspectives that focus on questioning the roles school, curriculum, and pedagogy play in knowledge production and reproduction (Barbosa, 2017). Formally, the 'Frankfurt School' developed critical theory, which arose as a re-examination of Marxism (Scott & Marshall, 2005). Critical theory is a heuristic with preliminary structure but with no single definition. In this sense, critical theory takes a critical view of society and adopts an ideological focus, typically associated with emphasising the analytical importance of sociohistorical context, an emancipatory agenda, and reflexivity.

On the other hand, a post-critical theory is a pluralistic approach to consider the possibility of the symbiotic co-existence of multiple realities (Hayward, 2007). It expands critical theory and refers to the research inherent in race and ethnicity, class, gender, identity and difference, curriculum, culture, teacher training, and power relations in education (Barbosa, 2017). In this sense, knowledge is inextricably, centrally, and vitally based on what we believe, what we have been, who we are, and what we would like to be. In other words, knowledge is based on our identity and subjectivity.

A post-critical approach in pedagogy seeks to transform reality through critical analysis, and similarly a critical approach is based on empathy, inclusiveness, transformation, and reflexivity (Hayward, 2007). This approach might be appropriate to apply in activities carried out outside the classroom because real-life experiences might generate more substantial commitment among students (Freire, 1970).

The first appearance of the concept "post-critical" appears in the book by Hungarian-British author Michael Polanyi (1958), *Personal Knowledge: Towards a Post-Critical Philosophy*. He positioned it as a justification of scientific knowledge and about knowledge theories. In his book, Polanyi criticises the traditionally understood concept of theory and incorporates elements about the subjective and objective experience of the subjects. He points out that a theory on which subjects' knowledge is not affected by external fluctuations and may be constructed without regard to one's normal approach to experience. He uses the post-critical concept to describe this fusion of the personal and the objective as personal knowledge, leaving traditional theories behind.

Even though scholars in Europe developed the approach, from the Latin American perspective, Da Silva (1999) proposes that the question of power is what produces a historical break and is what will separate traditional theories from critical and post-critical theories. Traditional theories pretend to be just that: neutral, scientific, disinterested "theories" (De Silva, 1999) and more readily accept the status quo, knowledge, and dominant knowledge without questioning the power structure. Furthermore, usually, they end up concentrating on technical matters. In contrast, critical and post-critical theories argue that no theory is neutral or disinterested but inevitably is implicated in power relations within the framework of social epistemology.

Studying post-critical theories involves studying identity, otherness and difference, subjectivity, representations, gender, race and ethnicity, and multiculturalism. From Latin America, post-critical frames understand that subjects relate to interactions of environmental, historical, and political dimensions. Unlike critical theories, based on Marxist theories concerning the forms of ideological, economic, and political power, these post-critical theories are based on post-structuralism about the critical analysis of discourses and meaning processes (Cieri, 2019).

To summarise, critical theories revolve around ethnicity, queer theory, feminist studies, postcolonialism, culture and critical multiculturalism, ideology and social reproduction, social class, and emancipation (Andrade da Silva et al., 2020). Similarly, critical and post-critical pedagogies differ from traditional theorising since they encompass the analysis of the power which permeates social and cultural relations.

What differentiates post-critical theories from critical theories is the subject's position since, in post-critical perspectives, this position is marked by processes of objectification and subjectivation. These processes can be understood as a historical production, as a product of the relations between knowledge and power. According to Da Silva (1999), "post-critical theories expand our understanding of domination processes […] and provide us with a more complex map of social relations of domination than critical theories, with their almost exclusive emphasis on social class" (p. 34). Along the same lines, Kawahara and Sato (2017) point out that the paths for environmental education in the framework of post-critical theories consider the subject and the intersubjective relationships of the human being, creating new possibilities for practices that strengthen human relationships. Therefore, post-critical theories admit ambiguities of reality and understand that identities are not fixed structures. Furthermore, these theories aim at promoting decentralisation of power, breaking with the universalisation of subjects and with the premises hegemonic. Therefore, in a climate, ecological, social, and health crisis scenario, we rethink research paths in environmental education and science outside the classroom. In this sense, critical theories value local contexts, the subjective dimension of reality, and subjects' subjectivity.

7.1.2 A Complement of Critical Theories: Critical Scientific Literacy as an Approach to Tackle the Climate Emergency

The transformations of contemporary societies, the increase in inequalities, environmental degradation, violence, and racial, ethnic, and gender stereotypes, impacted the purpose of scientific education and the vision of scientific literacy (Laugksch, 2000; Sjöström et al., 2020). Roberts (2007) described two visions of scientific literacy. The focus of *Vision I* is acquiring scientific knowledge and processes relevant to the understanding of its applications. V*ision II* aims to understand the practicality of scientific knowledge in life and society. Sjöström and Eilks (2018) discussed the relevance of science education associated with the different visions of scientific literacy from a humanistic approach and proposed a third vision, or *Vision III*, critical scientific, technological, and environmental literacy. Hodson (2011) reduced it to *critical scientific literacy*, which implies a politicised scientific education that promotes critical thinking for dialogic emancipation and socio-ecojustice, emphasising transdisciplinarity and global sustainability-oriented praxis (Sjöström et al., 2018).

In this sense, we should see science education and its connection with teaching and learning outside the classroom not as a preparation for future life but as active participants in the community (Lee & Roth, 2002) that allows people to develop the capacity and commitment to take appropriate actions responsible and effective in social, economic, environmental, moral, and ethical matters (Hodson, 1999, 2003), based on an intellectual and personal autonomy (Hodson, 2011). We can see the different visions of scientific literacy as different orientations or theories of the science curriculum (Eilks et al., 2013). In this sense, teaching science from a vision of critical scientific literacy implies a challenge for public policy, training institutions of teachers, schools, and teachers in general, because it stresses the traditional teaching of science and necessarily invites us to reflect, rethink, and make decisions towards a critical vision of science education. Consequently, it is necessary to strengthen research, curriculum development, and continuous professional development of teachers from *Vision III* (Sjöström et al., 2018).

For Tate (2001) and Barton (2002), the science curriculum must incorporate civil rights and responsibilities within the framework of ideas of equity and social justice. This vision implies a more politicised, complex, sceptical, and reflective approach based on actual problems and topics connected with scientific, social, technological, and environmental dimensions (Hodson, 2011). Thus, this chapter takes from previous evidence some ways in which out-of-classroom contexts can provide an opportunity to develop a critical scientific literacy from critical theories approaches:

1. The out-of-classroom context might generate extended and original practical work and access to 'big' science and 'real data' (Glackin, 2019). Students and teachers affected by environmental conflicts should deliberate and find solutions to the problems from the real world through empirical data collection engaging with sustainability principles and values (Cohen et al., 2015). Moreover, participants build understanding and shape their values through collaboration with others, fostering deliberation about real problems and their potential solutions.
2. Different activities outside the classroom, such as field trips, hiking, camps, visits to natural reserves, can develop student's sensitivity to the environment through direct personal experiences and subjectivities (Braund and Reiss, 2005; Palmberg & Kuru, 2000), which might be the first step to promoting action skills and questions about the impact or links of macrostructures of power.
3. This approach offers the opportunity for students to develop their meanings during interactive field trip activities; therefore, evaluating his/her interdependence with the environment. Moreover, outdoor science promotes an empathetic relationship to nature, which is essential to start questioning about social and eco-justice and to promote social and environmental responsibility (Bartosh et al., 2010; Palmberg & Kuru, 2000).
4. Outdoor activities structured from a post-critical approach, can promote new relationships with nature developing a sense of interdependence between human and natural system and contribute to progress in environmental education research and the learning of science outside the classroom (Andrade da Silva et al., 2020).

7.2 Critical Theories in Teaching and Learning Outside the Classroom

This section presents three examples of how we can apply a critical and post-critical theory approach. The three examples below offer insights from chapter authors into how we can promote critical approaches using socio-environmental and contextualised conflicts and eco-routes beyond disciplinary boundaries, taking advantage of the opportunity offered by scenarios outside the classroom. The first example is presented by Lorena Rojas, Chilean chemistry teacher, and researcher in science education who developed research projects with their students from a critical perspective. The second example.

7.2.1 *Outdoor Science Education: Experiences from a Critical Theory Approach and Vision III of Scientific Literacy (Lorena)*

I (Lorena) aimed to design, implement, and evaluate an outside the classroom project in a remote context based on the identification of a socio-scientific problem within the framework of the thematic units of the course. The goals of the course were to strengthen the development of professional skills that allow pre-service teachers to promote critical scientific literacy and science for personal and social. This project aligned to the challenges of the twenty-first century and the promotion of social justice (Montané, 2015). In this sense, to achieve the purpose of the project, we used a didactic approach using project-based learning (Sanmarti & Márquez, 2017) and socio-scientific issues (Pérez & Bravo, 2018).

7.2.1.1 Methodology

We structured the course in the process of four articulated stages we describe in Table 7.1. The assessment plan incorporated different approaches following Förster (2018): (hetero-evaluation, co-evaluation, self-evaluation), different intentions (summative-formative), and diversity of situations/assessment instruments (report, poster, presentation/KPSI, rubric).

7.2.1.2 Example of a Project Developed by Pre-service Teachers

The results of each stage of the project are described below.

Stage 1: *Socio-Scientific Problem.* The expansion of forestry with pine and eucalyptus plantations in southern Chile impacts the balance of the territories' ecosystems and the communities that inhabit the intervened localities, predominantly indigenous communities such as *Mapuches* indigenous. They have lost access to their sacred spaces, sacred trees, and medicinal plants, essential for the development of their daily life and celebration of ceremonies and rituals such as *Ngillatuwesus*, profoundly affecting the relationship of the indigenous communities with the spiritual world (Hepp, 2015). Stage 2. *Design and Project objective*: Communicate from the indigenous perspective, inhabitants of the area and people interested in the matter, the loss of *Mapuche* traditions and natural resources because of the impact of pine and eucalyptus forests in the territory. Stage 3 and 4: *Description of Intervention:*

Table 7.1 Stages of the Innovation Project based on critical theories and critical scientific literacy

Stage 1-Research	Stage 2-Design	Stage 3-Implementation	Stage 4-Communication
Participants were preservice teachers/students who developed activities outside the classroom intending to identify a socio-scientific issue. Student groups investigate and provide evidence contextualising the problem to their territory and its population. They provide arguments of relevance and justification of the study	Students designed a project that considered objectives, rationale, description, and Gantt chart of activities. The focus was on the contribution to solving the identified socio-scientific issue	Students implemented the project in dialogue with people affected by the socio-scientific issue	Students prepared a poster of their projects to socialise the experiences in a closing seminar of the course

A poster (see Fig. 7.1) about the project and a YouTube channel with five audio-visual capsules of representative people who provide background information on the identified problem, based on their experience, voice, and knowledge:

- How is monoculture forestry affecting indigenous people (*Mapuches*)? Anthropology student, University of Chile.
- Testimony about the impact of monoculture forestry in the Maule Region. Member of the Ayllu Puka community of the *La Placeta* nature reserve, Maule Region in Chile.
- Testimony of the environmental and socio-cultural impact of forestry companies. Anthropology student at the University of Chile.
- A proposal to reduce the impact on the flora caused by forestry. Natural Resources Conservation Engineer.
- Monoculture and its impact on the environment. History teacher and activist of the Wetlands Collective of the Quilicura commune.

Pre-service teachers disseminated the products of the project in the social network with the group of students of their career (see Fig. 7.1). They used the number of subscribers to the channel and the visualisation of the audio-visual capsules as evaluation indicators.

Fig. 7.1 Example of a poster pre-service teachers designed, "Take care of our forests": destruction of ecosystems through monoculture and negative impacts on indigenous communities

7.2.1.3 Some Reflections and Final Thoughts About the Project Outside the Classroom

The socio-environmental impact of the forest industry causes irreparable loss of the native fauna and flora of the place and the lives of thousands of peoples in the surroundings of these large plantations, more specifically the *Mapuche* people. In this context, science cannot be indifferent. It can intercede in government decisions through scientific arguments, thus satisfying the real and existing needs fairly in the area. We believe that it is crucial to continue disseminating socio-environmental problems like this to raise awareness among pre-service teachers who will be future teachers. Furthermore, we need as many people as possible to begin a transformative change. In the case of this project, we should preserve *Mapuches*' culture, which has suffered so much with frivolous and lucrative government policies on ecosystems (pre-service teachers' reflections from the project).

Pre-service teachers designed, implemented, and evaluated a project identifying a real, local, contextualised socio-scientific problem from a critical approach. They connected the environmental dimension with political, social, and environmental implications, considering indigenous ontology. The development of the project promoted opinion and decision-making at a personal and social level from an interdisciplinary approach. Motivation, creativity, autonomy, and regulation of their learning were developed and developing knowledge, skills, and scientific attitudes from an approach situated and critical. However, one of the main difficulties identified as a teacher was the equitable distribution of tasks and monitoring of learning for each team member. On the other hand, the students indicated that the collaborative work and the teams' organisation were significant challenges.

It is expected that this activity with science pre-service teachers contributes as an application of critical theories, with evidence to strengthen the development of professional competencies to promote among students a critical scientific literacy.

7.2.2 Analysis of Critical Science Teaching Experiences Outside the Classroom of Teachers Participating in a Continuous Training Program from a Critical Perspective (Corina)

In 2015, the Chilean Ministry of Education started the Scientific Inquiry Program for Science Education (ICEC), currently the plan has been implemented in 16 regions of the country, with the collaboration of 14 universities. This program aims to improve the teaching and learning of science at the level of pre-basic, primary, and secondary education by promoting scientific inquiry as a didactic pedagogical approach to teaching science. ICEC involves a professional development model for educators and teachers organised into four main areas: (a) training in school scientific inquiry, (b) collaboration and exchange of experiences among peers, (c) linking with the environment, and (d) the development of pedagogical resources to support the implementation of scientific inquiry in the classroom (Hernández et al., 2020). From 2015 to date, the program has facilitated the specialisation of more than 1800 science educators nationwide belonging to urban and rural schools.

Recently, a Chilean scientific journal called *Electronic Journal of Innovation in Science Teaching* (REINNEC for its acronym in Spanish) published in two special issues the projects/experiences of coordinators and teachers who participate in this ICEC program. This journal includes a section called, "Science teachers in action", where, for these issues, teachers participating in the program related their pedagogical experiences. Among nine experiences reported in both issues, three dealt with science teaching experiences outside the classroom. My particular interest (Corina) was to analyse these journal articles experiences considering critical theories and the critical scientific literacy approach. To do this, I considered the following questions: (a) What elements of critical scientific literacy and critical theories do the stories present? (b) How do the stories contribute to a contextualised scientific education in Latin America considering our socio-environmental situation? Table 7.2, describes the work carried out by students and in-service teachers.

Concerning the elements of critical scientific literacy from vision III, the stories presented from the REINNEC, I can preliminarily point out that, in all three cases, education outside the classroom generates knowledge and appreciation of the local environment among students. Likewise, all three cases deal with scientific inquiry,

Table 7.2 Projects and experiences from the Scientific Inquiry Program for Science Education in Chile published in REINNEC

Title of project	Schools/Place or territory	What the author(s) did?	What was the aim of the project?	Who was participating?
Eco-Routes Laboratories	Technical High School and College Carlos Alessandri Altamirano de Algarrobo/coastal town/Valparaíso Region	Authors designed and implemented an educational Eco-route in a collaborative and interdisciplinary manner, which involved a 2.5-h journey along the coastline, from a natural park to a fishermen's cove	Connect students with the environmental, cultural, and historical dimensions of those places visited, knowing and recognising the flora, fauna, climatic characteristics, and environmental problems of the sector, to generate a link for students with their local territory, its treasures, natural conditions, their problems, and responsibilities that might be assumed to protect it	Five in-service teachers of Natural Sciences, History and Physical Education, and a group of students from 6th grade (primary level) and 1st grade (secondary level)
Knowledge and appreciation of the endemic flora of "Chilecito" and its surroundings	Chilecito School, rural town, interior valley, Coquimbo Region	Authors carried out an investigation among teachers and students to determine the level of knowledge and appreciation of the endemic flora by the community of "Chilecito School" and its surroundings, through tours to recognise the endemic flora, in addition to interviews with various community actors	Become aware of the importance of the community knowing and valuing the endemic flora to promote behaviours and habits of care and conservation, including the rejection of agricultural practices that destroy it	Students from 5 to 8th grade, a science teacher, the school psychologist, two agricultural engineers, and 20 people from the community with widespread or ancestral knowledge about medicinal plants

(continued)

Table 7.2 (continued)

Title of project	Schools/Place or territory	What the author(s) did?	What was the aim of the project?	Who was participating?
The magic of science	Colegio Renacer, Cerrillos, rural town, interior valley, Coquimbo Region	Authors designed and implemented a guide to address the exploration and knowledge of the environment by preschool children. This guide included outings to nearby places	Promote scientific inquiry skills in children, as well as knowledge of the local natural environment	Boys and girls of the prekindergarten and kindergarten levels of 3 schools and their teachers

promoting students' scientific thinking skills. In older students, I observed the promotion of a critical vision about observing the negative impact that human beings can generate on the environment, including economic activities, both agricultural and industrial. Regarding the elements of critical theories, we can point out that, all three journal articles promoted an affective bond with the environment and a sense of belonging and identity with the local environment. At the same time, the endemic flora experience integrated the knowledge of the local community and other extra-school actors and valued them as relevant to promoting attitudes of caring for the environment.

Analysing the three experiences from the journal gives us insight into where scientific education in Chile and Latin America should consider its environmental situation. Linking students from an early age with the environment in which they live through exploration and inquiry promotes an affective and empathetic connexion with the environment, promoting care attitudes in the long term. At the same time, the critical analysis of the intervention of the human being can help promote actions that resist extractive economic activities that do not consider the common good or the care of the natural environment.

7.2.3 *An Example of Teaching and Learning Science Outside the Classroom from Critical Theories (Gonzalo)*

Following critical theories, in my Ph.D. project, my rationale is to consider outdoors activities critically and connect a visit to a National Park with a local socio-environmental conflict. I am considering this conflict as a network of actants and as a *dispositif*, grounded on Actor-Network-Theory (ANT) (Latour, 2005). A *dispositif* is a complex network of discourses, scientific statements, regulatory definitions, architectural forms, administrative measures which emerges from interactions of power relations and relations of knowledge. To illustrate this idea and from ANT, I analyse how environmental conflicts are intertwined with business, political, financial and scientific discourses, and architectural forms with multiple interests of capitalist circles and markets.

I encourage using outdoor science activities to seek a deep understanding of relations between living and non-living entities or actors (actants) based on socio-environmental conflicts. Whiting ANT, an actant is considered something that acts, or which activity is granted by others. Thus, my specific aim is to understand the network of actants within a socio-environmental conflict to be used as a pedagogical tool for expanding eco-justice networks. In my project, I suggest applying critical theory to promote awareness of environmental responsibility and the development of environmental literacy among students (Aflalo et al., 2019; Palmberg & Kuru, 2000). Besides, my aim is to promote socio-political activism. I am of the opinion that outdoor science education might benefit from critical theories to promote social and eco-justice outside of the classroom (Reiss, 2003). In this, sense, to tackle conventional scientific literacy approaches — typically aligned with the status quo—I propose a community-based outdoor education approach as a contribution to expanding and strengthening networks within eco-justice *dispositifs*.

As an example, I am using a specific local socio-environmental conflict in Santiago called Alto Maipo hydroelectric power project (Alto Maipo, hereafter). Alto Maipo was developed by AES Andes S.A., formerly AES Gener SA, subsidiary of the second most extensive North American company in energy, AES Corp (Folchi & Godoy, 2016). Alto Maipo is currently under construction outside Santiago, it is being executed by STRABAG SpA Chile (Austrian-based technology company with nearly 5000 employees from over 20 nations). The hydroelectric project will start operating in 2022. In 2011, AES Gener and Aguas Andinas (the largest sanitary company in Chile) signed an agreement to divert the water destined for water supply concession of the city of Santiago to be used in the hydroelectric project. The project is intended to channel the water of the main river that supplies water to the capital city of Chile, Santiago of the main tributary streams of the Maipo into a system of tunnels, leaving a very minimal ecological volume of flow in the river, inadequate for life (Godoy, 2014). The associated infrastructure involves (among others): 2 run-of-the-river centrals; 73 (km) of abduction tunnels of 6–8 (m) in diameter. The system of tunnels passes below the Andes Mountains and below National Park "El Morado" where we developed a fieldtrip and the San Francisco Glacier. The hydroelectric project is affecting flora and fauna and potentially will affect the city water-supply. The project potentially can be connected with science curriculum during the fieldtrip.

I intend to include different voices from several institutions/communities, such as pre- and in-service teachers, members of indigenous communities, leaders of environmental activists, park rangers, and scientists. I framed the methodology on Community-Based Participatory Research (CBPR). CBPR approach is based on collaborative partnerships between researchers and practitioners aimed to contribute a more robust educational theory and practice (Penuel et al., 2015). This approach can also enhance the role of teachers as researchers and means to increase value of studies for both researchers and the community being studied (Viswanathan, 2004). Moreover, from the critical theories mentioned in previous sections in this chapter, associative partnerships aim to be based on empathy, inclusiveness, transformation, and reflexivity. In this case, CBPR aims to manage and support activities carried out outside the classroom, presenting a conceptualisation of scientific literacy towards social and eco-justice. CBPR is designed to ensure and establish structures for participation by communities affected by the issue being studied (Hacker, 2013). Finally, collaboration is further understood as necessary as a tool for addressing power imbalances to endorse ecojustice education (Sperling & Bencze, 2015). Therefore, CBPR can contribute to understanding different networks of actants or *dispositifs* and blur boundaries among researchers, teachers, scientists, academics, and activists with different backgrounds and trajectories.

Participants in outdoor science activities in local contexts may also view themselves as relevant actors in their communities, as a choice- and change-makers, and become part of growing discourses or networks pro-eco-justice. For instance, students and teachers affected by environmental conflicts in their communities should be allowed to deliberate and find solutions to problems engaging with sustainability principles and values (Cohen et al., 2015). In summary, we can apply critical theory considering socio-environmental conflicts as scenarios in outdoor science activities aiming at reflecting and developing senses of interdependence with nature, questioning macrostructures towards a more politized, complex vision of scientific literacy (Andrade da Silva et al., 2020).

Based on this alliance, and as Barton and Roth (2004) suggest, I propose understanding actors in science education as potential actants of a network of relationships and discourses that can promote a scientific and environmental literacies possible as a collective rather than individual (Roth & Barton, 2004, p. 51). Furthermore, in this approach, I agree with the authors that scientific literacies emerge from struggle between hegemonic and counterhegemonic *dispositifs* in real problems. In this sense, participation and dialogue with others are fundamental. Besides, this new network potentially offers opportunities to analyse roles of non-living and other living actants from different perspectives and expertise. This new actant can amplify voices and make calls for action.

7.3 Importance to Research

Regarding the visions of scientific literacy, it is essential to mention that teachers' training in institutions has focused on a disciplinary vision of science. In the case of Chile, it has been the curriculum in science education that promotes a Vision II, with science more connected to the daily life of students (Guerrero & Torres-Olave, 2021). However, as we see in the experiences illustrated in this chapter, much remains to be done to move towards a more critical vision of scientific and environmental literacy. Nevertheless, we have a good opportunity from out-of-school experiences to promote a *Vision III*.

All experiences shown in the chapter reflected, changed, and adapted our views of science education from critical/post-critical theories. Therefore, there is also an invitation for in-service teachers and researchers to address outdoor education, from a political understanding of teaching and learning outside the classroom towards a critical view based on social justice and action.

As a recommendation for other researchers and scholars, we suggest using critical theories in outdoor activities from a critical approach. We strongly recommend carrying out activities outside the classroom focusing on *Vision III* of critical scientific literacy. We can do it usually in any experience. For instance, considering that we are living in an environmental and ecological crisis, we suggest the Global Atlas of Environmental Justice, which shows conflicts and communities who are struggling to defend their land, air, water, forests and their livelihoods from damaging projects and extractive activities with heavy environmental and social impacts. In this atlas, you can find places affected by socio-environmental conflicts, and we can think about experiences to carry out with our students.

This approach implies rethinking our teaching and learning theories outside the classroom towards transformation. For instance, we could pose social and environmental problems into the history and nature of zoos, highly controversial institutions. We can visit museums to analyse the colonisation and distribution of wealth and its impact on indigenous communities and nature. We can develop eco-walks with students to analyse waste management, land conflicts, fossil fuels and climate justice/energy to question the impact of climate change and human beings (and specific groups) on nature. The invitation to readers is to re-reconsider our connection and interdependence with mother earth from a critical theory and an eco- and critical literacy approach and go outside with our students or colleagues.

Critical and post-critical theories in education come to challenge the traditional way of teaching and learning science. While they pose complex challenges in politicising teachers, approaches of this type are essential for future research endeavours, considering the current emergency context in which we are living. Critical theories attempt against individualistic approaches. They position themselves from a collective and pluralistic approach. They propose considering the different experiences of the subjects and respecting the realities and subjectivities of subjects empathetically. In this sense, experiences in activities outside the classroom are unique and non-transferable. Therefore, these approaches, from this vision, could connect with the everyday and collective realities the subjects share in their own contexts. Learning outside the classroom is a didactic tool that offers many opportunities to question and learn and act in the real world from a dialectic process. Critical theories offer reference frameworks and lenses to create, produce, and ontologically question a social reality in this sense.

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Part III
Identity Theory

Chapter 8
Playing to Become a Science Person: The Application of Play and Identity Theories in Two Out-of-School Settings

Phyllis Katz

8.1 Introduction

Since they are not compulsory, out-of-school science activities must have a certain magnetic quality. Children and/or adults must select these optional activities. *Play* is that magnet in that it provides pleasure or satisfaction as motivation. One science educator put it well: "Play and science are partners in research and invention. The fun and interest that come from playing around with phenomena can set positive attitudes toward future learning in all fields." (Jarrett, 1998, p. 181). Whether we imagine ourselves in a fantasy or follow the rules of a game, as young learners, we construct our identities within these play scenarios. "…the significance of play is vitally important at this time—play is a form of auto-didacticism in which children endeavor to understand and give meaning to their world and to themselves as actors in it." (Jarvis, 2006, p. 45). Reflexively, the identity we take on can determine the roles we play. (Varelas, 2012; Varelas et al., 2007). Teaching science through play presents opportunities for the players to think of themselves as "science people," an inclusive identity that gives us permission to participate, enjoy, and perhaps even contribute to science research and science teaching and learning.

I define science in its broadest term of *learning about how the world works*, especially for children, but effectively throughout our lives. In her teacher education text Howe wrote, "Science teaching should lead to a deeper understanding of relationships and interrelationships, of causes and effects, of how we as human beings know what we know and how we can find out more" (2002, p. 7). From a learning researcher's perspective, Jarvis wrote, "…the processes of learning are a fundamental stimulus for life itself …" (2006, p. 3). This biologic theory of learning suggests that learning is what we do continually in and out of school, throughout life. Vygotsky broadened our understanding of learning beyond an internal mental process to one

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that was dependent on social interactions (John-Steiner et al., 2010). Play behavior is present throughout our lives. We recognize it readily in children as they experiment with body and mind among peers and adults. As we age, play takes the form of physical or mental challenges and enlightenment with the pleasure in testing our skills (Ackerman, 1999).

Out-of-school learning, including science, happens most of our lives beyond school years. It is known by several acronyms: OST (Out-Of-School Time), ISE (Informal Science Education), CSL (Continual Science Learning), and sometimes Lifelong Learning. I prefer CSL because it is positive, science specific, and has more importance in my mind than "informal." CSL educators provide play opportunities to attract their audiences. Whether national park trails, programs to search for signs of geologic or life patterns, or science centers where you observe, crank, or animate, or games and challenges in afterschool programs, or everyday activities at home, the attractor is the promise of pleasure or the fun that play provides. What CSL does is create opportunities to see new connections to play, to pace oneself, to get excited by interactivity, and to identify (see ourselves and be seen) as participants in the everyday science community. The task of CSL educators is to package these opportunities to attract participants and to welcome those participants into the realm of STEM (Science, Technology, Engineering and Math) with its pleasures, mysteries, challenges, and practices (Bell et al., 2009).

Play and identity theories have been connected for a long time, although the terminology varies. It is impossible to separate play from identity as we play with ideas and/or materials and/or others and must position ourselves to engage. The theoretical backgrounds of play and identity development thus undergird CSL learning. For those of us who design and implement CSL, these theories are crucial to the planning and engagement in out-of-school science education, in which we spend most of our professional lives. Two key publications by the National Academy of Science in the U.S. made this difference more visible by the basic strands each outlined (Bell et al, 2009; National Research Council, 2007). The latter, *Learning Science in Informal Environments* (2009), contributes to the science learning strands or goals, just those elements of excitement and identity development that happen as we engage in playful non-school learning.

Learning, as an adaptive human characteristic, receives nurture in different environments and happens regardless of setting (Tal & Dierking, 2014). I see play and identity theories woven together in the examples I present. In these two examples, I deeply and consciously was involved in creating environments that excite, stimulate conversation, present challenges, and invite participation in science exploration. In many places, my colleagues continue to do the same, growing pleasure, awareness, and confidence in many facets of science as a useful tool, providing settings to expand experiences in personally meaningful ways.

8.2 Application in the Literature

8.2.1 Historical

What do we mean by "play?" What do we mean by "identity?" The concepts of play and identity are so basic to human life that philosophers, historians, psychologists, biologists, and educators have studied and written about them for a long time. While the emphases differ, there are common elements in the descriptions.

The Greek words for play (*paidia*), child (*pais*) and education (*paideia*) have the same root. Plato (428 BCE-348 BCE) wrote in his dialogues that the Socratic method itself was a form of play between a teacher and student. For Plato, play was a way to become a learner/philosopher/citizen. This western-philosophy origin tells us the goal of children's play was an incipient form of learning through play as a first step to becoming a recognized identity (citizen) within Greek society (Hunnicutt, 1990). Play theorists have proposed play is a child's way of learning and as humans age play becomes less of a mechanism or necessity. For an equally long time, other thinkers proposed that human play never stops because it is necessary in many forms throughout our lives (Brown, 2009; Forencich, 2003; Sutton-Smith, 1997).

Huizinga, a cultural historian, described play as process and emotion:

> It [play] is an activity which proceeds within certain limits of time and space, in a visible order, according to rules freely accepted, and outside the sphere of necessity or material utility. The play-mode is one of rapture and enthusiasm, and is sacred or festive in accordance with the occasion. A feeling of exaltation and tension accompanies the action. (Huizinga, 1955, p. 132)

In her studies among children and their play, Paley provides a generalized example that brings to life Huizanga's general definition:

> Their first task [children at play], she observed, was the business of deciding who to be and who the others must be and what the environment is to look like and when it is time to change the scene. Then there was the even bigger problem of getting others to listen to you and *your* point of view while keeping the integrity of the make-believe, the commitment of the other players, and perhaps the loyalty of a best friend. (Paley, 2004, p. 2)

Play is most recognizable when young children engage. In addition, Paley notes the direct connection between play and identity. She observed children to be auditioning different roles. She described children's play as their "work," declaring it was, in fact, a necessary activity, blurring the work/play concept of Huizinga's definition above that play is outside of necessity or material utility. I resolve this in my own mind by considering the concepts of ultimate and proximate causation in biology. With the publication of Darwin's *Origin of the Species* in 1859, thinking about education also became the realm of biology. Darwin proposed evolution continually selects for successful traits. Karl Groos (1861–1946) reasoned that youth or childhood exists because of the necessity to play. He proposed the young do not play because they are young, but rather youth allows time for play to happen, turning previous considerations of play on their head. E.O. Wilson, the father of sociobiology, described play (and identity) behaviors as adaptive activities common not just to humans, but to all higher vertebrates and some birds. Animal observations yield data that these social animals play as a form of practice and positioning within the social group. Play, "may even stem from the same emotional processes that impel our highest impulses toward scientific, literary, and artistic creation" (Wilson, 1975, p. 167). Wilson's connection resonates for me in my studies of science education. Ultimate biological utility describes how successful traits lead to the survival of species. Work has ultimate utility in that it serves the needs of physical survival directly or indirectly (salary) providing for nourishment and protection with a set of genes surviving over millions of years. Play has proximate utility because it allows for experimentally trying out adaptable behaviors at a given time and place. I view "play" as activities that provide us with pleasing challenge, choice, and practice. If you test an airplane for safety as your job, it is work. If you fold paper airplanes to test out the fastest shapes, it is play. If you are fortunate enough to consider your work mostly enjoyable, the line blurs. Richard Feynman (1985), a famous physicist, wrote that he saw his work as play—perhaps an approach that is key to science learning at any age. This suggests that who, what, and how we play, questions that help define our identities as well, are bound tightly together with the concept of play.

In addition to the need play fills for practice, some have written that play provides a means to relieve stress in daily physical and mental activities (Forencich, 2003). Play allows our bodies and brains to take a break. Research shows that such breaks result in more productive, healthful activity afterwards (Trudeau & Shephard, 2008). During the No Child Left Behind educational policy act in the U.S., several states eliminated recess, stating they could not meet proposed standards without usurping the "non-work" minutes of programmed play. This approach did not work.

8.2.2 Contemporary Applications

Recent research confirms play and identity are bound together. Culture also clearly determines opportunities. A review of children's play and culture, focusing mostly on non-western settings scant in earlier literature, found play remains universal among children, although opportunities and parental attitudes vary among cultures. Parents in some cultures consider play frivolous, while parents in other cultures encourage creative play (Holmes, 2013). Holmes found technology encourages more indoor than outdoor play. A study in South African rural communities discovered as environments change, formerly accessible forest and river areas become less available to girls because of politically evolved dangers in the area, whereas boys have more freedom (Alexander et al., 2015). Girls could explore limited areas near their homes, but well-meaning protection limited their play within outdoor environmental science settings, introducing clear gender bias to opportunities. A comparative study of three out-of-school learning programs in Canada yielded these observations:

> Learning was about being able to contribute to the practice, contributions that were respected yet also expected. Learning entailed embodied science, a science that emerged from doing, social interaction and negotiation, and that was stretched across the artifacts of the practice. Engagement in science led to opportunities to take on the role of agents of science. (Rahm, 2010, p. 302)

In a recent three-year study of free choice play among preschoolers in England, researchers observed young children in many kinds of activities, such as sand play, water play, cooking, construction, ball games, and measurement. Researchers observed the children's choices and questions they wanted to answer with assistance of their adults. Researchers found children's choices and inquiries provided foundational experience in science learning (Tunnicliffe & Gkouskou, 2020).

Culture enables and limits what we can do. Learning always happens within cultures, be they family cultures, tribal cultures, or national cultures. From birth, we begin to imitate the humans around us (Meltzoff & Marshall, 2018). Adults individually and within groups provide opportunities to mimic and learn. Conversations that include "What if?", "How did you come to think about that?", "How could we…?" encourage children to use prior experience and creativity to consider how their world works. Adults guide and apprentice children, not only by the situations and materials they provide, but also by their emotional reactions (Rogoff, 1990).

Since the late 1950s, the science education reform movement has sought to understand and implement changes that encourage children to study science and adults to remain curious and supportive. Those who have studied and reported on children's science learning recognize the intersection of play and identity development in their activity descriptions even when they use alternate terminology. Lazar Goldberg, an early proponent of science play and group work, provides numerous examples of how children learn through experience with materials and how they stimulate each other through problems/questions that arise (Goldberg, 1970). Later authors describe one child, for example, played with pendulum paintbrushes. While figuring out why the brushes were not making the marks she wanted, she made material choices and experimented. "The lessons she learned here went beyond learning about pendulum arcs and have a lot to do with her perception of herself as an independent problem solver" (Chaille & Britain, 1991, p. 8). Fleer described the teacher, teacher aide, and student interactions of elementary students. Although she did not perceive that she witnessed science concept formation, Fleer found good examples of materials manipulation and group work (Fleer, 2009). Some recent researchers focused on culture as a determinant of how and with whom children can play as limits to both the activity and social identity (Alexander et al., 2015). I see a progression here from establishing play as acceptable, to accumulating examples of play and identity development, to considering the adult roles and impact in detail, and, more recently, to exploration of cultural affordances and limits in a more global view of human relationship and the place of science education.

I revisited earlier landmark policy publications in science education to look for references to play and found little. It made me wonder if this omission stems from science's similarity to play and the desire to distance science research from play to establish the field as one we should take seriously. I suggest we have accepted play as children's activity for millennia and therefore we associate play with childcare and women. Men dominated professional science and science education as these modern disciplines developed. Perhaps, by separating out the play component, these earlier male scientists were communicating a desire to be taken seriously in a way they did not believe playing with variables could be taken at the time.

8.3 CSL in Two Contexts Beyond Schooling

In this chapter, I offer two examples of how play and identity development theories guide my work in CSL. I chose these two settings as examples because they illustrate how play and identity development coincide in very different places within my CSL experience. In the first, I describe a chemistry series from a team I led that developed an afterschool program we designed to engage children from preschool through elementary school (in four different age-grade groupings). In the other, I tell a story of how I use my skills in my own family to encourage a playful approach to science learning within everyday home activities.

These examples offer common placed-based, non-required science learning opportunities (community and family) in which playful activities are employed with an experiential science education purpose. In both cases, the players have the opportunity to learn from each other. The younger participants have opportunities to learn to see and feel themselves as active participants in science endeavors relevant to their young lives. The adults learn to respond to children's interests and to engage in science with everyday activities and materials. These illustrate ways that learning, in these cases, science learning, are accumulating from different CSL sources. The adults come to these activities with a positive attitude that encourages the children to mimic enjoyment as well as the manipulative experience itself.

In the first, with a team of creative people, I developed the Montgomery County [Maryland] Council of PTAs county-wide afterschool Hands On Science Program (MCCPTA-EPI HOS). The U.S. National Science Foundation (NSF) awarded funding to the program to explore adapting it to wider distribution. Within several years, under its national non-profit organization, Hands On Science Outreach (HOSO), the afterschool science programs were available around the U.S. HOSO provided activity guides, materials kits, and adult training. We designed the structure to distribute equitable quality. We designed the content to allow situated flexibility.

The second example is a personal one. As a grandmother, I bring my science education learning/teaching to my grandchildren. Here, I describe how I interact with one granddaughter to encourage her to feel capable and confident as a young female explorer—an everyday scientist.

In the summary/discussion, I consider underlying needs play and identity development fill. Convinced that CSL is about offering opportunities, I created two columns. One illustrates play opportunities and the other identity development opportunities. I do this to demonstrate the presence of both in a given episode. I draw the qualities of informal science learning/play from Bell et al. (2009). The identity descriptors are from Carlone and Johnson's model for identity's three components: performance, competence, and recognition (2007).

8.3.1 Play and Identity Development Intertwine

8.3.1.1 Play and Science Identity Development in an Afterschool Science Program

In the afterschool program whose development I led, our team knew we had to attract families with both play and learning components. Parents were eager for educational enrichment and children, enrolled after a day at school, looked forward to playing. We provided all materials for the activities in leader boxes, enough for each child to engage in each activity. The materials then went home with the children to encourage further exploration through playing within the family setting, explanation to family, and, when appropriate, pride in display, evidencing a science "performer" identity within the family. A three-year rotation of topics allowed children to participate from Pre-K through 6th grade without any repetition. Activities were selected with these qualities in mind:

- Play potential to engage the participants in embodied learning physically and intellectually, seeing themselves as science participants (identity)
- Science potential to safely explore phenomena and patterns within their groups
- Flexibility to consider local relevance and cultural adaptations

For these examples of the application of play and identity theories, I created a table (Table 8.1) that illustrates the planning that went into the HOSO program to provide opportunities to be part of the cumulative support in science education. The Chemistry series example below illustrates one class from each of the four age/grade levels. For ease of reading, although they blend and often concur, one column provides the play activity opportunities and the other column the identity development opportunities.

Each session began with the Adult Leader eliciting the children's previous experiences with the day's explorations. This was one way the children built identities as participants, but also helped the Adult Leader to gain insights into how to connect science with prior knowledge. All children did all activities. We limited groups to 11 children, who took home materials for explanation, reuse, and displaying competence to their families. Leaders used appropriate scientific vocabulary, increasing children's exposure to greater ways to express themselves.

8.3.1.2 Play and Science Identity Development at Home

At home, my husband and I invited our granddaughter, Toby (pseudonym, age 5 1/2), to help us put together a furniture table kit.

Table 8.1 HOSO program planning

Pre-K (4 years old): WATER CHEMICAL MAGIC Session 6: Mixing and Separating Colors Prior knowledge question: What do you remember about mixing two different colors when you were coloring or painting?	
Play Opportunities (Engagement, excitement, challenge, pleasure)	Science Identity Development Opportunities (Performance, Competence, Recognition)
1. Poem to sing or say: Mix and pour; mix and pour Some are less and some are more Fill the spoon; try the cup Drop by drop they do add up Measure this, make it right Hold it up and check in the light I'll be careful. Look at me I'll begin my chemistry 2. Liquid color mixing (diluting or almost disappearing) 3. Make a toy: filter paper butterfly 4. Separate food colors with filter paper	1. Poem draws attention to child's performance and pride in "doing chemistry" 2. Use of a "big" word: chromatography and experiencing the meaning to explain to the rest of the family (recognition) 3. Personal use of pipette and filter paper as science tools to demonstrate at home (performance and competence)
K-1(5–6 years old) CHEMISTRY DETECTIVES Session 6: "Little Miss Muffet" Question: What are some uses for glue?	
Play Opportunities	Science Identity Development Opportunities
1. *Linguistic pleasure*: poem: "Little Miss Muffet" 2. *Textural pleasure*: Messing about with dry milk powder, warm water, and vinegar to form curds and whey 3. *Intellectual pleasure*: More changes to create a glue 4. *Textural pleasure/intellectual pleasure:* Messing around and comparing school glue with homemade glue 5. Making a paper spider that requires glue 6. Play at new rhymes about a Miss Muffet who is not afraid of spiders	1. Measuring ingredients (competence) 2. Observing and describing changes using sight, smell, and touch (performance) 3. Describing properties (performance and recognition) 4. Vocabulary development: curd (performance) 5. Glue making and spider discussion to share with family (competence and recognition)
2–3 (7–8 years old): CHEMISTRY CREATIONS Session 2: "Paper Capers" Question: What do you think might be going on in your stomach if you feel sick from eating too much pizza?	
Play Opportunities	Science Identity Development Opportunities
1. Paper absorption race 2. Color separation prediction and comparisons with each other 3. Making designs, using separation properties 4. Word find game (absorb, chromatography, separate, water)	1. Measuring and standardizing (competence) 2. Predicting and testing (performance) 3. When might you need to know which kinds of things get wet quickest? (New knowledge and relevance to child's life and competence) (Recognition)

(continued)

Table 8.1 (continued)

4–6 (9–11 years old): YOUR OWN MINI-LAB Session 8: Funny Putty Question: How does chemistry help us have fun?	
Play Opportunities	Science Identity Development Opportunities
1. Making a play putty 2. Playing with putty and its properties	1. Figuring out a workable formula (performance and competence) 2. Comparing properties (stretch, bounce, cleavage) (performance) 3. What would you name it? (Recognition for creativity)

Play Opportunities (Engagement, excitement, challenge, pleasure)	Science Identity Development Opportunities (Performance, Competence, Recognition)
Adventure pleasure: We asked Toby if she would like to help assemble a table kit. She is enthusiastic. First, we open the packaging, then she discovers the instructions. The instructions are in images, not words, to accommodate any country/language It is a good match for a non-reader	Recognition—We invite Toby to see herself as part of a family-building team

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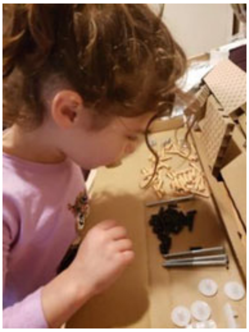
Decoding: Toby grabs the assembly booklet and asks, "What does this mean?", when she sees the first illustrations of one person with a big "X" and the next with two people. I ask her what the difference is between the two images. She says one has one person and the other two. "What can that mean?" I ask. Quickly, she asserts that the project should be done by more than one person. She is happy to belong I ask her how the faces look. She says "happy." I said she should keep that in mind as we go along	 By asking Toby to interpret the images, I encourage her to feel capable of doing so—competence and recognition
Showing power: We open the 2 boxes, and she starts to move pieces around, finding the bag of pegs, screws, and other small hardware. I ask her to sort (classify) and count (number practice) the pieces. "Why are there two kinds of screws?" she wants to know. "Wait and see," I suggest. (delayed satisfaction)	 I provide confidence in her ability to sort and count accurately By suggesting she wait to see why there are two kinds of screws, I express confidence in her ability to answer her own question

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Challenge: The first assembly is the table's gate legs. The instructions require two pegs hammered into two pre-drilled holes. Toby immediately grabs the hammer and says, "I can do that." She lines up two pegs. Where will they go? We locate their positions, and she realizes they must be straight to match the holes into which the other sides of the pegs must fit. She adjusts the angles and works to make the pegs straight on. The other side of the wooden connecting piece also has two holes but is more difficult because the piece already has two pegs and cannot rest on a flat surface to hammer in the pegs on its opposite side. Toby sees this and notes it, but perseveres, consulting the illustrations	Toby's assertion that she can tackle the assembly step is unchallenged. She thinks of herself as capable, and we will let her try

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Testing and Showing knowledge: We are not sure why the kit producer chose to pre-insert some hardware and not other pieces, but the gate legs for the folding table already are assembled. Following the illustrations, Toby positions the pieces in the same orientation as the images, finds the metal connecting bars and the appropriate screws. "You need two kinds of screwdrivers", she announces. "A flat head and a Phillips." She already knows about these two kinds of tools. She finds the right one and begins to screw on a metal connecting bar, positioning her arms to get the greatest torque. The holes require more pressure than she can apply, so grandma and grandpa pitch in	 We trust Toby to choose the correct tools and she trusts us to assist in a task she admits she cannot handle We support Toby as we assist her identity as a young child with physical limits, supported by the adults around her

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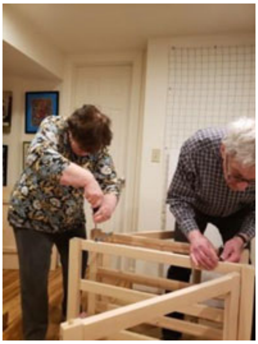
Play with technology. Toby takes the cell phone camera and succeeds in taking photos of her grandparents, holding the camera still and snapping a series (technology)	 Comptence, recognition Mastery: Toby can hold the phone steady enough to take a clear photograph
Physical challenge: The next instruction calls for us to screw small wooden pieces into the tabletop. First, we must lay out the cardboard box to protect the top against the flooring (and vice versa)	 Toby performs the tasks, exhibits competence in the team, and receives recognition for each accomplishment. She positions the box and wooden top sections on the cardboard, selects the wooden pieces and screws, and begins to attach these pieces

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Accomplishment: Next is the application of the hinges to the wooden sections. She takes one hinge set and lines it up with the pre-drilled holes and begins to position the screws in one 4-screw section. "It works better if you screw the four in part way and then get them all the way in," she observes. Carpentry lesson learned	Performance, Competence, Recognition She and grandpa work in parallel to move the project along, while I take photos  The screwing is slow, the holes not well drilled. Grandpa finds his mechanical screwdriver, which has a much longer handle. Toby observes. "Why is that easier?" "What do you think?" I ask. "Well, it's bigger." "Is Grandpa turning the screwdriver in the same way?" "No, he is pressing down and the screwdriver is turning itself." "Is it easier to press down or twist your hand?" "Easier to press, because it's easier to push with your whole body instead of just your hand." "Good observation," I add. (Building vocabulary, supporting confidence.) Big smile from Toby

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Wondering, humor, recalling: Toby finds two Allen wrenches and asks what these are for. We tell her these turn special pieces of hardware. "And," she notes, "You can save them and use them again." "Yes," we say, "We have a collection of these wrenches because the kit producer includes them with its kits, when needed." She laughs. "Why are they called Allen wrenches?" she wants to know. "We don't know," we say (Adults do not know everything.). I quip, "Maybe they should be called Toby wrenches?" She answers, "Maybe the people who named them had a kid named Allen?" Well, maybe. We could look it up (research). I remind her the loose refrigerator handle upstairs has a special tiny Allen wrench to tighten it. She remembers that (experience, recall, connection)	 Toby performs as a participant and a recycler She shows competence in tool use and language development She receives recognition for her inquisitiveness and ingenuity

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<table>
<tr><td>Challenge, prior knowledge
"What's this?" she asks, holding a tubular metal piece with a flat screw head and a threaded hole. I recognize a specialized kit attachment piece that secures a screw head that comes in at the perpendicular. "You will see later, when we use it." (delayed gratification)</td><td></td></tr>
<tr><td colspan="2">Grandpa says his hand hurts from applying pressure on the screwdrivers and we should wait awhile before continuing. Grandpa is getting grumpy. Grandma is getting grumpy from the not-quite-right drilled holes. I ask Toby if the illustrations show characters getting grumpy from frustration. She flashes a smile and says, "No." Is he smiling, as in the first instruction image? Not right now</td></tr>
<tr><td colspan="2">Toby wants to have a snack and play pickup sticks, a new favorite game. She would like to finish the table, but we grandparents need to rest. Energy abounds. She already understands grandparents do not have quite so much</td></tr>
</table>

8.4 Importance to Research: The Essential Role of Continual Science Learning in Expanding Possibilities Beyond Schooling

8.4.1 Learning Science: Making a Choice

Choices are voices that express values. In the first example presented in this paper, parents make a decision to enroll their children for afterschool activities focused on science. In some cases, they make the added commitment to take the training and lead a group. They may dedicate money, but they certainly commit a child's time and some of their own, if only in arranging logistics. In the second example, in my home, I invited my granddaughter to expand and reinforce her engineering skills in furniture kit building. Any home has many opportunities during daily activities such as cooking, cleaning, organizing, or walking in the neighborhood, to talk about measurement, comparisons, and evidence. These opportunities are choices that families can make, that tell their children that learning science is valuable to their families.

8.4.2 Learning Science: Intergenerational, Trustful, Flexible

In the chapter examples there is evidence for how two CSL settings presented socially different opportunities for adults to encourage children to enjoy learning science. That there is this rich intergenerational social interchange around playful science learning opportunities is one part of continual science learning. In one case, adults choose to play with children under the heading of science and happily guide them. The home setting reflects a home culture, choices and values. Home is where many children learn to trust their adults. Theory proposes that trust is essential to learning (Fisler & Firestone, 2006; Avraamidou & Katz, 2019). Play behavior is place to learn what builds trust. It may reduce conflict and can allow for thinking flexibly as situations change, forwarding adaptability. Nelson suggests that perhaps the very existence of a long childhood allows time to develop culture through imitation and play (Nielsen, 2012). Biologists generally agree that play among the young is an intensive period of learning without the serious consequences of adult life-death decisions. We play to recognize phenomena and patterns under the heading of science in my examples and we play to audition possible social roles as we develop our identities. The children in the afterschool program were "chemists" for an hour a week and my granddaughter was a female engineer.

8.4.3 Science Learning Within a Cultural Context; Imitating and Preparing

In this chapter, there is evidence of children imitating the adults around them. Adults provide models of how to use materials and allow physical, mental, and emotional space to vary within safe boundaries for themselves and others. Culture is the way we transmit a group's response to their environment. In these science experiences, the existence/participation of afterschool science programs or the grandparent-grandchild relationship are culturally encouraged. The afterschool program itself or the communities that requested it, found ways to make it financially feasible for those to whom fees could be an obstacle. In this example, science was recognized as valuable enrichment not only by related people, but by community groups. Learning and liking science has been positioned in the U.S. not only as a way for individuals to think critically throughout life, but also as a way to prepare for gainful work in the service of the United States culture. In the history of science education reform, the report, *A Nation at Risk,* called for schools and educators beyond schools to engage more of the population to protect the U.S. as a leader among nations (National Commission on Excellence in Education, 1983).

Early play experiences, such as those described in this chapter lay a foundation of attitudes and experience that can lead to lifelong curiosity and a sense of identity as one who can investigate. In the U.S. we often contrast play with work, with the latter being what children *must* learn to prepare for their adult lives in the context of a given society, or what adults *must* do to survive directly or indirectly to obtain their needs (Huizinga, 1955). However, we find that our need to be resilient and responsive to unforeseen changes in our physical or social environment during our lifetimes presents a continued need for play (testing, evaluating, creating) throughout our lives. We have devised many games and toys to hone our abilities to strategize, to practice physical agility, or to invent new mechanisms during both childhood and adulthood. These require science approaches to assess, evaluate, and create. Parents and their communities recognize this in valuing science enrichment when participating in afterschool science enrichment. There are different kinds of play as well as different kinds of pleasure or satisfaction. For children, the delight of their new world presents many surprises that produce adrenalin and learning. Watching (or making) colors change in chromatography is exciting, as is making edible cheese from milk in the afterschool chemistry program. For adults, the pleasures of play may derive from mastery or personal challenges (Ackerman, 1999). If we have learned to find our pleasures in science, it is likely a result of cumulative positive experiences (Tal & Dierking, 2014). These are supported by a culture of encouragement.

Professional scientists have cast their occupations at the intersection of play and work. They do what they do to make a living (it is therefore *work*), but they see exploration and experimentation as adult *play* where there is space to explore or experiment and have fun/pleasure. What is a laboratory if not a well-outfitted play space? What is everyday science, if not a chance to play with our physical or social environments as practice? My time together with a young granddaughter to assemble a table is meaningful, fun, and instructive as she grows within our family culture to feel capable of exploring, solving challenges, using tools, and feeling the pleasure of playing with the table kit as a real "toy," advancing from Legos or wooden train pieces.

8.4.4 Continual Science Learning Intertwines Play and Identity Development Theories as Adaptive Strategies

The two examples in this chapter focus on play and science identity theories as enacted between adults and children. That we play and have dynamic identities describes us as human beings. Play and identity development theories are bound together in their social settings and in learning about how the world works (science). Science "play" gives us tools and processes to learn adaptive strategies. The more experience we have with alternative solutions, the more likely we are to be prepared for what may happen in our lifetimes—thus more adaptive. We study out-of-school science education, as in *Cascading Influences* (McCreedy & Dierking, 2013) or in *Learning Science in Informal Environments* (Bell et al., 2009). Compulsory education attempts to provide basic literacy and skills to the greatest number of growing minds to run a democratic society. CSL enriches people's lives with increased opportunities around and beyond school years. What those of us who work in, and study continual science learning are providing, and investigating are play and identity building *opportunities* beyond schooling to increase learning potential throughout life. The examples in this chapter are two instances of evidence about how we prepare and enact a broader range of experiences than are possible in school buildings with class sizes. We often refer to these experiences as "place-based" as a way to describe the settings of the museums, science centers, parks, outdoor exhibits, planetariums, aquariums, playgrounds, and, yes, homes, where out-of-school learning can be built in. These opportunities are not required or bounded in ways necessary to schooling. But such learning is necessary throughout life. How the next generations view the balance of schooling and "beyond schooling" is changing. Learning opportunities outside of schooling can—and should—receive better support (Rogoff et al., 2016). To survive, we must learn when and how to continually adapt to a changing world.

As I considered play and identity development theories in CSL, I came to see them as inseparable. Experimenting with our identities is one part of playing as we try to solve problems in safe, non-threatening environments. My earlier research showed evidence that both parents and teachers who participated as adult leaders in the HOSO afterschool program brought the program's techniques home to their children (Katz, 2015). This led me to understand that this kind of supported adult learning can benefit the next generation through introducing positive attitudes to adults, some of whose prior experiences with science education were negative.

The illustration below shows the overlap of science play and identity development as I have come to see it (Fig. 8.1). In this chapter, I have provided examples of science play and science identity development as they occurred in both a designed science learning opportunity and a supportive home setting. I realized that play and identity development had these qualities in common.

I am an advocate for professional Continual Science Learning or informal science education because it is the longest and most pervasive form of science education,

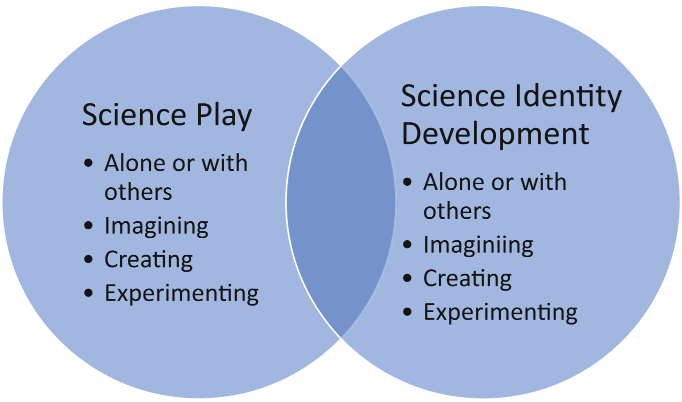

Fig. 8.1 Common qualities of science play and Science Identity Development

playful and useful throughout our lives. As the world evolves, we must prepare to adapt along with it, both individually and as members of society. Play has pleasure and pleasure is an enabling mechanism. We repeat what we enjoy (Forencich, 2003; Sapolsky, 2017). I engage in doing and studying CSL because it is a pleasure to pass on information, techniques, and tools that help people understand ways to lead full lives and themselves help the next generation. Teaching and learning science as adaptive skills and information is thus, to me both essential and a pleasure.

8.5 Summary: The Biology of Science Learning Helps to Explain the Theoretical Overlap

Choosing to learn science has an emotional component. Emotions are our sensors triggering action choices in the simplest of life's activities (Boyd, 2012). Both concepts of play and identity stand upon a physiological base that motivates us to live and be ready for life's adventures. Both play—playfulness—and identity development have roots in emotions. We play for practice, for challenge, for learning, and always for some form of pleasure. Play may be inquisitive, competitive, or imaginative, but always there is satisfaction or "fun." Identity provides a sense of security in our place among others. We are social creatures. We need to know how we belong in each of the settings in which we live to assist in action decisions. We have multiple identities. We belong to families. We belong to affinity groups, to assigned groups, to those into which we are born (Gee, 2001). Learning science is determined by how we sense our capacity and pleasure.

Play is a key mechanism for establishing identity in many settings. We play in science to understand phenomena and patterns. We play within our social world, alone for the moment or among our family, team, or other group, identifying participants. CSL provides experiences that strengthen a sense of capacity as it welcomes those who show up to its expanded opportunities. If we accept that play gives us opportunities for developing flexibility in our survival skills, then we can view the science learning opportunities of out-of-school places as those for expanding our ways of surviving. In that sense, they are essential. But play is optional because of the way in which we have organized society. We have designated the time we perform our jobs or careers as "work." These activities provide us with income to have the food, shelter, and clothing basic to our needs. What we do in science education "places," beyond schools, including our homes, is teach the pleasure in playing with materials and ideas and the identity to do so. We can revisit the familiar or invent, providing flexibility that serves our adaptability. Play is necessary in the long run, but optional in each instance. Parents and teachers who pass on the sense of pleasure in science learning help us live more adaptable lives. Schools fill a need to pass on accumulated learning. Thus, we may perceive schools as work or play. Beyond schooling, we must flex to learn what has not yet made it into the canon or what comes along later in life.

As we continue to research the field of CSL, I suggest we promote the connection even more between the pleasure or "fun" elements of our work and learning science. We have honed this approach because we have needed to attract our audiences. As we combine efforts with schooling, as suggested, for example by *Connected Science Learning*, an online National Science Teachers Association journal (https://www.nsta.org/connected-science-learning), it would be helpful to answer more questions about how classroom teachers can make required curriculum more playful. Many teachers do not have fond memories of their own classroom science learning. What CSL techniques and resources can we share?

What more can we learn about what constitutes pleasure in different cultures? What is it possible to share? How do teachers from different cultures learn to understand and apply the cultural pleasures of those unlike themselves in engaging with science concepts? How do different forms of play impact the science-identity development of children from differing cultures? How do we better reach families, where many attitudes towards science form, and invite them to share the pleasures of science exploration as we know it? How do we encourage more families from cultures foreign to us to share their science knowledge and perspectives with us? We have issues of equity to explore further. Who can take advantage of CSL experiences? For my part, I would like to see advantaged families better understand the importance of a "science for all" goal inherent in our interdependency for survival. Diversity of experience and thought lead to a richness of possibilities or alternative solutions to our life challenges. How do our out-of-school science education developers do their part in that? How could they do more? What measures would we use?

I am finishing this chapter in the middle of 2021. A worldwide pandemic has tested our ability to adapt. Not everyone can access a science center, museum, zoo, aquarium, national park, or other CSL-rich venue. However, the world is replete with opportunities every day. Those of us who create programming and research out-of-school science education have an imperative to make it possible for a much broader group of people to gain the benefits of play and CSL identity. We must reach more families, which create attitudes from birth. We must put even more energy into using our skills and talents to design and deliver places and programs accessible to a worldwide population. We must all play in our differing roles to survive as inhabitants of the planet earth.

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Chapter 9
A Mobile Theory of Learning and Identity in and Through Relations of Dignity: A Research Framing for Research Outside the Classroom

Jrène Rahm, Laurent Fahrni, and Ferdous Touioui

9.1 Introduction

9.1.1 Vignette: A Walking Visit of the Botanical Garden

It was freezing cold outside but a beautiful sunny day that we spent in the greenhouses of the Botanical Garden in Montreal, admiring the tropical plants and smells that came with it. At the time, I was running a Saturday Science Club in a community organization serving primarily immigrant youth and their families, offering homework help and opportunities for multiple language speakers to practice French, the official language of Quebec and its school system. We had given cameras to the youth and encouraged them to take pictures of things they liked or stood out for them. We were trying to accumulate some visual footage to then be integrated into their video documentaries on a topic of science of interest to them. None of the youth had ever visited the Botanical Garden before and we ended up being rushed in time as we had lingered too long in the section exhibiting different tropical fruit trees. Ken, one of the participating youth, has a long history of academic struggles. He came to the club together with Alishia, his cousin, and Gonzalo, an old-timer in the club. They met in a pull-out program during elementary school given their shared academic struggles. Ken and Alishia are both from Jamaica and speak primarily English at home, while Gonzalo is from the Philippines and speaks some Tagalog with his mother

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and primarily English at home. All of them speak French in school only. We moved quickly through the greenhouse where the cacti are housed. Ken switched his phone to video mode and tried to capture the astonishing sizes of the cacti and their multiple forms that stood out and left us all in awe. He continuously stopped in awe, pointing ‘look at this’, ‘so cool’, or ‘look at all the cactus, wow’, ‘agh’, ‘oh’.

9.1.2 Interpretation of Vignette

That navigation of an informal science venue with a group of youth who was new to that setting stayed with me. The plants and sensing of the tropic climate in the greenhouse brought forth memories of Ken’s home country, Jamaica. That sensing also immediately repositioned Ken in the moment as a knowledgeable youth who could easily name different plants from his home country that were on display. Touching them and smelling them invoked many emotions and memories, some that were kept silent and others that were shared through mumbles of astonishment. Ken confided later that he deeply missed his home and culture, where he felt understood. Looking back at it, the vignette offers a rich depiction of learning and becoming *in* movement. In doing so, it expands the space–time lens, in that the deeply embodied meaning making that is happening throughout that navigation takes us beyond that space and time. Ken struggled in school academically and often talked of returning to Jamaica. When walking through the garden, Ken shared his feelings and frustrations that constituted his becoming, which we understand as entangled with his history of being uprooted and far from home, “I miss this so much and just look forward to going back home.” That comment makes evident the entangled nature of his identity work in the moment with his history in person. The vignette also underlines the need to understand learning and identity in movement as a relational process where the physical place for learning constitutes and is a component of learning and the learning ecosystem (Tuck & McKenzie, 2015). As a consequence, a relational unit of analysis could be envisioned as the interaction and entanglement of youth, educators, and the more than human-nature, understood holistically, and as “working together iteratively and reciprocally to support the co-construction of interest and identity development” (Hecht & Nelson, 2021, p. 3). It implies a decentering of the human in research, focusing on deep connections with more than-human elements in place and practices. Those elements are understood as key actors constitutive of learning and identity development in movement.

Taking a relational view of learning and becoming in movement also resists the objectification of learners and educators and implies instead attentiveness to human interrelationships. A relational grounding calls for the enactment of radical love as invoked by Freiré and further developed by Kincheloe in his work with teachers and students (Agnello, 2016). It calls for the recognition of possibilities and transformations that uplift students and flatten power differentials that too often undermine the thriving of students positioned at the margin. That framing is well aligned with Espinoza et al. (2020) definition of educational dignity which they refer to as “the multifaceted sense of a person's value generated via meaningful participation in substantive intra- and inter- personal learning experiences that recognize and cultivate one's mind, humanity, and potential" (p. 19). In line with sociocultural theory and its relational stance, dignity is not a property of an individual, but instead, continuously affirmed and remade in action through social interaction and fueled by affective stances that are dignity affirming and embody a sense of care and well-being of and for each other (Keifert et al., 2021). In light of the vignette and Ken's history in person, it becomes evident that formal education was experienced by him as dehumanizing, positioning him as a student who struggled academically and whose strengths went unnoticed. In contrast, our walk through the Botanical Garden was a moment of centering possibility (Warren, 2021). It was a humanizing and empowering moment of learning and becoming in movement that was uplifting, building on Ken's expertise which was understood as an asset to new meaning making and future becoming as a person.

In this chapter, we make the case for a conceptual framing of future research on learning and becoming in science in light of these three key notions: (1) learning and becoming in movement, (2) a relational reading of learning and becoming in movement, implying more-than-human interaction, and (3) dignity, understood as continuously in the making through social interactions that go beyond the human, implying also the material. We show what an analysis of dignity affirming learning and becoming in science in movement might imply. We do so through the sharing of two additional vignettes, with the aim to push the field forward, towards a more critical and nuanced reading of the potential contribution of informal science education to learning and becoming in science, resulting in a nuanced understanding of learning lives. The three vignettes imply learners who are positioned quite differently in terms of race, gender, and socioeconomic status. We make the case for the urgent need to bring an intersectional lens to studies of informal science education.

9.2 A Brief Synopsis of the Current Literature on Learning Outside the Classroom

Learning outside the classroom is often understood through a container view of learning which resulted in a focus on what it is not, when compared to formal learning, typically associated with structured settings like schools. Yet, we argue that the latter might be best referred to as education, which we distinguish from learning which happens wherever children, youth, and adults spend time. In that sense, we agree with Rogoff et al. (2016), who call for attention to *how* learning happens, rather than where, while they also outline some shared features that unifies learning outside of the classroom: "It is nondidactic; is embedded in meaningful activity; builds on the learner's initiative, interest, or choice (rather than resulting from external demands or requirements); and does not involve assessment external to the activity" (p. 358). When asking who is involved in informal learning, Rogoff et al. (2016) point to multiple formulations from learning among children, between children and adults, in families and communities. In all instances, skills, life ways, and philosophies are passed on through attentive observation, pitching-in, and joint-engagement in cultural practices.

Our own work has been mostly committed to the study of learning in designed programs and community organizations—in both instances, programs that enrich learning and identity work of children and youth not well served by the formal educational system or attending schools in underserved communities lacking resources and manpower to offer rich and stimulating curricula. Our work has also been driven by an interest in understanding "how, when and why" children and youth seek out such opportunities for learning (Barron, 2006, p. 194). We have been inspired by Barron's work on learning ecologies, implying the study of learning across settings where children and youth spend time, like "home, school, community, work and neighborhoods" (p. 195).

We also assume that learning is entangled with identity work or the becoming of a certain kind of person (i.e., how one sees oneself as a learner or in relation to a subject matter; Holland et al., 1998). We are interested in the study of learning and identity as processes driven by future possible selves or becoming, emergent from different forms of engagement over time, in activities that are either created by learners or sought out by them. As such, we position learners as agentive and creative actors of their learning and identity work which has to be understood as life-deep, happing within programs over time, yet also life-wide and across settings, as learners navigate the educational landscapes accessible to them. The latter hints at the need for an intersectional lens in that such navigations are always marked by power and politics, and imply attention to their underlying social, racial, gendered, economic and political conditions (Nasir & McKinney De Royston, 2013).

Barron (2006) also suggests that we must attend to "multidimensional relationships between learning activities across contexts when they are taken up as a result of interest" (p. 201). Hence, we became interested in the accrual of navigations among practices at the crossroads of formal and informal science, attending to mobility. In doing so, we became interested in documenting how "moment-to-moment interactions related to, and could be made to relate to, broader contexts in which they could become consequential for learners" (Jurrow & Shea, 2015, p. 288). That lens led us away from simply imagining learning ecologies or designing for effective learning and becoming within such systems. Instead, inspired by Leander and Hollett's (2017) critique of studies that focus solely on connecting the dots of activities and representational reading of lifelong learning, our focus changed, from "learning across settings" to "learners crossing settings" (p. 1). That led us to attend to embodied experiences of space–time.

Building further on these ideas in this chapter, we propose the study of learning and identity not as resulting from movement, but instead, as happening *in* movement, a key distinction we see as essential to understand lifelong learning in science and learning lives. We assume that moments of learning and becoming drive new ones, lead to transformations and emergence of still qualitatively new ways of doing, being and becoming in science. Katz (2017) refers to it as continual science learning. As shown in the vignette at the beginning, Ken's meaning making was charged with emotions and marked by living and learning that "are complex and cumulative" (Katz, 2017, p. 23). It was not about place or location which has come to define so much of the literature on informal science learning. Instead, and as Katz (2017) reminds us, the field of informal science education has much to offer in terms of revisiting and re-envisioning learning and becoming in and through science. What this implies, we explore through two case studies of informal science learning and in doing so, propose a vision of lifelong learning and becoming that is generative, transformational, and charged with emotions while being entangled with place but not contained by it. We do so by proposing a mobile theory of learning and becoming.

That grounding pushes the discourse on informal science learning towards a fluid stance to learning environments and place, making possible a new way to talk about how dwelling in place brings alive stories of the past, present and future. An interest in the fluidity of lives and in what the learning and making of lives implies opens up studies to heterogeneity at many levels. On the one hand, it makes possible a move beyond "disciplinary coloniality" which is essential to move science education, and science, teachnology, engineering and mathematics education or STEM, toward "equity, social justice, and polysemia" (Takeuchi et al., 2020, p. 219).

That stance also implies a deep commitment to attend to the cultural heterogeneity of the learners. In doing so, it moves discourses on informal science beyond a "colorblind and assimilationist" reading, that has deeply grounded the field in ideologies of historical and systemic violence of learners from non-dominant groups. We show how such a stance opens up our eyes to the complexity, multidimensionality of lives deeply colored by politics, racism and as such, entangled in complex systems and marked by multiple layers of contradictions. Yet, such contradictions become laminates of learning and becoming and can also be read as generative of things that could be, as the opening vignette makes evident. Most important, we propose that to understand learning and identity in movement, we need to not focus on pathways of individuals but instead, focus in on moments of dwelling and then explore such moments through a space–time reading and movement. We take for granted that learning and becoming is a lifelong and nonlinear process, and is about movement which brings stories from the past, present and future together through "knotting" and "meshworking"—key concepts proposed by Ingold (2011) that we return to in the discussion.

9.3 Mobile Theory of Learning and Identity in Action

We now offer two other illustrations of what a mobility lens can make evident about learning and identity, drawn from our own research outside the classroom. We draw upon ethnographic studies of programs and activities, juxtaposing multiple data sources such as video data, fieldnotes, journal notes, artifacts, interview data, and dialogue from focus groups. The two examples in this section come from a five-year partnership from 2016 onward, with a community organization *"ruelle de l'avenir"*

(RA), that offers in-school enrichment activities as well as afterschool family activities during the academic school year, next to summer programming for children, youth, and families from underserved communities. We think of RA as a learning ecology in that most children we met initially participated in an in-school enrichment activity and then moved on to either afterschool or summer family or youth programming, broadly touching the following subjects: chess, movie making, youth radio, cooking, gardening, biodiversity, robotics, language arts, and geography, gardening and entrepreneurship.

The first example relies on data from a video ethnography of the family cooking afterschool program (offered after school hours, or on Saturday (morning and afternoon), during academic school year). The video data made possible the study of embodied ways of learning and becoming in interaction with objects and bodies, marked by different space–time scales (Goodwin & Cekaite, 2018). We rely on interaction analysis (Jordan & Henderson, 1995) that the co-authors of this paper pursued together, leading to telling moments of learning and becoming in movement, marked by dignity—the "thing" in the words of Marcus (1998)—that we followed over time, across activities and programs. Telling moments were then shared in team sessions and transformed into narratives, implying a bricolage of the multiple data sources (Kincheloe & Berry, 2004), embodying key moments in action, with special attention to bi-directionality in child–adult interactions, agency, and forms of affective engagement (Espinoza et al., 2020; Goodwin & Cekaite, 2018).

The second example takes a somewhat different stance, given its focus on specific participants' forms of engagement over time. Our interest in expanding the space–time scale resulted in the collection of longitudinal data of a subset of youth participants who we met in a maker project also assumed by RA. Through ongoing analysis, those data sources (e.g., observations in situ, interviews, timelines) were then transformed into rich stories and visualizations of learning pathways (Barron et al., 2014), two of which we present here in somewhat different ways from one another. The two examples offer insights into qualitative studies of learning and becoming understood as an on-going process, achieved through interaction among bodies, embodied actions, assemblages of bodies, objects, next to expressed and shared affect, all of which we understand as marked by spatial affordances. Throughout, pseudonyms are used for all subjects.

9.3.1 Example 1. Navigating Worlds—Family Cooking Afterschool Activity

Mobility was a design feature of the cooking activity. Its designer, Marcela, the trained nutritionist in charge, wanted to step away from a focus on nutrition and create an activity that would entice families' curiosity by engaging them with other cultures' cooking practices and imaginary travel. To illustrate, we focus in on key moments, organized around emergent themes from our joint-analysis of the practice.

Fig. 9.1 Illustration of objects serving as imaginary geographical explorations of culinary practices and diverse geographies

9.3.1.1 Culinary Travel

Each cooking activity began with a short introduction, inviting all parent–child dyads to sit together in a circle in front of a window decorated with objects and images associated with the chosen country of the day (e.g., Mole Pablano in light of Mexico, the dessert mocchi in relation to Japan, and the desert Cheese-Kalitsounia Kritis in relation to Greece, Misir Wat when traveling to Ethiopia, and Chocolate Pizza Brigadeiro when imagining travel to Brazil). Marcela always started the session with a whole group introduction that implied a suitcase from which the children could retrieve objects, images, and art, aligned with the country they would then travel to virtually that day, through cooking, accompanied by authentic music from that country in the background. The children were asked to retrieve an object from the suitcase and guess what country it made them think of (see Fig. 9.1). It was an activity that brought the families together, but also a moment for parents and their children to affectively connect with each other after a busy day at school and work. Some children and family members also shared stories in light of their own travel to the country they explored together.

9.3.1.2 Hidden Creative Moments of Engagement with Science

Mobility as a design feature manifested itself also in the manner science was entangled with the cooking activities, supporting mobility among disciplines and practices. For instance, when making the Cheese-Kalitsounia Kritis from Greece, Marcela first modeled how to make ricotta cheese by mixing lemon juice with milk once the latter has been heated up to a specific temperature, a rather tricky task, that led to mixed results in terms of the consistency of the produced cheese. Once the parent–child dyads worked on their own ricotta cheese, Marcela circulated, noting, "excellent, its coagulating, it's like a scientific experiment that we are doing, it's real science!" Note the use of the scientific term coagulating, purposefully evoked by Marcela. Marcela also aimed to offer simple two to three step visual recipe descriptions, easy for dyads to follow. In this case, the steps are summarized in Fig. 9.2 on the left, while the illustrations on the right make evident the steps involved in making the paste and its transformation into the desired shape of the cookie. The latter was adapted by one family, however.

The father of Vincent, Fernando, is from El Salvador, Central America, a history in person that sneaked up on that dyad as they created their Cheese-Kalitsounia Kritis. Instead of copying the model that Marcela provided ahead of time (see Fig. 9.2, right), their pastry took on the form of an empanada, a common shaping practice of pastries in Latin America and certainly well-known by Fernando, given his history-in-person. While few creations and adaptations were observed first-hand, Marcela strongly believed in the creative potential inherent to cooking.

Fig. 9.2 Example of recipe

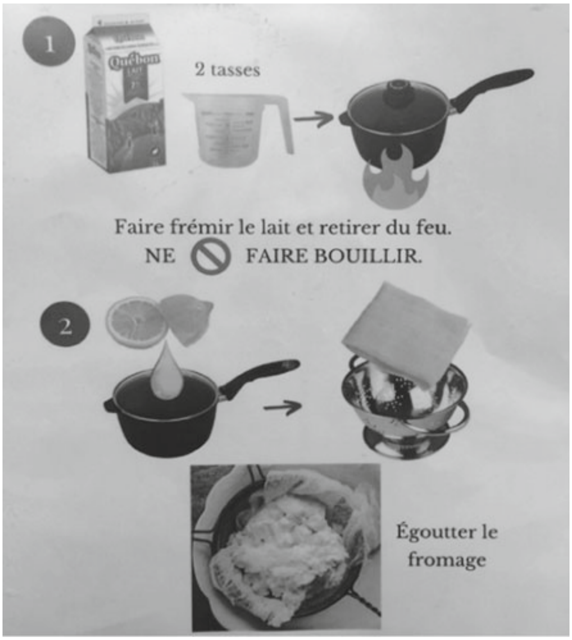
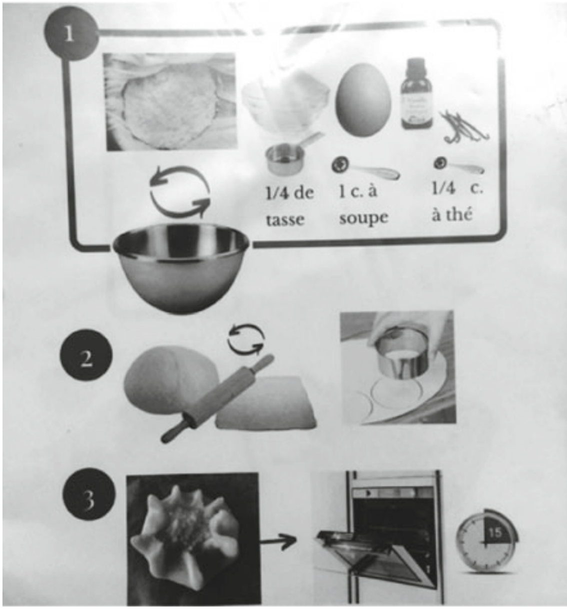


Fig. 9.2 (continued)



9.3.1.3 Enactment of Affective Stances Supportive of Dignity

Parent–child interactions also make evident different forms of care, resulting in a wide range of forms of dignity that are enacted in practice. In general, it was amusing to observe the manner Marcela continuously put parents at ease by commenting here and there, helping them see the strengths of their children. Marcela believed strongly that some parents took over the difficult tasks, not giving their own children a chance to even try. Some parents also did a lot of cleaning while others took over the cooking. Yet still others stood out, given the genuine guidance they offered their children. Those children also manipulated the objects and shared affectively charged positive moments with their parents. Figure 9.3 offers two quite different manifestations of it. On the left, we see affect entangled with and emergent from a social interaction and as such, implying a bidirectional flow of care (Goodwin & Cekaite, 2018). In contrast, in another father-son dyad on the right, we see a form of grooming which embodies care and love by the father for his son, which is well received. We would contend that in both cases, these joint-actions help the children grow and actualize themselves, yet in different ways. Acts of this nature were rather common among some parent–child dyads, supporting the experience of dignity within this activity.

Another father-son dyad stood out, as we observed a similar object-body configuration as above on the left. In passing, we also like to note that the father above only participated once, as he usually accompanied his daughter to another activity within the same building, also organized by RA. Some parents took turns participating which Marcela accepted.

Fig. 9.3 Embodied cooking and dignity

As shown in Fig. 9.4 on the left below, Nelson draws Eric's attention to the recipe by pointing to the measurements that Eric got mixed up. Previously, he measured a fourth of a cup of flour for the pizza dough. Now, it asked again for a fourth of something, yet Eric was too quick and did not notice that the unit of the measurement had changed to a teaspoon. We see in the image the father pointing to the recipe so Eric could see and notice what was wrong. In the image on the right, we see the father adding the last ingredient to the dough and then asking Eric to mix it with his hands:

> "I'm not eager to mix it up, it's your turn to mix it up". The father (Nelson) responds: "No, no, you were the one who wanted to do a cooking class. This is a cooking class for children, it is not an adult cooking class!"

The latter was said with humor, making it an incident of teasing rather than disciplining in ways that would have undermined feelings of dignity. Eventually, Nelson took over, which then supported a moment of play by Eric with the transparent pastry rolling pin. Eric turned it in all directions, looking through it multiple times, varying distance to objects he observed through the pin, which of course led to fascinating visual distortions. While experimenting, his father kept busy kneading the pizza dough. The cooking activities were purposefully designed in ways to ensure the positioning of children as "agentic co-creators" (Keifert et al., 2021, p. 2), yet

Fig. 9.4 Guiding child in cooking task (left); asking child to take over (right)

Fig. 9.5 Joint-cooking of pancakes

in some dyads, parents still manipulated the objects while the children looked on. The manner objects and bodies were entangled offered us rich insights into the pedagogical value of the interactions, but also how an ethic of care was entangled in such joint-work. Returning to the same father-son dyad as they are about to cook a pancake, we note another fleeting moment of congruent alignment among the father-son dyad, ending with a display of intimacy, as depicted in the sequence of joint-actions in Fig. 9.5.

On the left, Eric carefully transfers the pancake mix with a soup spoon into the frying pan. In the middle, we note a change in the positioning of his body and emotional traces of pride in his face, followed by a shared gaze between the father and the son, which we understood as a bidirectional instance of care and affirmation of joint-achievement and pride. The latter can be read as a form of corporeal intersubjectivity and embodied act of care (Goodwin & Cekaite, 2018).

9.3.1.4 The Role of Spatial Affordance in Subject-Object Interactions

The spatial layout of the kitchen makes evident material arrangements supportive of engagement in and through dignity. For instance, the height of the cooking islands is adapted to the height of children (e.g., availability of a step that makes counter and cooking islands accessible to younger children in secure ways; see Fig. 9.6). In addition, plastic labels on all cabinets oriented the dyads to material content. The cooking tools provided were real, inviting all children to use knives in all shapes and sizes. Children were also invited to work on the gas range, under supervision of the parents. Many families appreciated the opportunity to have access to such a wonderful kitchen space that was inviting, for both adults and children. It is in this manner (material availability), that dignity was further conveyed and affirmed within the program.

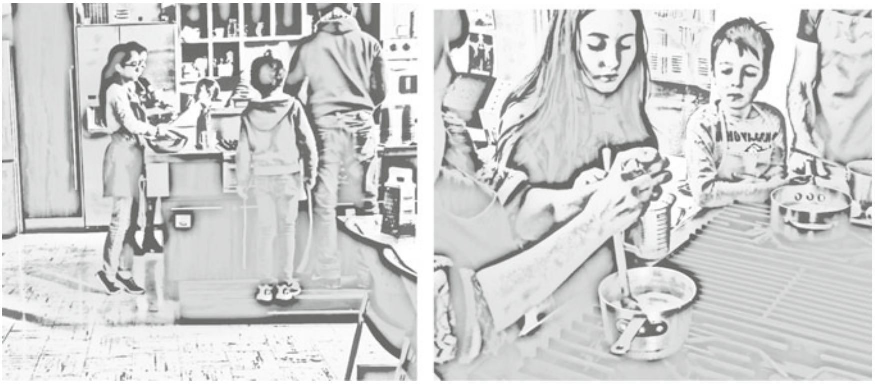


Fig. 9.6 Note the foot step on one side of the gas stove (left) which supports joint-engagement in cooking (right)

9.3.1.5 How Moments in the Program Are Entangled with Ideologies of Parenting

The different data points make evident in what ways a lens on learning and becoming in movement offers a means to understand the local interactions as embedded in a rich web of relations of trails, in the words of Ingold (2011), that constitute learning lives. Those trails make up a meshwork that is unique to each family, yet it also has to be situated in larger ideologies of parenting. Past research has shown that parents play a significant role in the organization of their children's out-of-school time and that such socialization practices are heavily marked by socioeconomic status, race, gender, and culture (Heath, 2010). For instance, Lareau (2002) suggests that working class families rely more heavily on their children to seek out participation in structured afterschool activities while for higher income families, the parents typically take on that organizing role. Through interviews we learned that the dyads we touched on in this paper were for the most part heavily involved in out-of-school structured activities during the week while they spent their weekends in their cottages, pursuing some structured sports activities next to relaxing as a family. It is a form of organizing that is often referred to as hyper-parenting and marked by the neoliberal tainted educational system that pushes for an intensified focus on a market driven form of schooling, with the illusion that high academic success can only be achieved through a portfolio of children's lives steeped in a rich and diverse set of complementary educational activities (Lessard, 2020). That emphasis on individual's accrual of opportunities has colored the field of structured afterschool and out-of-school education, pushing forward the design of essentially market driven learning ecologies (Heath, 2010; Lee, 2017). While couched in terms of making learning accessible to all, it reinforces an ideology of a market driven educational system.

Interviews of parents and children literally confirmed that they were working on developing a rich curriculum vita that would serve them in their future. Understood in light of this market driven era of education and valorization of hyper-parenting, we contend that the cooking activity became a space–time to escape, at least for a moment, that fast-paced life, and experience shared moments of dignity supportive of a shared sense of well-being, creativity, and agency. Take for instance Eric's family who affirmed that their week is extremely busy between long work-hours, sports, grocery shopping and seeing their friends, while weekends are reserved for family time in their cottage. Nelson, Eric's father, described their weekly activities as taking on the form of single-parenting, emphasizing that the couple spends little time together. For this reason, they also took turns participating in the cooking activity, yet ended up referring to it as "a privileged moment" or 'a darling moment' when we do an activity for him, and with him, it was so interesting!" Both parents highly valued it. Yet, the mother affirmed that she typically is too directive and has to force herself to slow down and guide Eric's development of his own autonomy. She figured it had to do with the fact that all household related activities like cooking at home, had to go fast, as there was never enough time and because of it, there was no room to include Eric within it, a deeply ingrained disposition she carried to the cooking activity and that then marked her interactions with Eric. In contrast, Marc took the time to guide Eric and enjoyed their joint-engagement, as shown above. What we aim to highlight here is the manner trails of learning and becoming are also entangled with macro-level political structures and ideologies that constitute learning lives and mark educational practices. While the families we followed in this chapter did not represent the kinds of families the program aims to serve, analysis suggests that a relational view of learning and identity made evident the practice of care the cooking activity supported and that is part of "doing family" in the words of Goodwin and Cekaite (2018). In light of their study of embodied family choreography, they suggest that it "renders visible specific practices through which social dimensions such as responsibility and trust, bodily integrity, moral accountability, intimacy, and care in families may be assembled, experienced, and negotiated" (p. 258). We suggest that the cooking activity offers a window into family practices and the unique contribution of an afterschool program in "desettling" ingrained ideologies in the case of the middle and upper-class families we described. The program and activity structure Marcela envisioned and reinforced in practice brought back a focus on creativity, agency, and well-being in and through learning that an individual focused market and merit driven educational system steeped in neoliberal ideals aims to crush. As such, participation was experienced as valuable and empowering for the families we described. At the same time, it is clear that the program was primarily committed to families with different histories, whose children had access to few structured activities in the non-school hours. But since they solicited participation through schools they had partnered with in the past, which have become more heterogenous in terms of the families they serve and income level, their afterschool family activities fell at the margin of the families the program targets for at times. It was clearly the case during this study, but not systematically so, as other activities we documented reached well the students and families RA intended to serve.

9.4 Example 2. Youths' Learning Pathways

To focus on and make evident embodied temporalities of forms of learning and identity while pushing back on representationalism (Leander & Hollett, 2017), we did focus on telling moments in the first part of this chapter. Yet, "longitudinal trajectories of materials and resources" (Ingold, 2011, p. 14) can serve as yet another methodological pivot to do so. To offer an illustration, we focus on two youth we met in a high-school enrichment activity, organized by RA, inspired by the maker movement, implying the coding and making of an ecologically sound house. A video-ethnography of that 20-week long activity was conducted in the academic school year of 2017–2018, an activity that implied a partnership with a first-year science high school teacher in a public high school offering the International Baccalaureate Program, serving an ethnically diverse student body who is academically strong and selected through an entrance exam. We focus on two youth, Saashi and Alexi, through data points that follow materials and resources entangled with their lives over time. As such, we follow the wayfaring and "rhythms of embodied learning" (Leander & Hollett, 2017) rather than the endpoints of such movement, as we are committed to a vision of learning and identity as a lifelong never-ending and dynamic process.

9.4.1 Case Study 1: Saashi

Saashi was three-years old when she moved to Montreal from Dhaka, Bangladesh with her parents. Her parents decided to come to Canada to pursue further education and to offer their daughter access to a solid education. Her father was a Professor of Physics, Chemistry and Mathematics back home, while her mother had a degree in Sociology. Her father discovered serious kidney malfunctioning once in Canada and never managed to hold a job, receiving a kidney transplantation in 1997, once Saashi was in high school. Her mother took up work in a bank, once in Canada. Saashi herself also struggled with health issues and eventually found herself with a busted appendix, after having been sent home from the emergency. The struggle to find work, as well as the struggle to get medical help are entangled with well-documented racism many immigrants of color experience upon relocation. At the same time, Saashi is a high achieving student highly interested in science and receiving much coaching from her father on any STEM topic. As such, she has access to crucial science capital at home. At the time of the interview in 2019, Saashi really wanted to learn more about programming as she was interested in computer science but also likes "science and maybe economy" she hesitantly added. At the same time, she claimed not to be particularly good at coding, an activity she engaged in with two other girls and that led to their ecological house with three wired LED lights. Figure 9.7 offers a summary of her learning pathway.

Saashi's case study makes evident the manner mobility constitutes her learning and becoming. On the one hand, she strongly identifies with her history as a girl of

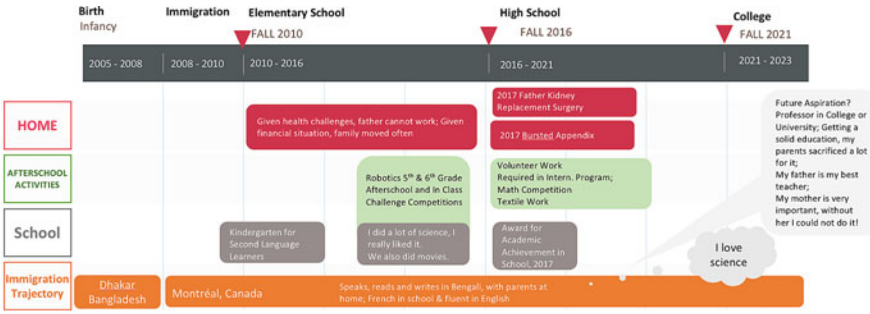


Fig. 9.7 Saashi's learning pathway

color and Muslim from Bangladesh. She has stayed very connected with her larger family back home through social media and through her own cultural practices at home that she valued and shared with her parents, as also shown by the maintenance of her native language. She is a proud speaker of multiple languages, but also proud to do well academically, and all this despite health challenges her family and herself experienced. Her deep engagement and persistence in academic tasks became evident as she worked diligently with her peers, resolving problems with their code.

A relational reading of her learning pathway makes evident the material and human resources that are accessible to her and entangled with her academic work. At the same time, the tight affinity with her parents, teacher, but also peers in the coding project were dignity affirming and agentive in that they supported her ongoing forms of engagement despite the racism her parents experienced, whose educational credentials from elsewhere held no currency locally, leaving them unemployed and in a financially fragile state. That led to many relocations and lack of stability in their housing situation. Despite those challenges, Saashi worked hard and believed in future mobility in the complex learning ecology she now had access to. She did not see it as a burden to perform well academically, but instead, as something she wanted to commit to, given all the support her parents had given her. The case study shows in what ways the immigration project brought the three family members together, with all of them believing in new and empowering possible futures, in and beyond science.

9.4.2 Case Study 2: Alexi

Alexi who was 12 years old at the time of study moved with her parents from Romania to Canada eleven years ago. What stood out in her case is the manner her learning and becoming was entangled in complex ways with local macro-level language policies. Quebec is a designated majority French speaking province with an English minority. As such, a language charter was put in place in 1979, to ensure all immigrant families send their children into the French school system. Yet, Alexi, like Saashi, was an allophone, speaking Romanian, English, and French—languages among which her whole family navigated daily, and a form of languaging that marked in important ways how Alexi described her educational trajectory and how she saw herself:

> When I came here, I was sent to a private English daycare but they taught us French there already too, as they knew that most of us would have to pursue our education in the French School System. When I started Kindergarten, I was totally bilingual, but I always talked Romanian with my parents, while I talked English with my sister who needed to get better at it and practice it, and then most around me was in English, TV, the news, films, and more. The majority here is English (maybe referring to Canada), but then there is also the French in Quebec. So if we talk of it globally, it's really English that is the majority and now, I consider myself 100% English, I think in English, I count in English, when I just discuss with somebody, I have to translate my thoughts.

Her strong identification with English and Romanian were further reinforced during her work in the coding project in the fall, as she worked with another girl with a similar immigration history. It supported ongoing dances among languages also in the classroom, even though school policy insists on the conduct of educational activities in French. Note for instance the following exchange. They could not get the LED lights to turn on and raised their hand to receive help from the facilitator Daniel, who then showed up and checked the code to ensure there was no mistake:

Alexi: Mi-e egal; ai zis ca toutl este OK
Nancy: I know we did not listen, oh well
Alexi: Are they gonna put this in google translate and put like translate
Daniel: Je ne comprends pas ou est le problème… [I do not understand where the problem is]
Alexi: Same!
Nancy: It isn't working!
Alexi: I'm genuinely confused, normally I'm good at this
Nancy: (Answers something in Rumanian)

They then played with the wires, reconnecting them in new ways:

Nancy: It's working!
Daniel: Le programme était bon, c'est…y'avait des ptites…c'est la LED… [The code was good, just small mistakes, it was the LED]
Alexi: Ici c'est juste parce que je suis genre je suis fatiguée [It's because I'm tired]
Nancy: la LED était inversée pis le *buzzer* aussi, mais c'est ptits problèmes de branchement, c'est pas grand-chose! [The LED was wrongly wired, and the buzzer too, just small problems connecting the pieces, no big deal]

There is a complex form of entanglement of the youth with languages, not only the spoken ones but also the language of coding (i.e., coding in language C in English). The dances among languages seemed to be affectively charged and supportive of an affinity among the two girls further fueled by a similar history in person. The exchange was also entangled with the material of the situation, the LED wires, Arduino plate, code, and also video camera close-by, that recorded the interaction, as their allusion to us researchers makes evident "are they gonna put this in google translate and

Fig. 9.8 Interaction among the team members

put like translate." That entanglement offers deep insights into the manner Alexi assumed her identity and languaging in practice.

Moving on in time in our analysis, we take a look at another entanglement we observed later in the school year. Alexi now worked with two other girls on the actual creation of the ecological house which they would then wire with LED lights and automatic doors that they coded in language C. Figure 9.8 shows Rose and Mila to the right of Alexi, who took over the measuring and imagining of cutting of the board pieces needed for the construction of the house, ignoring Alexi's suggestions. While Alexi initially tried to contribute, as made evident by her attempt to gain the floor by pointing, she was silenced, and retreated in frustration from the joint-work, as her head movement suggests.

Interview data confirms that Alexi did most of the coding in this project and enjoyed doing so, having been coached heavily by her father at home since elementary school years, as he is an accomplished programmer. That she could not put those skills to work was frustrating to her, as she explained, "we wanted to create a house with a code to open the door, which in the end never worked as we had just too many wires, and the code, technically it was flawless but in practice, given the wires, it worked one out of five times. I think in the end we managed to make it work." Note her reference to the fact that "it was technically flawless" which underlines that the problem was not the code, which she was in charge of, but the rest.

When asked about her future career aspirations during the interview, Alexi projected herself as pursuing a career in Aerospace Engineering. She continued, "I want to make spaceships" (in English, before continuing in French), "anything about space always fascinated me." Yet, her passion and expertise seemed to be continuously challenged by her peers, who purposefully positioned themselves as the experts, as shown next:

Rose: That's what I said!
Mila: Bravo, you were right (puts her hand on her shoulder)
Rose: Thanks, for once, I am the misunderstood one…
Mila: Yes, really, a misunderstood genius
Rose: Yes, right, that's it, since a while our engineer, like interviewing on TV and stuff, I told you Marie and Alex!
Mila: (laughing)
Alexi: If anyone of us here is gonna end up being an engineer I think I'm most likely to!
Rose: Oh, do not worry! But who knows, I suddenly may want to become an engineer too, who knows!

That kind of on-going teasing threatened Alexi's identity work as somebody who can do science and be recognized as a science person. It undermined interactions marked by dignity and can be read as a form of micro-aggression that many youth with histories of immigration experience daily in classrooms, and that might also be entangled further with the political struggle that marks Quebec's language policy.

The two cases offer deep insights into moments that mark embodied learning and identity work, understood as taking form over time yet also constituting learning pathways in ways that are not linear but imply movement forth and back in time. In both cases, the girls' learning and becoming is entangled with trails of family life, some having to do with histories of immigration, others having to do with language discontinuities, and still others with science and computing, all of which mark and constitute ongoing embodied learning and identity work of the two women in somewhat different ways. Neither of them seems to be recognized by their peers as a science person, yet both have big educational aspirations for the future. The positioning as a science person in the case of Alexi is conveyed through affect, bodily expressions and verbal expressions, embodied relations among ways of being and becoming next to emotions and interactions with materials the coding project implied. The latter also makes evident Alexi's ease with coding and the manipulation of materials, next to language, a fluidity that marks her life in unique ways and quite differently from her peers who seem to struggle to appropriate the task and tools in ways supportive of joint-success and respectful work relations among the members of the team, which as is, seem to seriously challenge dignity. Yet, they do get away with it. In contrast, Saashi invests heavily in portraying herself as academically strong and able, despite health challenges that made her miss out on some school time. She was also recognized for her perseverance and academic rigor through an award at the end of that school year, making evident treatment with dignity by the school. It is the entanglement of these elements that make for a meshwork that is distinct yet constitutive of each girls' learning and becoming in movement.

9.5 Importance to Research

In this chapter, we made the case for a mobile theory of learning and identity in science through relations of dignity which we understand as a valuable lens for future research of studies of learning outside the classroom given its emphasis on more-than-human interaction while also attending seriously to dignity and intersectionality. In doing so, we purposefully engage with the ethical and political of informal learning in and beyond science. Using that lens, we looked at a navigation of a greenhouse in a Botanical Garden, analyzed an afterschool cooking family activity, and looked at learning pathways of youth who participated in an enrichment activity within a high school implying coding and making, assumed by the same community organization as the cooking activity. Through these examples, the chapter makes evident the vast nature of informal science venues while it also aims to map out the contested terrain of it, building on equity issues in the field that have been raised by Philip and Azevedo (2017), among other scholars committed to equity and social justice driven science education (Calabrese Barton & Tan, 2020).

As shown through the opening vignette and analysis of moments in the family cooking activity next to the case studies and learning pathways of two youth, there is a vast diversity of meshworks which Ingold (2011) defines as "entangled lines of life, growth and movement" (p. 63) that constitute our lives. As Ingold suggests, "we thread our ways through this world" (p. 151), which we hope is evident in the data points shared. As shown, the walk through the greenhouse was a moment that offers deep insights into Ken's "web of life" (p. 63). We talked about his identity by attending to his history in person, his educational trail by explaining his academic struggles and positioning within formal education, yet we also described his learning and becoming in movement at the moment, in the greenhouse, deeply grounded in dignity and emergent from complex relations among bodies, plants, and worlds the objects and senses invoked.

Much research on informal learning and identity work has invoked a static view of the learner with a focus on products rather then processes of informal learning (learning gains, constructed and assumed identity positions). Still today, few studies attend to the manner learning and identity emerge from and are deeply embedded in complex relations among people, places, materials, and more then human worlds, marked also by dignity and politics. For this reason, we turned to wayfaring and a mobility lens as it offers a means to look at moments-in-the making and "interwoven and knotted strands" of life, as in the case of Saashi's and Alexi's learning pathways. Both youth are learning and becoming which is entangled in a web of multiple trails such as histories of immigration, histories of language struggles, and complex local language and immigration policies, but also academic achievement and future aspirations, all further marked by dignity or lack thereof. A mobile theory of learning and identity entangled with and attending to dignity and complex relations, makes visible many contradictions that mark lifelong learning of children, youth, and families, yet those contradictions also make visible new possibilities. For instance, Kevin's case study resonates with Warren's (2021) emphasis on challenging "Black folk's subordination to Eurocentric expectations for thinking, speaking, and being" (p. 21) and recenters possibility. As shown, it is essential to reposition children like Kevin but also Saashi and Alexi and focus on possibility instead of failure. The notion of rightful presence proposed by Calabrese Barton and Tan (2020) makes a similar point about erasure, and emphasizes the need to "make present the lives of those made missing by the systemic injustices inherent in schooling and the disciplines" (Calabrese Barton & Tan, 2020).

In contrast, the cooking activity makes evident a complex entanglement between ideologies of parenting and participation in afterschool activities that also mark the field and that need to be unpacked if we are serious about educational equity and the need to center positive emotions and dignity in education. The moments we analyzed showcase how a non-representational reading can enrich our understanding of contradictions at stake that need to be engaged in and deeply questioned, to center possibility. We questioned the market driven consumption of education which includes informal learning and is understood as supporting an increase in achievement and also identification with science (Philip & Azevedo, 2017). Applied here, we could argue that some families participated in the cooking activity to further enhance their children's achievement and possibly also interest in science, something that would then have future educational advantages for their children in their navigation of the larger marked-driven education system. In contrast, enrichment of formal science education through a partnership with a community organization and joint pursuit of a coding and maker activity ensured that the involved students lived moments in which they could envision themselves as a science person while also imagine new possible selves for the future.

As suggested by Philip and Azevedo (2017), "it is by studying the full space of everyday science practices, across settings and in their full complexity as sites of contestation, that we better understand the possibilities and limitations of everyday science learning for equity and justice" (p. 530). The theoretical grounding we offer in this chapter—the study of learning and identity in movement, through a non-representational yet relational reading of it, marked by dignity and intersectionality, we believe, is a lens that will help us move onward to better understand the potential of informal learning in centering possibilities and flattening power differentials and make visible the creative and agentive nature of human learning and lifelong learning lives in and beyond science. It is a framework that helps us understand continual science learning (Katz, 2017), moving the field onward as well, beyond a narrow functional reading of informal science learning as a means to close opportunity gaps in STEM learning or respond to market-driven needs of trained scientific staff. As shown, by bringing micro and macro levels of analysis together, we can both cue in on limits yet also the potential of informal learning and its role in constituting learning lives, trails and meshworks that center brilliance and new possible selves.

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Chapter 10
Application of the Contextual Model of Learning and Situated Identity Model in Informal STEM Learning Research

Kelly Riedinger and Martin Storksdieck

10.1 Introduction

The conceptual model of learning and the Situated Identity Model are two theoretical frameworks prominent for understanding learning in informal STEM learning (ISL) environments. In this chapter, we will describe both of the theoretical frameworks including a brief history of their development and examples of their application in the literature. We then explain how we applied them in a study we conducted with zoos and aquariums to understand the complexity of factors that contributed to visitors' learning.

10.2 The Contextual Model of Learning

The Contextual Model of Learning (Falk & Dierking, 1992, 2000; Falk & Storksdieck, 2005) is a theoretical framework for generally understanding learning in ISL environments and the complexity of factors that contribute to visitors' meaning making processes and the learning outcomes they take away from a visit. The model emphasizes that learning is a process and product of three overlapping contexts over time: the personal, the sociocultural, and the physical. The basic premise of the model is that learning is complex and contextualized.

In their article, Falk and Storksdieck (2005) describe the evolution of the ISL field in applying learning theories to research. They argue that historically much of the prior work in ISL was atheoretical until the introduction of models such as

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constructivist, cognitive, and sociocultural theories. Falk and Dierking first introduced the Contextual Model of Learning as a theoretical model in their book, "The Museum Experience" (1992) and then later expanded on these ideas in, "Learning from museums: Visitor experiences and the making of meaning" (2000). Falk and Storksdieck (2005) then empirically tested the model at the World of Life Exhibit at the California Science Center and published it. This study sought to test systematically the factors identified in the model to understand how the variables contributed to visitor learning. Storksdieck (2006) extended the model to the context of field trips to ISL settings and empirically validated it as the Integrated Experience Model within that context, adding the element of linkage between formal and informal settings.

10.2.1 The Personal Context

The Contextual Model of Learning emphasizes that context drives learning and learning is a process and product of a visitors' personal, sociocultural, and physical context. The personal context builds on constructivist theories of learning by recognizing that a learning experience is an individualized experience that is shaped by factors such as prior knowledge, experiences, interests, and beliefs. In essence, the personal context represents all of the personal experiences and characteristics that learners bring with them to the setting. It considers, for example, the individual's motivation for the visit, their agenda and expectations for the visit, their interests and beliefs as related to the content of the ISL setting and the setting itself, and the visitor's desire and actual ability to have choice in his or her engagement with learning-related experiences. Falk and Storksdieck (2005) identified and tested the following five factors as most important in the personal context and found evidence that all of them mattered somewhat, even when taken in consideration simultaneously as part of a relatively short (less than one hour on average) visit to a science center gallery:

- Visit motivation and expectations
- Prior knowledge
- Prior experiences
- Prior interests
- Choice and control.

10.2.2 The Sociocultural Context

The sociocultural context builds on sociocultural theories of learning (Vygotsky, 1978; Wertsch, 1985) and recognizes the socially constructed nature of learning. The sociocultural context acknowledges that learning is socially mediated, shaped by factors such as the cultural value society places on ISL settings and through social relationships such as other members of a visiting group. Learning in ISL settings is influenced strongly by the social interactions visitors have within their social groups as they engage in joint sense making (Ash, 2003; Crowley et al., 2001; Ellenbogen, 2002; Falk & Dierking, 2000; Falk & Storksdieck, 2005), as well as social interactions with those outside their group through interactions with docents, educators, and even other visiting groups (Crowley & Callanan, 1998; Falk & Storksdieck, 2005).

Falk and Dierking (2000) and Falk & Storksdieck (2005) identified the following key factors as aligned with the sociocultural context:

- Within group social mediation
- Mediation by others outside the immediate group.

10.2.3 The Physical Context

The physical context assumes learning is an interaction with the physical environment and posits that elements of the physical space (for example, the design of a specific exhibit or the placing of exhibits relative to one another within an exhibition or gallery) influence learning. This includes large-scale aspects of the learning environment, such as the physical properties of space, the exhibit lighting, and climate, as well as small-scale factors that include aspects such as exhibit labels and objects. The physical context also considers how well visitors can orient themselves to the space, such as through the availability and ease of use of wayfinding tools and the ability to navigate the ISL context intellectually, for instance, using advanced organizers.

The following are key factors that influence learning within the physical context (Falk & Dierking, 2000; Falk & Storksdieck, 2005):

- Advanced organizers
- Orientation to the physical space
- Architecture and large-scale environment
- Design and exposure to exhibits and programs
- Subsequent reinforcing events and experiences.

10.2.4 Other Factors

In their subsequent text, *"The museum experience revisited,"* Falk and Dierking (2016) note the importance of an additional, fourth dimension that Storksdieck's (2006) Integrated Experience Model already included: time. While they acknowledge that time is not necessarily a contextual factor, they argue it is an important dimension to consider because learning is a dynamic and continuous process. A museum visit or other ISL experience is only a snapshot in time and influences the shifting interactions of the three overlapping contexts over time with meaning constantly negotiated and reshaped. In fact, Falk and Storksdieck (2005) investigated the factor of time in their longitudinal design as subsequent reinforcing experiences, revealing the complex ways in which science center visitors integrated the visit and subsequent experiences into an amalgam of memory and learning, giving empirical support for the emerging Situated Identity Model. Research on the Integrated Experience Model also included time as a factor but in this case it was conceptualized as a "follow-up experience" that resulted from a visit to a planetarium show on climate change and solar power (Storksdieck, 2006). In that sense, the models predated the now-accepted sense of connected learning across time and space that forms the basis for ecological perspectives on informal learning (National Research Council, 2015).

10.3 The Situated Identity Model

Falk (2006) first articulated the Situated Identity Model, a theoretical model that suggests visitors' identities drive their motivations for visiting ISL settings and influence their resulting visit behaviors and learning outcomes (Falk, 2006, 2009; Falk et al., 2008). We define identity here as how others think about us, how we think about ourselves, and how we want others to perceive us (Falk, 2009). The Situated Identity Model argues that identity drives behavior and constantly is under negotiation depending on the context. That is, it is dynamic and reflects the immediate needs and affordances of the social and physical context. Falk (2009) draws a distinction between big "I" Identities and small "i" identities, noting that we each have broad Identities (for example, gender, race, ethnicity) that are more enduring, but we also have multiple identities that express at different times depending on the situation and context.

The Situated Identity Model posits that an individual's identity-related needs and interests, or what Falk (2009) refers to as their identity-related motivations, drive the visit experience. These identity-related motivations influence visit behaviors and ultimately shape the basic trajectory of the visit experience. The factors listed in the Contextual Model of Learning then drive the specific details of the experience.

Several studies informed Falk's (2009) theoretical model of situated identity, including a study in collaboration with Storksdieck (Falk & Storksdieck, 2010) at the California Science Center, and with other colleagues (Falk et al., 2008) in a study with zoo and aquarium sites across the country. Both studies included data collection with visitors that incorporated questions designed to prompt visitors to articulate their motivations for visiting. The California Science Center study specifically sampled 192 visitors through short entry and exit interviews, full visit tracking, and 12–18 months post-visit in-depth interviews with about 50 of those initial study participants (Falk, 2006; Falk & Storksdieck, 2010). The zoo and aquarium study involved over 1500 participants across multiple sites and incorporated pre- and post-visit surveys complemented by interviews on-site, and long-term follow-up through telephone or online surveys. In both studies, Falk and colleagues (Falk, 2006, 2009; Falk et al., 2008; Falk & Storksdieck, 2010) concluded that visitors to museum-like settings choose to visit for different reasons and these motivations were identity-related in that they were context-specific, or "situated." The motivations generally clustered into five categories Falk initially termed Explorers, Facilitators, Professionals/Hobbyists, Experience Seekers, and Spiritual Pilgrims (Falk et al., 2008), later renamed Rechargers (Falk, 2009). After broadening to consider other cultural institutions, Bond and Falk (2012) detailed two additional motivation categories: Respectful Pilgrims and Affinity Seekers. We expanded each of these categories in Table 10.1 and included definitions by Falk (2009, 2011).

Table 10.1 Identity-Related Visit Motivations

Visit motivation category	Definition	Example
Explorers	"curiosity-driven with a generic interest in the content of the museum. They expect to find something that will grab their attention and fuel their learning." (Falk et al., 2008, p. 57)	A person who visits a science center because s/he generally wants to learn more about science
Facilitators	Facilitators are socially motivated. A visit for facilitators "is focused primarily on enabling the experience and learning of others in their accompanying social group" (Falk et al., 2008, p. 57)	A parent facilitating a museum visit for their child
Professional/Hobbyist	The professionals and hobbyists, "feel a close tie between the museum content and their professional or hobbyist passions. Their visits are typically motivated by a desire to satisfy a specific content-related objective" (Falk et al., 2008, p. 57)	A photographer visiting a zoo to take photos of animals
Experience seekers	"Experience Seekers perceive the museum as an important destination, so their satisfaction derives mainly from having 'been there and done that'" (Falk et al., 2008, p. 57)	Out-of-town visitors going to a museum identified as an attraction to see in the city
Recharger	"Rechargers are primarily seeking to have a contemplative, spiritual and/or restorative experience. They see the museum as a refuge from the work-a-day world" (Falk et al., 2008, p. 57)	A visit to a botanical garden to find a quiet, restorative place away from the business of city life
Respectful pilgrim	"Respectful pilgrims visit out of a sense of duty or obligation to honor the memory of those represented by an institution/memorial" (Falk, 2011, p. 148)	A veteran visiting the WWII museum out of respect for fellow veterans

(continued)

Table 10.1 (continued)

Visit motivation category	Definition	Example
Affinity seekers	"Affinity seekers are motivated to visit because a particular museum or exhibition speaks to the visitor's sense of heritage and/or personhood" (Falk, 2011, p. 148)	A visitor going to a local history museum to learn more about the history of their city

10.4 Prior Application of the Models

In this section, we discuss how previous studies across the ISL literature applied the theory to answer different research questions. We start with detailing earlier studies that implemented the Contextual Model of Learning and then we discuss studies applying the Situated Identity Model.

10.4.1 Contextual Model of Learning

A number of studies across the ISL field implemented the Contextual Model of Learning. We detail two uses here: one by Kisiel (2003) applies the Contextual Model of Learning to teachers' use of field trips at a museum and a second example by O'Connell et al. (2020) uses the model to interpret findings from a study at the Oregon Eclipse Festival.

10.4.1.1 Teachers, Museums, and Worksheets

Kisiel's (2003) study investigated how teachers' motivations for a field trip influence the field trip experience and pedagogical approach. Specifically, Kisiel's study aimed to examine how use of worksheets by teachers with students on field trips to a museum might provide insights into the teachers' purpose for the visit.

In the study, Kisiel (2003) used the Contextual Model of Learning to examine the worksheets teachers used to organize field trip experiences for students and draw comparisons between worksheet features as influenced by teachers' reasons for visiting. Kisiel's analysis and interpretation of the worksheets, coupled with teacher interviews and field trip observations, suggested two broad, overarching teacher agendas for field trips to museums: a survey agenda and a concept agenda. Kisiel described a survey agenda as teachers wanting students to see or experience all or as much as possible of the museum, and a concept agenda as teachers using the field trip for a particular goal such as learning about a specific science concept.

By analyzing the worksheets, Kisiel (2003) noted differences in characteristics based on teachers' agendas for the field trip and linked these to factors identified in the Contextual Model of Learning. One characteristic identified, task density, referred to the amount of work students were asked to complete during the field trip (for example, how many exhibits they visit, number of questions on the worksheet, amount of time required to complete each question on the worksheet) and directly relates to the personal context (for example, the teacher's motivation for the visit, prior experience in class) and the physical context (for example, orientation cues for students efficiently to navigate the physical space). Kisiel concluded the worksheets can serve as an advanced organizer for students (physical context), can mediate social interactions within the group (sociocultural context), and can serve as a subsequent reinforcing experience if the student revisits and connects to the worksheet back in the classroom (personal and physical context).

10.4.1.2 Guerilla Science at the Oregon Eclipse Festival

A study by O'Connell et al. (2020) describes a Guerilla Science event hosted during the Oregon Eclipse Festival. Guerilla Science is an organization that develops and brings live science programming to the public at events and in places where science is least expected, for example, music and arts festivals, urban spaces, theaters, or night-clubs (Rosin et al., 2019). A research team at Oregon State University conducted a study of Guerilla Science events at the Oregon Eclipse Festival, a 5-day music and art festival that attracted more than 30,000 participants to Eastern Oregon during August 2017. Researchers designed the study specifically to explore the research question: *Who participates and what are the motivations for participating in informal science learning events in cultural settings?* A key underlying question was whether Guerilla Science activities would attract culturally interested individuals who ordinarily would not choose to engage in informal science; that is, was the Guerilla Science approach able to attract and engage new audiences to science, expanding participation beyond the proverbial "choir" (Storksdieck et al., 2005)?

O'Connell et al. (2020) used the contextual model to frame and interpret their findings; they concluded that the Guerrilla Science events at the Oregon Eclipse festival addressed all three of the contexts that influence learning. They argued that the Guerilla Science events offered a physical context where people who normally would not engage in science gathered to explore new experiences in science. It provided a sociocultural context where individuals could interact with their social group around science content while also connecting with scientists. Finally, it linked to festival attendees' personal context through creating science experiences that leverage their identities, prior interests, and motivations.

10.4.2 Situated Identity Model

A number of prior studies specifically examined the personal context by applying the Situated Identity Model. In this section, we will provide examples of several studies that implemented the Situated Identity Model to understand visitors' identity-related visit motivations including the first and second iterations of the Why Zoos and Aquariums Matter (WZAM1 and WZAM2) studies (Falk et al., 2007, 2008), a study by Stein and Storskdieck (2008) at the United States Botanical Garden, a study comparing motivations across an aquarium, a science center, and eco-tour boat excursion (Rowe & Nickels, 2011), and an article by Storksdieck and Falk (2020) that describes the education value of National Parks.

10.4.2.1 Why Zoos and Aquariums Matter Studies

The Situated Identity Model was a theoretical framework used in the WZAM1 and WZAM2 studies (Falk et al., 2007). The WZAM studies examined the overall impact of visits to zoos and aquariums and how they contribute to the public's understanding of conservation. As part of the multi-year, multi-institution study, the WZAM team developed an instrument to investigate validly and reliably individual's motivations for visiting zoos and aquariums. The instrument contained 20 items representing each of the five identity-related visit motivations and was administered with more than 5500 zoo or aquarium visitors. Falk et al., (2007, 2008) concluded that visitors do have specific identity-related motivations that directly impact their visit behaviors and ultimately learning outcomes, including what meaning they make of the experience. The study resulted in direct implications for zoos and aquariums, including a "Visitor Impact Toolkit" that zoo and aquarium sites could use to better understand their visitors toward designing multiple levels of experiences and ensuring there was something for all visitors, regardless of their dominant visit motivation (Falk et al., 2007).

10.4.2.2 United States Botanical Garden Study

Stein and Storksdieck (2008) conducted an evaluation study at the United States Botanical Gardens (USBG) to characterize visitors—specifically, who visits the USBG, why they visit, the extent and nature in which they engage, and what they take away from the visit. The Situated Identity Model was used as a theoretical lens in this study to understand visitors' motivations and how they influence visit behaviors and learning outcomes. During exit interviews, visitors answered questions related to their reasons for visiting and expectations of the visit. Falk's (2009) identity-related motivation categories were used to create a modified 20-item, closed ended scale to measure the relative presence of five visitor motivations (each with four items), and to analyze and interpret the data. Stein and Storksdieck also made comparisons between their study at a botanical garden to findings from Falk and colleagues' (2007, 2008) work at zoos and aquariums.

Overall, a few key findings emerged from the study conducted at the USBG. First, most visitors to the USBG were “explorers”, while “recharger” and “professional/hobbyist” were the second and third most common visit motivations. “Facilitator” and “experience seeker” were the least common visit motivations among visitors to the USBG. In contrast to zoos and aquariums, facilitators and experience seekers were less common at the botanical gardens. Stein and Storksdieck also noted a seasonality to motivations among visitors in their sample in that the motivation “facilitator” was more common during special displays and holidays. In contrast to previous studies, individuals primarily were not assigned one situated visit motivation. Instead, the study showed that individuals mostly were motivated by multiple identity categories, with implications for potential interpretive strategies that need to bridge between them.

10.4.2.3 Visitor Motivations Across Three Informal Education Institutions

A study by Rowe and Nickels (2011) applies and compares the Situated Identity Model in three contexts: an aquarium, a science center, and an eco-tour boat excursion. At each of the three sites, Rowe and Nickels administered an adapted version of the identity-related motivation instrument Falk et al. (2007) developed. The study was an intentional follow-up to the WZAM studies to test whether valid and reliable implementation of the identity-related visit motivation instrument in other ISL contexts was possible. Similar to the USBG study, Rowe and Nickels, in their analysis, acknowledged the presence of multiple motivations during a visit. They grouped visitors into one of three categories: single-dominant motivation, dual-dominant motivation, and non-dominant motivation. Single-dominant motivation represented individuals who expressed a single, dominant motivation from one of the categories. The dual-dominant motivation category referred to visitors who had strong motivations in two categories. Non-dominant motivation referred to visitors who did not have strong motivation in any of the five categories. Overall, the findings of Rowe and Nickels were consistent with the WZAM study and effective application of the tool in other ISL settings was possible. As in the WZAM studies, more than half of the visitors were in the “non-dominant” category. Across all sites, “explorers” and “facilitators” were the most common visit motivation categories while “experience seekers” and “rechargers” were the least common. A few notable differences between the three ISL contexts emerged. Professional hobbyist was more common at the science center as compared to the aquarium and boat-based eco-tour. A seasonal effect at the aquarium was also noted in that professional hobbyists were more common in the summer and explorers were more common during the winter.

10.4.2.4 Understanding Visitor Motivations in National Parks

Storksdieck and Falk (2020) used the Situated Identity Model in an article that highlighted the educational value of National Parks from the perspective of free-choice learning. The authors provide a series of vignettes in which they describe different identity-driven motivations and how those motivations influenced visitor behavior and learning outcomes during trips to various National Parks. For example, one of the authors (Storksdieck) contrasted two different trips to National Parks: one visit to the Grand Canyon while he was a graduate student, visiting with a friend, the other a visit three decades later with his family that encompassed three generations. Comparing these examples, the article illustrates how behaviors and learning outcomes during each visit differed based on the motivation for visiting, the social context of the visit, and the dominant enacted identity-related behavior during each visit. The article highlights the complexity of situated identities, motivational factors, and resulting learning outcomes.

10.5 Why Zoos and Aquariums Matter Study

The third iteration of the Why Zoos and Aquariums Matter (WZAM3) studies builds on the earlier WZAM1 and WZAM2 studies by exploring broadly how visitors' agendas—their plans and expectations for the visit—align (or not) with the conservation goals of zoos and aquariums. The third wave of WZAM aimed to understand:

- How visitor goals and behaviors impact learning,
- How the conservation education agenda of most zoos and aquariums interlaces with those goals, and
- How the public situates the voice of zoos and aquariums in society, in the social context.

The WZAM3 project responds to shifts in the mission of zoos and aquariums over the past decade to a conservation focus, resulting in new education approaches that focus on conservation education and pro-environment behaviors and actions (Carr & Cohen, 2011; Patrick & Caplow, 2018; Patrick et al., 2007; Patrick & Tunnicliffe, 2013; WAZA, 1993). As a result of this shift to a more conservation-oriented mission, zoos and aquariums focus interpretive practices on conservation education and promoting pro-conservation behaviors. It is unclear the extent to which visitors share this conservation-oriented agenda. For example, in a study conducted by Ballantyne and Packer (2016), visitors to zoos and aquariums primarily felt motivated by seeing animals and having an enjoyable social experience and similarly, a study by Linke and Winter (2011) concluded that visitors identified entertainment as a primary driver for their visit. This does not mean necessarily that visitor and zoo/aquarium agendas are at odds. A study by Falk et al. (2007) concluded that nearly half of visitors acknowledged the role of zoos and aquariums in promoting conservation education. A study by Patrick (2017) offers additional nuance and describes various ways visitors understood the conservation mission of zoos that ranged from visitors who acknowledged and explicitly stated the conservation mission of zoos to visitors who were unaware of the conservation mission. For some visitors, the conservation mission may align with their agendas, while for others, these goals are secondary or even at odds with their visit agenda. Limited research to date explores the overlap of visitor and institutions agendas. The WZAM3 study aims to address this gap by examining whether visitors understand, embrace, and act upon the conservation mission of zoos and aquariums.

10.5.1 Full Visit Cycle

The STEM Research Center at Oregon State University (OSU) collaborated with Knology, the Center for Research and Evaluation at COSI, and the Association of Zoos and Aquariums (AZA) for the WZAM3 project. We designed WZAM3 to explore the full visit cycle to understand how the public thinks of zoos and aquariums at different times: what value people **assign** to zoos and aquariums and what role it can play in conservation and STEM learning, what people **bring** with them to the zoo or aquarium visit, what they **do** during the visit in terms of their behaviors, what they **take** away from the visit, and, in between visits, how they integrate what they learned (Fig. 10.1).

The full visit cycle provided a framework to explore how zoos and aquariums function across a person's lifecycle and how visitors' beliefs, preconceptions, expectations of the visit, visit agenda, behaviors, and learning outcomes relate (or not) to the conservation agenda of zoos and aquariums. The full visit cycle acknowledges that a zoo or aquarium visit is one component of a broader learning ecosystem for

Fig. 10.1 Full visit cycle

the visitor (NRC, 2015) where one visit is the precursor for another, and is itself influenced by prior experiences and perceptions of visits to the institution that other factors may shape (Falk & Dierking, 1992, 2000; Storksdieck, 2006).

The research team at OSU particularly focused on the “do” aspect of the full visit cycle and guided the study by the following research question: *What are the entry characteristics of visitors to zoos and aquariums and how do these characteristics inform behaviors and outcomes during a zoo or aquarium visit?*

10.5.2 Theoretical Framing

We applied the Contextual Model of Learning (Falk & Dierking, 1992, 2000) and the Situated Identity Model (Falk, 2009, 2016) to our study of visitors to zoos and aquariums. Our guide was Falk and Storksdieck’s (2005) study at the California Science Center’s World of Life Gallery, which examined not only what people learned during the museum visit, but also what factors or combinations of factors influenced their learning. This study was the first to gather empirical evidence for the various elements of the contextual model. In our study, we took a similar approach to understand the visitor experience at zoos and aquariums, aiming to capture the complexity of factors contributing to visitors’ behaviors and meaning-making processes.

Within the personal context, we applied Falk’s Situated Identity Model to study visitors’ identity-related motivations for visiting. Specifically, we used the model as a theoretical foundation for considering visitors’ entry narratives and visit motivations which linked to their visit behaviors and learning outcomes.

10.5.3 Study Design

As part of the WZAM3 project, we collaborated with 6 zoo and aquarium sites across the country: Oregon Coast Aquarium, Phoenix Zoo, North Carolina Aquarium at Fort Fisher, Naples Zoo at Caribbean Gardens, Columbus Zoo and Aquarium, and Mystic Aquarium. We purposefully selected the sites to ensure diversity across the sites in terms of type of institution (zoo or aquarium), location, size, and annual visitation.

10.5.3.1 Data Collection

Both theoretical models informed our data collection to ensure we captured factors in each of three contexts, including understanding visitors’ motivations within the personal context.

To capture the incoming group demographic at each site, we mounted GoPro cameras facing the entry of the participating six sites to capture video of all visitor groups entering the zoo or aquarium for three to four full days at each site. At each

Table 10.2 Data Collected from video tracking study

Entry Interview (n = 62)	Z/A Observations (n = 70)	Exit Interviews (n = 61)
• Group characteristics • Prior experience visiting zoos and aquariums • With whom do they typically visit • Motivation for the visit • Plans for the visit • Perceived mission of zoos/aquariums	• Time at exhibits • Time in transit • Time engaged in meaning-making talk • Use of wayfinding tools • Social interactions • Meaning-making conversations and behaviors • Decision-making conversations and behaviors	• Remembered visit behaviors • Extent to which group adhered to visit plan • How groups made decisions • Learning about group members and about self • Perceived mission of zoos/aquariums

site, we intercepted around 150 groups for brief interviews about group composition (size, age of group members, gender, and race/ethnicity) and correlated those groups to our observations for reliability testing of observed features of the group (size, composition), and individuals within the group (approximate age, gender). Observation estimates were accurate, on average, 91% of the time.

We recruited a random selection of visitors to participate in a video-based timing and tracking study (Serrell, 2020; Yalowitz & Bronnenkant, 2009). As part of the tracking study, we asked one member of the group to wear a hat-mounted GoPro camera throughout their visit, which captured all of the group's talk and visit behaviors, including where they went and for how long they visited each exhibit in the zoo or aquarium.[1]

The GoPro camera data, coupled with the entry and exit interviews, allowed us to contextualize each participating groups' visit by understanding what they brought with them to the zoo or aquarium, their behaviors (for example, within group interactions and decision-making processes), and their perspectives about the visit, including what they took away from the zoo or aquarium experience. We complemented camera data by entry and exit interviews with each group. Table 10.10. 10.2 displays all data we collected for the study. We designed all data collection activities to ensure we captured factors from each of the three contexts. For example, entry interviews included questions related to visit motivations, expectations of the visit, and prior experience visiting zoos and aquariums. Camera data elucidated social interactions within the group and with others, such as interactions with zoo or aquarium educators and docents. Camera data also provided insights on factors related to the physical context, including crowding and use of wayfinding tools such as directional signage and zoo/aquarium maps.

[1] Note that the presence of the camera/microphone seemed not to influence the dynamic of the visit, in line with previous findings from Serrell that cueing before observations seems not to alter visit behavior after about 15 min of visit time (Serrell, 1998).

10.5.3.2 Data Analysis

We developed a coding framework, guided by both theoretical models and prior research (Allen, 2002; Ash, 2003; Clayton et al., 2009; Tunnicliffe, 2000; Zimmerman et al., 2010), to systematically analyze and interpret all data toward understanding how the various factors influence visit behaviors and learning outcomes. The framework included codes aligned with the personal context to identify each groups' demographics (for example, group size, composition), if they were locals or visiting from out-of-town, their prior experience visiting zoos and aquariums, including whether they were members and their motivations for visiting. We designed the coding framework to help us understand visitors' decision-making processes and their meaning-making behaviors, including the nature of their talk during the visit and the extent to which they engaged in conversations related to the conservation mission of zoos and aquariums. Table 10.3 displays the codes we used to identify types of talk among visiting groups in our study.

Because decision-making processes were a particular focus of our study, we developed sub-codes to have a more detailed analysis of groups' active decision-making talk and behaviors. Table 10.4 provides the sub-codes with descriptions for the codes we used to analyze group decision-making talk and behaviors.

We trained all data coders to use the coding framework and protocol for analyzing videos. We engaged in iterative training and discussions across all coders until we established satisfactory levels of inter-rater agreement (80% agreement or greater across all coders and codes) and inter-rater reliability (0.6 or above indicating substantial to near perfect reliability).

10.5.4 Study Findings

The data we collected helped provide insight into our guiding research question regarding how visiting groups' entry characteristics and agendas translated to visit behaviors and outcomes. While our study focused on the "do" aspect of the full visit cycle, we contextualized these findings by exploring what visitors brought with them to the visit. We organized study findings here by these aspects of the full visit cycle.

10.5.4.1 What Did Visitors "Bring" to the Visit?

We tested our approach of identifying groups' characteristics from entry video data by conducting spot interviews with 150 groups per site (N = 900) to estimate our error rate for coding group demographics. We learned that overall, we were accurate 91% of the time in coding for these demographic variables. From the entry camera data, we learned that about two-thirds of groups during the study period were visiting with children and about a third of visitors were adult groups without children or visiting alone. Overall, the average group size was three visitors, most often a parent visiting

Table 10.3 Learning talk and behaviors during Z/A Visit

Type of talk	Definition	Evidence from video data
Conservation talk	Any talk related to visitors' understanding of the need to conserve the environment, wildlife, and the places animals live. This included: environmental & conservation issues, behaviors, actions, and values; global/interconnected views; connectedness to nature; understanding of nature benefits & services; the role of Z/A in conservation efforts	*"Your zoo visit helps Florida panthers and other animals in the wild."*
Animal welfare talk	Any talk—positive, neutral, or negative—concerning emotional well-being or mental state of the animal, habitat or living conditions, animal nutrition and health, and human handling of animals	*"Why is their water so nasty*?"
Meaning-making talk	Talk where individuals construct understanding or make sense of new information or content they found in Z/A exhibits and programming. This included STEM conceptual talk, connecting talk, strategic talk, and perceptual talk (Allen, 2002; Zimmerman et al., 2010)	*"I see a zebra…what color is a zebra? It's black and white."*
Decision-making talk & behaviors	Any comments or actions where an individual or the group makes a choice. The decision could be made deliberately through use of wayfinding tools (for example, maps) or discussion, or could be an unconscious choice (for example, a group is drifting or unconsciously following the pathways)	*"[The baby] is ready to move on. [The baby] wants to go through the tunnel."* *"We gotta go this way* [points and shows location from map in hand]."

with two children or two parents visiting with one child. Although across all data, groups of 3 were most common, when we looked at only adult groups the average group size was 2, usually a couple on a date or an adult parent with an adult child.

In our analysis of the entry camera data, we visually estimated group composition in terms of gender, race, and age category. When we compared to regional census data, the typical zoo/aquarium visitor in our sample was more likely White and more females as compared to the gender breakdown in census data. The age groups 0–5, 5–9, 25–34, and 35–44 were overrepresented in the visitorship during the time

Table 10.4 Decision-making sub-codes

Sub-code		Description
Kind of decision	Planning/Strategic	Discussion about what to do overall: what exhibits, animals, or experiences to visit or see For example, *"We should make sure we see the sea otters during one of their feedings."*
	Engage/Move on	Decision to stay at exhibit/exhibit element or to move to a new exhibit/exhibit element For example, "I think we've been at the touch pool long enough. Let's move on to the sea lions before we run out of time."
	Path	Decision about what path or direction the group should take through the Z/A or to new exhibit For example, *"Should we go this way to the sea otters or right to the sharks?"*
Decision-making participation	An individual	One individual in the group, child or adult, brings up a question or discussion and decides
	Sub-group	Some, but not all, of the group brings up a question or discussion and decides
	Full group	The entire group engages in deciding
Awareness of decision	Deliberate	Group makes decision by group discussion and deliberate plan, or by attending to advanced organizer or wayfinding tools, if available
	Non-deliberate	Group makes decision unconsciously or without deliberate thought. For example, group makes decision just by following the path or unconsciously following other groups

(continued)

period when we collected data at each site. These data confirm findings from previous studies (AZA, 2020; Dillenschneider, 2018, 2019).

Our entry interviews included questions designed to identify groups' motivations and plans for the visit.[2] Most of the visitors in our study (85.5%) entered the zoos

[2] Note, participants could indicate multiple plans for their visit.

Table 10.4 (continued)

Sub-code		Description
Discussed versus enacted decision	Discussed	At least 1 member of the group mentioned or discussed a particular decision, but ultimately the group did enact that decision. For example, a group discusses wanting to see the sea otter exhibit, finds them on the map, and points in the direction of the exhibit, but ultimately follows that path into the coastal exhibit
	Enacted	Group actually enacts the decision, whether or not the group discussed it. For example, a group walks into the shark exhibit
	Discussed and enacted	Group both discusses and enacts the decision. For example, a group talks together about attending the sea lion show. They use the map to find the sea lions and walk to the exhibit to attend the show

and aquariums with plans to see animals generally or to see a specific animal (for example, baby polar bears at the Columbus Zoo) or exhibit (for example, visiting exclusively to explore the *Arizona Trail).* This is consistent with previous research (Klenosk & Saunders, 2007; Sickler & Fraser, 2009). Other dominant visit plans included foraging to see what the zoo or aquarium had to offer (31.7%), visiting another installation or experience (25%) (for example, ride the carousel or playground area), and having a fun or an entertaining experience (11.7%). Less dominant plans included getting exercise (10%), attending a specific program or experience (6.7%) (for example, an IMAX movie or to participate in a behind the scenes experience), or spending time with their social group (6.7%) (family or friends).

Using the categories identified in Falk's (2009) Situated Identity Model and outlined in the AZA toolkit (Falk et al., 2007), the primary visit motivation of more than half of our groups (52%) fell into the "experience seeker" category. This suggests that just more than half of visitors in our sample came to the zoo or aquarium because it was a place to be or destination to visit in the area. "Facilitators" and "explorers" were also common motivations among visitors in our sample. "Facilitators" were those who wanted to enable an experience for another (for example, parents facilitating a zoo or aquarium experience for their young children) while "explorers" generally were interested in the topic of zoos and aquariums (that is, their motivation was wanting to learn more about animals). When we made comparisons among motivations by group characteristics, we learned there were no significant differences in visit motivation between local visitors versus tourists or groups visiting from out-of-town (more than a 3-h drive). This surprised us as we expected more "experience seekers" among groups from out-of-town when we compared to local visitors. We did, however, note differences among groups based on their prior experience with each zoo or aquarium site. Groups that included a visitor who was a member of the zoo or aquarium or groups who had prior experience at the specific zoo or aquarium site were more likely "explorers", while groups with limited or no experience were more likely "experience seekers." This confirmed our study assumptions about the link between visit motivation with prior experience and familiarity with the specific site (Falk & Storksdieck, 2010). Our findings from WZAM3 are consistent with the earlier WZAM studies (Falk et al., 2007, 2008) related to the "explorer" and "facilitator" motivations. However, our findings differ from the earlier studies in that we had a greater proportion of "experience seekers" in our sample as compared to WZAM1 and WZAM2.

As related to our broader project framing, we wanted to understand the extent to which visitors to the zoos and aquariums acknowledged and understood the mission of zoos and aquariums. We designed and asked a series of questions to focus on visitors' perceptions of the zoo/aquarium mission. Our analysis of this data suggested that most visitors are aware of and acknowledge conservation and education as key elements of the mission of zoos and aquariums. This is consistent with findings from the earlier WZAM studies (Falk et al., 2007; Fraser & Sickler, 2009), which concluded visitors generally understood the role of zoos and aquariums in promoting conservation education.

10.5.4.2 What Did Visitors "Do" During Their Visit?

The video tracking data we collected helped us to understand interpersonal communication within the group (the sociocultural context) and how groups engaged in talk to make meaning of their zoo or aquarium visit experience. The tracking data also provided insights into each group's decision-making talk and behaviors.

Across all groups in our study, visitors spent on average one hour and 45 min at the zoo or aquarium. More than half (55%) of this time they spent engaged with education exhibits—locations within the zoo or aquarium that allowed for observation of animals, interpretive signage, and/or other interpretive resources (for example, interpretive programs, docents). The remainder of time they spent either in transit between exhibits (37%) or at non-education areas (8%) at the zoo or aquarium (for example, at the gift shop, restaurants, or playgrounds).

Table 10.3 presents the types of talk we coded in the data—conservation talk, animal welfare talk, meaning-making talk, and decision-making talk—and their operational definitions for the study. When we looked across all groups in our study, we learned that meaning-making talk was overwhelmingly the most dominant type of talk, representing 69.7% of the talk we coded in this study. By meaning-making, we refer to talk in which groups engage to process information and collectively make sense of the content. The excerpts from our video data we provided below highlight meaning-making talk among visiting groups to an aquarium:

Two boys visiting a saltwater aquarium as part of an exhibit gallery

Visitor 1: (Points to an animal) "What, what are those things? It's like a snake thing."

Visitor 2: "It's a garden eel."

A family group viewing a reef aquarium

Visitor 1: (Looking into the aquarium) "Well, there's a few different ones in there but they're still all clownfish."

Visitor 2: (Reading a sign) "The anemones and coral are animals, not plants…Coral is an animal."

Visitor 1: "Maybe he (anemone) doesn't want to be coming out. OH! There he goes, he's out now."

In our study, we considered making connections across exhibits or to another experience (for example, between visits or a connection to something they learned somewhere else, such as in school or at another learning setting) as an important type of meaning-making talk.

Adult couple at a wolf exhibit:

Visitor 1: "Every time I come here, he [wolf] is always on the right side of the exhibit…Wolves are mostly pack animals, right?"

Adult visitor at an aquarium habitat:

Visitor 1: "Look at the seahorse. I almost bought one before but they eat brine shrimp. They don't eat regular food."

Another notable insight from our analysis of visiting groups' meaning-making talk was that it was not limited to designed, educational exhibits. We also have evidence in our data of groups engaging in meaning-making talk in transit between exhibits, at the zoo/aquarium restaurants and gift shops. The following examples from our tracking data offer evidence:

Adult group leaving a whale habitat and walking to the next exhibit

Visitor 1: "Yeah, there's a bunch of those whales around here. Like, not just at the aquarium but also in the local area…Those look so much longer when you are in a boat and they come up right next to the boat. I think they are also part of the odontocetes which means they're toothed. Teeth as opposed to baleen."

Adult couple stopping to eat at the zoo's café

Visitor 1: "It's like koalas. They eat for like six hours and then just pass out."

Visitor 2: "When we go to Australia, I am going to find koalas and kangaroos."

This finding has important implications for how we think about where learning happens and illustrates the socially mediated nature of learning. Meaning-making conversations, where visitors discuss what they saw and experienced to make sense of the content can happen anywhere during or even after the visit and are important subsequent reinforcing events.

Evidence of both conservation talk and animal-welfare talk were relatively scarce in our study sample and accounted for only about 1% of the talk we coded. This finding confirms earlier work by Tunnicliffe (1995, 2000) from research conducted with school and family groups at exhibits.

We further sub-categorized animal-welfare talk into positive, neutral, and negative welfare talk and felt encouraged when we learned not all animal-welfare talk is negative. At times, visitors simply noted habitat conditions or even positively remarked about the quality of the habitat or the care. For example, one visiting group observed a keeper cleaning an animal habitat and commented, "*Oh, that's good they clean their cages out.*" In another group at a zoo, a visitor noted, "*There's a coyote. He looks really healthy.*" This suggests that while there may be a broader concern among the public and a potential marketing issue, it was not necessarily a salient conversation feature for visitors in our study who attended zoos and aquariums.

We noted limited evidence of conservation talk among the groups in our study, even when the groups were at exhibits with specific conservation messages. This does not suggest these conservation education interpretive practices are ineffective. Instead, we speculate that groups may not engage in socially constructed meaning around the conservation-oriented messages. In fact, many groups suggested during exit interviews that they paid particular attention to conservation messages during this visit because they were cued as a result of participating in the entry interviews and several groups cited specific instances of conservation messages they noted during their visit. One visitor, for example, explained during the exit interview:

Visitor: It seemed very apparent that they were definitely wanting to help wildlife around the world.

Interviewer: Can you share an example of what made it apparent for you?

Visitor: Every person that presented said something about whatever the animal was and where it was from and how [the zoo] was helping that species. All the signs along the way were saying, we're helping, the money that you're spending today is helping to go towards this and towards that.

We learned from our study that the entry interview, in which we asked visitors what they believed was the mission of zoos and aquariums, served as an advanced organizer that cued visitors to pay attention to these messages during their visit.

Our video data captured each group's decision-making behaviors and talk. This included generally coding when groups made decisions and discussions in which they engaged to make decisions. In our sample, decision-making accounted for 28.2% of the talk for which we coded. During exit interviews, groups self-reported that about half of the decisions they made were deliberate (for example, through use of wayfinding tools) and a result of discussion about what to do or see next, while about half of their decisions were non-deliberate, made by following unconsciously the crowd or path. However, when we observed and coded for groups' decision talk and behaviors, the data revealed a different pattern of groups more often making

Table 10.5 Decision-making talk and behaviors

Decision type	Evidence from video data
Deliberate decision making	*"Over here (points), everyone! I want to see the seals! Where are they?"*
Non-deliberate decision making	*Group leaves the lobby and walks along path, which leads them into the Shipwreck exhibit*

deliberate decisions (71.1%) as compared to non-deliberate decisions (29.0%). Table 10.5 highlights examples of decision-making talk and behaviors from our video data. We corroborated this when we coded for decision action; a total of 60.3% of decisions were "discussed" (22.4%) or "both discussed and enacted" (38.0%). Table 10.5 highlights examples of deliberate and non-deliberate talk and behaviors from our video data.

As this study demonstrates, visiting groups to zoos and aquariums exhibited different patterns in their talk and behaviors. All groups engaged overwhelmingly in meaning-making talk, suggesting social interactions are important for groups as they engage jointly in making sense of the experience. Evidence from our data suggests this talk is not confined to designed exhibits and instead takes place everywhere at the zoo and aquarium (for example, walking between exhibits, at the café).

In terms of mission-related talk, we did not find much evidence of visitors engaging in conservation or animal-welfare-oriented talk and this corroborates previous studies (Tunnicliffe, 1995, 1996). Decision-making talk and behaviors accounted for about a third of talk and although groups perceived they made those decisions unconsciously, observations suggested they made these decisions more often deliberately through discussion or use of wayfinding tools.

10.5.5 Discussion

The WZAM3 study aimed to understand what visitors "do" during a Z/A visit as part of a broader study we designed to examine the full visit cycle. The OSU team explored the question: *What are the entry characteristics of visitors to Z/As and how do these characteristics inform behaviors and outcomes during a Z/A visit?* We synthesize study findings across data we collected in this section, organized by three contexts identified in the Contextual Model of Learning.

10.5.5.1 Personal Context

The data we collected provided insights into visitors' personal context and demonstrated that groups bring diverse backgrounds, prior experiences, motivations, agendas, and expectations to the visit. We learned that visitors to zoos and aquariums are not just families visiting with young children; adult-only groups represented a substantial (approximately 1/3) proportion of visitors in our sample. Zoos and aquariums, as well as other ISL settings, should consider this as they plan education and interpretive strategies. The GoPro cameras mounted at the entry of zoos and aquariums showed overrepresentation of visitors in some categories as compared to census data. Although these findings only represent the six sites in our study for three to four days during a particular season, they are notable and are a reflective opportunity for zoos, aquariums, and other ISL settings to consider who visits and who does not. Our study findings also suggested that visitors come to zoos and aquariums with a range of prior experiences, from tourists visiting for the first time to members that come to the zoo or aquarium on a weekly basis.

The results of our investigation further confirmed that visitors come to a zoo or aquarium visit generally understanding the conservation education goals of zoos and aquariums (Falk et al., 2007). Although visitors may not always engage with their social group through conversation about the conservation messaging, they acknowledge and expect to see conservation messaging during their visit. Moreover, we learned in our study that cuing visitors toward the start of the visit, such as using advanced organizers, may focus their attention on these messages.

10.5.5.2 Sociocultural Context

The sociocultural context considers within-group social mediation and interactions with others outside the group as an important influence on learning in ISL settings. In our study, we specifically explored social interaction within the group by looking at visitor talk focused on meaning making and decision-making. The video data revealed groups spend a lot of time socially interacting with one another to construct a shared interpretation of their experience. This finding resonates with prior studies exploring social interactions in ISL settings, including earlier research on parent–child interactions and family learning in museums (Allen, 2002; Ash, 2003; Astor-Jack et al., 2007; Crowley et al., 2001; Zimmerman et al., 2010). Another important finding was that meaning-making talk happens in places beyond designed exhibits, and it may be helpful to consider how to support visitor talk as subsequent reinforcing experience during the visit itself.

Notable was the limited presence of animal-welfare and conservation talk. Visitors' animal-welfare talk has been a concern for zoos and aquariums, but our study suggests it may be less so among populations that choose to visit zoos and aquariums, or, at minimum, it is not a central feature of what groups socially negotiate together when they make sense of their visit. Similarly, conservation talk was also minimal even though groups noted in exit interviews that they noticed conservation messages, especially as a result of cueing during the entry interview.

10.5.5.3 Physical Context

The physical context considers learning an interaction with the physical environment and how well learners can orient to the space. While our study focused on what visitors bring to a visit and what they do while at a zoo or aquarium—the personal and sociocultural context—we did consider various factors aligned with the physical context. For example, we noted the use of wayfinding tools such as maps and directional signs and how they linked with visitors' paths through the zoo and aquarium as well as their decision-making talk and behaviors. In our observations and analysis of the video data, we noted use of wayfinding tools and the ways they drove deliberate decision-making. However, we also noted instances where visitors tried to use wayfinding tools, but with limited success. Moreover, design of wayfinding tools could support all members of groups, especially families where, to some extent, one or more children drive decision-making. An unanticipated finding from our study was the effect of cueing visitors to pay attention to conservation messaging throughout the zoo or aquarium because of our questions about the mission in entry interviews. This suggests the potential of advanced organizers around mission-related content to support visitors in noticing and making sense of these messages (Falk, 1997; Koran et al., 1983).

10.6 Importance to Research

The application of the Contextual Model of Learning and the Situated Identity Model provided useful theoretical lenses through which to design our study and interpret findings. Collectively, the models helped capture the complexity of a zoo or aquarium visit and the myriad factors that influence learning outcomes.

The Contextual Model of Learning foregrounds this complexity and highlights key factors prior research demonstrated to be the most important in thinking about learning in museums and ISL settings in general. It is distinct from learning theories in formal settings in that it provides a holistic perspective in a way yet to be articulated fully in the cognitive or learning sciences.

Similarly, the Situated Identity Model offered a framework for investigating more thoroughly the personal context, specifically related to visitors' motivations and agendas for the visit. Although the model was controversial when first introduced, it provided an initial approach to thinking about why people engage in ISL and has evolved as more research has explored visit motivations.

Both models offer a theoretical lens for exploring research in ISL settings in ways that more fully capture the complexity of a visit or of engagement with STEM in free-choice or informal settings. Future research studies could leverage and build upon prior work that applies the Contextual Model of Learning by testing the model in additional ISL contexts beyond museum-like settings. Like the US Botanic Garden study, future studies that focus on visit motivations could explore more thoroughly the dynamic nature of visit motivations and more clearly link contextual factors to "i" identities and resulting visit motivations That is, what are factors that influence a visitor primarily acting as "facilitator" during one visit or in one context versus an "explorer" agenda during a subsequent visit or in a new context? Lastly, both models acknowledge the holistic nature of learning and all its myriad influencers. In some fundamental way, classrooms are not exempt from this complexity; they also represent complex physical and social settings, and students differ across the same personal factors that modulate engagement and learning in museum-type settings, whether that is their motivation for engaging, their interest in the setting or topic, or their identities. The models, therefore, might prove tremendously useful in research on learning in more formal contexts as well.

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Chapter 11
Leveraging Intersectionality and Positionality in Praxis-Oriented Teacher Learning

Déana Aeolani Scipio

11.1 Introduction

The deaths of Black, Indigenous, and People of Color (BIPOC) have motivated educators and others to rise up and demand change. Black Lives Matter (BLM) protests swept the nation and the world, in the wake of a series of killings of unarmed Black people in the United States (U.S.) in the spring and summer of 2020. One of the outcomes of the racial reckoning in the U.S. has been a push to explore the foundations of policing, social inequities, and critical race theory in an effort to name and exorcise white supremacy within intuitions. Public monuments to white supremacist leaders have come under necessary scrutiny with many physical monuments being pulled down in acts of social and political protest. This process has extended to the environmental education field and led to an exploration of the monuments within our field to white supremacy and settler colonialism both physical and intellectual. For example, a July 2020 piece by Sierra Club executive director Michael Brune entitled "Pulling Down our Monuments" highlights the conversation happening within their organization to reckon with the white supremacist and settler colonial ideology of the founders, including John Muir. The ideas and biases of John Muir and other founders of western environmental movement serve to erase the contributions of people of color who are contemporary stewards of natural environments and have been in relationship with more than human others since time immemorial (Medin & Bang, 2014). Environmental educators of color created an online community and resource hub to center BIPOC called Intersectional Environmentalist to push back against this narrative and move the field beyond environmentalism to intersectional environmentalism. Intersectional environmentalism (Brown et al., 2020) paves the way for a nuanced conversation about the experiences and contributions of people of color in environmental movements.

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Environmental Education (EE) organizations struggle to define the parameters of their work within increasingly diverse contexts (Romero et al., 2019). Our work as an EE non-profit entails using environmental science, outdoor, and informal education practices to work towards environmental justice. While broadening participation for educators from non-dominant communities historically underrepresented in EE fields is critical to this work, it is also necessary to prepare educators from within the dominant community to engage in the cultural and epistemic shifts that come with broadening participation in environmental justice education and action. I argue that the field of EE needs new kinds of educators who are prepared to embrace this work in the wake of the racial reckoning and the global pandemic.

Preparing educators who can think about environmental justice and the disparate climate impacts on people from non-dominant communities requires a different approach. The temptation to stay comfortably within the realm of environmentalism as a motivational frame aligns with an assimilationist frame that can pervade Western environmental approaches to understanding nature culture relations (Bang et al., 2012). EE is a historically and predominantly white field. Thus, my work towards broadening participation in EE involves multiple strategies. First, I am interested in increasing the numbers of people from non-dominant communities historically underrepresented in EE by changing the numbers of participants. This involves long-term goals for recruitment and retention of people from non-dominant communities whose experiences have and must continue to expand the field. In addition, as a field EE has a long way to go to avoid race-equity detours (Gorski, 2019). Gorski names four detours in his piece and five proposed solutions for educational equity, the approach that I describe in this chapter focused on curating learning experiences for the graduates in our program that are solution-oriented. We strive to "fix injustices, not kids" and take practical steps to help our graduates develop and deepen an "equity ideology" in their coursework. Parallel work could happen in orientation, training, and professional development contexts for educators who facilitate learning in informal learning environments.

Changing the demographics of EE must couple with a change to the existing paradigms within EE organizations that aligns with race-equity. This requires work at the organizational level to develop statements about commitments, trainings for existing and new staff, and organizational systems change to center Justice, Equity, Diversity, and Inclusion (JEDI). There is a unique opportunity in predominantly and historically white EE organizations like mine to develop approaches to work towards these changes within graduate programs that nest within residential EE centers. This chapter is a worked example of ways that leverage what we are learning in our graduate program to support training and development for educators in other informal learning environments.

When working with graduate students who are novice teachers and mostly members of dominant communities, it is important to engage them in conversations about JEDI through the lenses of intersectional identities and positionality. Positionality asks students not only to share about their intersectional identities but also to place themselves within structures of social practice (Bell et al., 2012). This work occurs at the border of intersectional identities and positionality (Bang & Vossoughi, 2016; Crenshaw, 1991, p. 3; Kleinrock, 2021; Kleinsasser, 2000, p. 3; Warf, 2010). When working with graduate students from dominant communities, I try to engage through the lens of positionality because positionality asks students not only to share about their intersectional identities, but also to put themselves into new contexts, challenge themselves to engage with new paradigms and epistemologies, and prepare themselves for the life-long work of un-learning white supremacist ideas. Kendi (2019) challenged his readers to engage in antiracism as an active pursuit. Kendi argues that the racist/not racist dichotomy is not serving our work, we need people to commit to becoming antiracist. This work seeks to move towards an anti-racist imaginary.

My students come to the graduate program, seeking the opportunity to engage in anti-racist and intersectional environmentalism (Brown et al., 2020; Thomas, 2022). Often, they want to begin by learning more about their students and seek out tool kits or sets of pedagogical practices. This is understandable because JEDI work is complex. Graduates recognize the privilege and responsibility they bear for creating learning environments for BIPOC youth and want to know how to start this work. I encourage them to begin by examining themselves, an approach that aligns with anti-racism projects in many critical and practice-based teacher education programs (Thompson et al., 2020).

11.2 Theories

11.2.1 Intersectional Identities

Intersectionality is a term Crenshaw (1991) coined and used in a legal sense to describe the unique ways women of color experienced issues that would not have been ameliorated by programs to support women or programs to support people of color. Intersectional identities are not additive but rather combine differently for each individual. Within our program, my goal is to leverage the fact that each graduate student has unique intersectional identities made up of their personal histories, experiences, and backgrounds. I ask graduates to explore which intersectional identity markers are most important to them—e.g. race, gender, ability, socio-economic status, etc.

11.2.2 Positionality-Positioning Theory

Positioning theory is fundamentally about relationships. I borrowed the term from the field of geography where it is defined as,

> the notion that personal values, views, and location in time and space influence how one understands the world. In this context, gender, race, class, and other aspects of identities are

> indicators of social and spatial positions and are not fixed, given qualities. Positions act on the knowledge a person has about things, both material and abstract. Consequently, knowledge is the product of a specific position that reflects particular places and spaces (Warf, 2010, p. 2258)

This definition pushes against the idea that intersectional identities are static and reside within individuals, rather they are not fixed. Positionality allows us to think about how individuals are in relationship to one another, to disciplinary content, and to broader systems of power, privilege, and oppression. It is an ideal theoretical construct to guide the work I do with graduate students in my program. I ask them to examine the ways in which they are in relationships to each other, to the youth with whom they work, to the discipline they teach, and to broader systems of power, privilege, and oppression that shape the knowledge they hold about interactional contexts within our society.

When I speak with graduate students in my program about the connections between intersectional identities and positionality, I use the metaphor of orienteering to describe the impact of the ways that they are each located in different places with respect to systems of power, privilege, and oppression. In EE, orienteering refers to using compasses and maps to navigate through unfamiliar territory. Each graduate's intersectional identities can be imagined as different locations on a shared landscape. The features of the landscape make it more difficult or easier for each individual to navigate their way towards their goal. Some people may find themselves with a clear pathway, while others have to navigate a hill or traverse a stream to reach the goal. An individual's starting location on the map is the interaction between their intersectional identities and positionality or relationship to broader systems of power, privilege, and oppression. This is essential self-work to prepare educators who will facilitate learning experiences for youth and adults in a variety of informal learning environments.

11.3 Framework/Conceptual Links

11.3.1 Persons in Structures of Social Practice

I am invested in my students learning how to toggle between their individual experiences or intersectional identities and recognizing their positionality by seeing the impacts of broader systems of oppression. I want them to hold their personal experiences of the world as sensemaking schema but when it comes to racism, sexism, or ableism personal experience cannot lead to an understanding of the ways these constructs function systematically to confer power, privilege, and oppression. As individuals we have many experiences that shape the ways we perceive the world around us and the opportunities open to us. These personal experiences do not exist within a vacuum but are shaped by systems of social practice (Bell et al., 2012). This can be a difficult concept for students to grasp as these systems are self-protecting and function in ways that obscure their impacts to people whose lived experiences are unchallenged. For example, a person whose name does not contain an accent would be unlikely to notice that most online systems cannot process accents. As a person whose name has an acute accent over the “e” changing the pronunciation of my name. I encounter a variety of error messages each time I try to write my name in an online form. My name is a big part of my identity and filling out forms on the internet for banking, medical, personal, and professional reasons, makes clear to me every day that my name is not “normal” or expected by persons who have power to design online data entry systems.

This part of my identity makes visible a systemic lack of recognition that people’s names are important. It means I cannot bring my whole self to most online spaces and often means I must write my name incorrectly to complete necessary forms. While this may seem a trivial example, it shows the ways in which lack of epistemic heterogeneity can create oppressive systems. If more designers of technological systems were people from non-dominant communities, these systems would include ways to enter accents or other diacritical marks prevalent in other languages and used in English by many people of the global majority.

11.4 Teaching and Learning Context

IslandWood’s graduate program in Education for Environment and Community is a praxis-oriented, designed learning environment that brings together theory and practice. Graduate students spend nine months immersed in a living and learning community. They take academic coursework while teaching in IslandWood’s practicum—a teaching experience nested within a residential environmental program that serves 4–6th grade students (ages 9–12) from a large metropolitan area in the Pacific Northwest (the Seattle metropolitan area and the Kitsap Peninsula). IslandWood’s program is a layered learning environment where youth and adult learners participate in a complex ecosystem of learning. Youth in IslandWood’s programs learn about environmental sustainability, interconnections, watersheds, ecosystems, collaboration and teamwork, natural history, ecology, and deepen their understandings of the natural world and their place within it. Graduate students’ coursework covers many aspects of education, e.g., science methods, philosophy, natural history and ecology, child development, and advanced instruction strategies. These courses are enhanced by the experiences that graduates have in the field working as instructors. Graduates can bring frameworks and approaches they are learning in their coursework into the field to enhance their teaching and sensemaking about their work with youth. Then graduates can bring the things they are learning through their experiences in the field to help with their sensemaking in their academic coursework. This is praxis.

Islandwood is a residential environmental education center on 255 acres of land that includes multiple ecosystems and field structures. Each are distinct but interconnected learning environments. Graduate instructors design Land and Waters-based learning experiences for each group of 4–6th graders who come to Islandwood.

The teaching and learning environment is a dynamic space that changes with the weather and season. Graduate instructors need to be prepared to flex their lesson to the demands of locations, weather, season, and to meet the needs that individual groups of students bring to their week at our school in the woods.

Each graduate student takes a group of 10–12 school overnight program (SOP) students into the field with a backpack full of materials, books, first aid supplies, binoculars, field guides, student journals, and plans that need to be able to change on a dime. In addition to the physical materials grads carry we want them to also have conceptual tools and always bring a JEDI orientation to designing and implementing antiracist pedagogies. This is the nature of our dynamic informal learning environment. Graduate student instructors must remain responsive to the environment and student needs, and we want them to be guided by a strong JEDI lens. This chapter focuses on the coursework that grads complete during the academic component of our praxis program in order to draw attention to the type of training and development that we feel best prepares them to make JEDI informed decisions in their curricular planning and pedagogical practices. I hope that this can serve as a guide to designers and managers of informal science and informal learning environments who are creating and implementing JEDI trainings for their staff at their respective institutions.

Prior to coming to Islandwood as a graduate student in 2007, I worked in a variety of informal learning environments with youth—museums, after school, and summer programs. The teaching and learning experiences vary greatly in these designed environments yet I was seldom asked to explore or name theories or biases that guided my pedagogical or curricular choices. This chapter offers a theoretical framework and approach to the kind of training and ongoing learning that can support instructors and facilitators who work in informal learning environments to develop a strong JEDI lens that can guide their work with the increasingly diverse audiences who visit their institutions.

In my role as program director, I teach two courses in our program, one a foundations of education class in the beginning of the year and I bookend the year with a degree-completion, qualitative methods course. I see many connections between these courses, as both teaching and research require iterative cycles of design, implementation, analysis, interpretation, reflection, and re-design. Critical frames on research and teaching ask researchers and practitioners to engage in reflexive (Harré et al., 2009, p. 6; Kleinsasser, 2000, p. 3; Ravitch & Carl, 2021) and interpretive (Rosebery et al., 2016; Warren et al., 2001) work to understand themselves in relationship to their teaching or scholarship and to create environments that allow them to hear the voices of their students or participants. These courses together contribute to a broader understanding of two of the high-level conjectures that shape the work in our graduate program. These two high-level conjectures (shared below) describe the core elements of the designed-learning environment in our graduate program. They are based upon years of graduate programming, prior design experiences within praxis-oriented teaching and learning environments, and insights from critical scholarship. They represent the intentions we have for this learning environment.

1. Praxis-oriented, iterative teaching and learning create a reciprocal relationship between theory and practice, allowing graduates to leverage personal experiences, develop schema, and deepen their understanding of educational theory.
2. Self-work is an important element of becoming a JEDI-informed educator. Deepening a sense of intersectional identities, understanding positionality, and developing a sense of place all play into this work.

In Fig. 11.1, I use conjecture mapping (Sandoval, 2014) to trace these high-level conjectures or design goals for graduate student learning through the embodiments and mediating processes that connect to these desired outcomes in our program. The figure is color coded to show how the high-level conjectures in the first column are connected to embodiments shown in column two, mediating processes shown in column three, and outcomes shown in column four. Embodiments refer to tools, materials, task structures, participant structures, or discursive practices. In the case of the IslandWood program, there is considerable overlap between the embodiments and mediating processes connected to each high-level conjecture. Conjecture mapping is a design and analysis tool that takes elements of designed environments, considers their impact, and makes visible how they interact with one another to lead to outcomes.

11.5 Teaching and Learning Approach

Booker and Esmonde encouraged learning scientists to leverage critical theories to "challenge normativity and address how power circulates and sorts" (2017, p. 163). I take this to mean it is incumbent upon me as a researcher and teacher educator to challenge normativity and address power in our learning environment—a school in the woods.

I take up this challenge in the foundations course at IslandWood. I ask graduate students to write a philosophy of education that includes intersectional identities and positionality statements. In the class, I define a positionality statement for my students. I use an academic definition of positionality and explain it refers to the stance or positioning of the researcher or educator in relation to the social and political context of a learning environment. I ask them to write a statement that includes their own identities and speaks to who they are in relationship to the discipline. I ask them to think about the following questions:

1. What motivates you to do this work? Why do you want to teach?
2. What aspects of your identity connect you to this work?
3. How do your values, viewpoints, and experience shape your connections to your teaching?

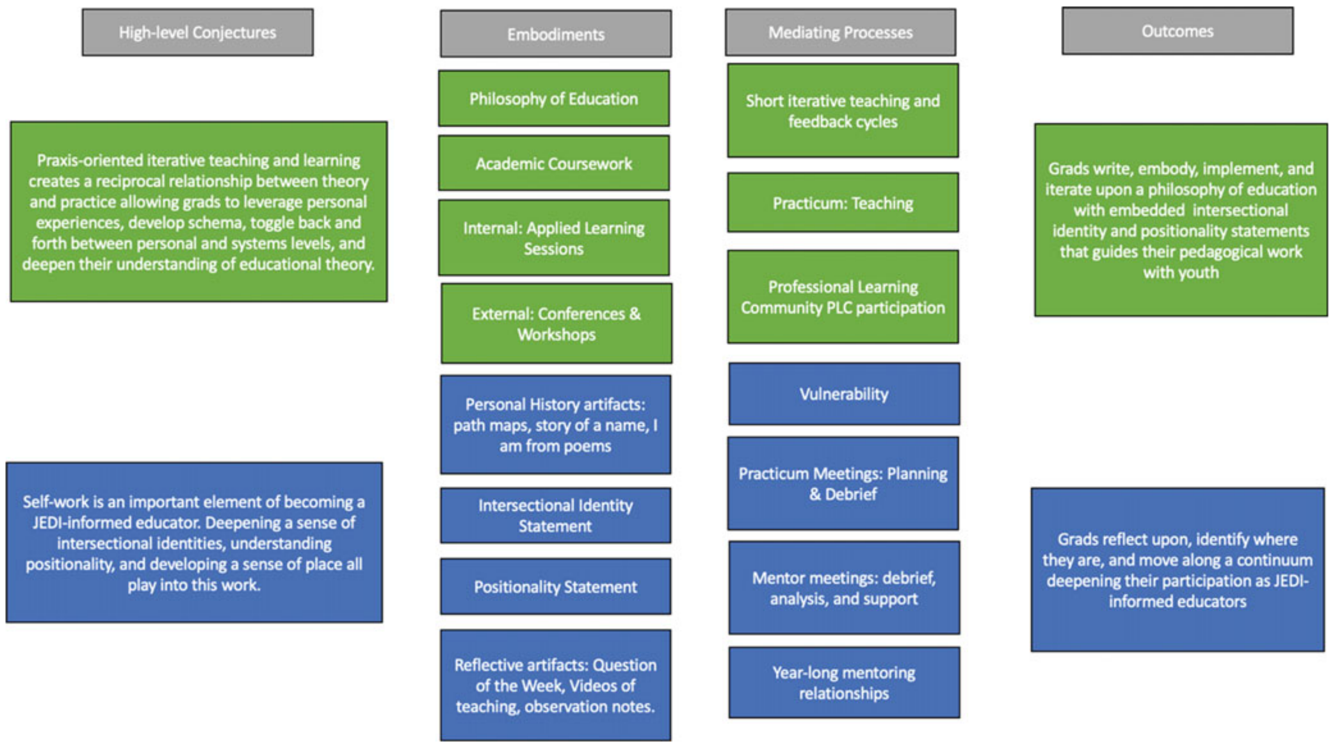

Fig. 11.1 Conjecture map (Sandoval, 2014) of the Education for Environment and Community graduate program showing two high-level conjectures with their interconnected embodiments and mediating processes leading to desired program outcomes

This approach creates opportunities for graduate students to leverage their lived experiences and place them into conversation with broader systems of power, privilege, and oppression. I use intersectional identity theory to help them better understand the complexities of their identities and positionality theory to push them to consider their identities in relationship to broader systems. The outcome is a situation in which graduate students can understand more about the role power plays in the relationships between their intersectional identities and systems of oppression. Graduate students come to realize that while certain aspects of their intersectional identities position them in powered ways, other aspects of their identities create vulnerabilities. Coming to understand these complexities helps the graduate students prepare themselves to work with youth from both non-dominant and dominant communities. This approach can be used by designers and trainers in many other informal learning institutions to prepare facilitators who can design antiracist curriculum and implement pedagogy to meet the needs of the increasingly diverse participants who come to their informal learning environments.

In the following sections, I share some vignettes to highlight how graduates respond to the assignment. For some students like Susan this type of work is novel and makes them explore elements of their identities that they may never have questioned before. The process of exploring their identities can make the familiar strange. Asking graduates to create statements about their intersectional identities resists normativity and the myth of objectivity in teaching and learning environments. Especially for members of dominant groups, it can be difficult for them to see how their identities shape their pedagogical choices, epistemologies, and the biases they are bringing into their work with youth. For Susan a member of many dominant communities who had never been asked to identify her intersectional identities this was a very dauting task. For Mary, a woman with both dominant and non-dominant identities, the activity opened up new pathways for her learning and development.

11.5.1 Positionality Vignette: Susan

One of the young women in my foundations class, I will call her Susan, asked me to meet with her during office hours because she was having a hard time drafting her philosophy-of-education statement. She was one of the younger and less experienced members of our class, having come to IslandWood straight out of an undergraduate program in natural sciences. She was typically silent in class, and I considered it a success when she began to share her opinions with the class. I sat with her during office hours and asked her to tell me what was challenging for her about the assignment. She told me she did not know how to answer the questions I had asked. The assignment pushed her to engage in a type of thinking she never had done before.

When Susan came to ask me about how to write her positionality statement, she came to figure out how to secure the grades she wanted for the class, and it was also the beginning of an exploration for her. The exploration of her intersectional identities was tied to her grade and thus the assignment pushed her boundaries and encouraged her to develop a better understanding of the frames that she uses to make sense of the world, and how they interact with systems of power, privilege, and oppression.

11.5.2 Positionality Vignette: Mary

Another young woman, let us call her Mary, came to office hours to discuss her positionality statement. She was the oldest person in the class and came to her writing from a different standpoint. Her journey through the class was one of coming to articulate her theoretical frameworks. The assignment pushed her to explore educational philosophy and theory to find work that resonated with her stances and approaches to teaching.

For Mary, the exercise allowed her to crystallize theoretical approaches she wanted to incorporate into her teaching practice. Whereas for Susan this exercise was one in which she confronted for the first time the idea of how to answer these questions. The assignment pushed both students to understand the theory and put into practice intersectionality and positionality.

Including self-work and introspection as a classroom assignment played a role in each student's willingness to engage in this task. The graduates in my program had to engage with these theories to complete the assignment which in turn pushed their thinking. However, I recognize the privileged position of doing this work within a graduate program. Without the formal teaching and learning structures of a graduate program, designers of educator training in other informal learning environments will need to explore the kinds of intrinsic and extrinsic motivations for engaging in this type of self-work.

11.6 Discussion

Strategically speaking, approaches that focus on developing empathy via engaging in conversations about privilege and white fragility remain problematic. The problem is not that these constructs are untrue but rather that they do not seem to be effective levers to pull as we seek to change perceptions and behavior, especially for educators with dominant intersectional identities and positionality that confer power and privilege. As an EE educator attempting to broaden participation in JEDI work within the field, I seek to support the development of race-equity conspirators and co-conspirators. Using the term co-conspirator to describe dominant participants appeals to me in race-equity work because it implies how deeply engaged we all must be. People with power and privilege must be to be willing to risk as much as their non-dominant colleagues as we strive for equity. I am interested in changing what it means to participate in environmental education such that more and diverse ways of knowing become included in our community of learners. This is the work of desettling environmental education (Bang et al., 2012).

Preparing educators who will work in informal environments to think about environmental justice and the disparate impacts of climate change on people from non-dominant communities requires a nuanced approach. The temptation to stay within an environmentalism frame aligns with the assimilationist impulses that can pervade unexamined western approaches to EE. Rather, this work can begin with asking educators to develop new complex understandings of themselves, their intersectional identities, and positionality. These more nuanced understanding can translate into more nuanced approaches to designing and working in informal teaching and learning environments.

If researchers and practitioners are interested in informal practitioners who can develop complex understandings of nature-culture relations and the generative power of multiple epistemologies, attending to intersectional identities and positionality as they write their philosophies of education is a starting point. The work of identifying and naming intersectional identities and positionality while writing philosophies of education challenges educators to consider how they have developed as persons within structures of social practice (Bell et al., 2012). The assignment highlights self-reflection and can make visible the connections between who educators are and how they teach. This assignment is one of the ways that teacher educators can push future educators to recognize the impacts of systems of power, privilege, and oppression on their lives and on the lives of the participants they will work with in informal teaching and learning environments.

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Chapter 12
Identity Construction in Informal Learning Environments: Applying Socio-cultural Situative Theory Through Linguistic Ethnographic Microanalysis

Dana Vedder-Weiss, Aliza Segal, and Neta Shaby

12.1 Introduction

Over the past two decades, youth and adults' science-related identity received growing attention in the science education community (Simpson & Bouhafa, 2020). Scholars attended to how young people develop aspirations for a science career and how they persist in or drop out of the so-called science pipeline. Rather than narrowly examining motivation or attitudes, research began to use the more holistic lens of identity to develop a broader and deeper understanding of learning and participation in science in informal learning environments (e.g., Calabrese Barton & Tan, 2010). Research also applied the concept of identity to explore challenges in science teachers' preparation and professional development in formal and informal contexts (Avraamidou, 2016).

In this chapter, we present a socio-cultural situative approach to identity, review literature that applied such a perspective to explore identity construction in different informal learning environments, and illustrate through three case studies how we apply this theoretical perspective to discourse analysis in various informal contexts.

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12.1.1 Theoretical Framework: Socio-cultural Situative Identity Theory

From a socio-cultural, situative perspective on learning, identity construction is central to science learning. Through experience, people learn to participate in science; that is, they learn how to engage in science practice and discourse, how to make meaning of these practices and discourses, and, no less important, how to belong to and become part of the community that shares these practices and discourse, that is, a science community of practice (Lave & Wenger, 1991). Thus, science identities develop through a process of situated learning in a science community of practice that involves participation in practices of knowing, talking, doing, and being (Lave & Wenger, 1991). The ways in which novices participate in the science community's practices, accepting, rejecting, or ignoring those practices, and the ways in which others respond to their participation, shape their science identities. Thus, people identify and are identified as members or nonmembers of a science community (or as a "science person", Carlone et al., 2014) through their interaction with others.

More specifically, this chapter draws on interactional approaches, which view identity as an unstable, situated, contextual construct (Carbaugh, 1996; Carlone et al., 2014; Gee, 1999; Holland et al., 1998; Wortham, 2006). These approaches broadly define identity as, "the social positioning of self and other" (Bucholtz & Hall, 2005, p. 586), maintaining that what people do through language and other activities is a way of constructing who they are. While psychological approaches view identity as an internal, stable construct that is the source of interaction, the interactional approach views identity as the product of interaction. Accordingly, identity is not the stories people explicitly tell about themselves nor is it the stories others tell about them (for example, in an interview); rather identity is co-constructed by the person and the people with whom s/he interacts through the way the person behaves and talks and how others respond (Gee, 2000; Gumperz, 1982).

This framework thus highlights the temporary interactional positions and roles people play (e.g., the smart girl, the science expert, and the reform-minded teacher) or others assume them to be playing, as central aspects of identity. Identity, according to this approach, shapes through the ways people position themselves in relation to others and to a given situation and through the ways in which others recognize them (Calabrese Barton et al., 2013). Following this approach, a science-person identity is "positioning oneself (deliberately or not) and/or getting positioned as a 'good' science participant" (Carlone et al., 2014, p. 839).

Although identity "can change from moment to moment in the interaction, can change from context to context, and of course, can be ambiguous or unstable" (Gee, 2000, p. 99), repeated roles and positioning accumulate to shape one's identity vis-a-vis a certain community, its practices, and its members (Calabrese Barton et al., 2013; Gumperz, 1982). In the moment-to-moment interaction, one is "responding to and drawing upon past experience as well as the resources and demands of the particular situation" (Holland et al., 1998, p. 40). Thus, while highlighting the situational, unstable nature of a science-person identity, the socio-cultural approach also acknowledges its cumulative nature. Through repeated identifications (by oneself and others) across time and contexts, people develop patterns of positioning and participation (Elmesky & Selier, 2007; Roth, 2006). Calabrese Barton et al. (2013) termed this development an "identity trajectory": "The actions girls take, the relationships they form at any given moment, and the ways in which these are recognized by others leave particular traces in time. We think of the accumulation of these traces, or in other words, these reified moments of identity work in space and time, as 'identity trajectories'" (p. 65). Thus, if children repeatedly identify and are identified as negligible science participants at school, this shapes a nonscience-person trajectory for them. However, if an informal learning environment, such as a museum or the home, offers them opportunities to identify as valuable science participants, this could shift their science identity trajectory. Similarly, repeated teaching or learning experiences in informal environments can shift teachers' professional identity trajectory, for example, by strengthening their disciplinary or reform-oriented identity (Luehmann, 2016; Mehli & Bungum, 2013).

12.2 Application of Socio-cultural Identity Theory in Literature on Informal Learning Environments

Science-related identity has become a growing focus of research and educational efforts (CAISE, 2018). Much of the research on identity development in informal environments has applied a socio-cultural perspective, predominantly exploring youth identity development in structured informal learning environments, such as science clubs (e.g., Tan et al., 2013). Some socio-culturally framed research also examined children's identity construction in everyday family context and informal science learning institutes (e.g., Uzick & Patrick, 2018; Zimmerman, 2012) and teachers' identity development in informal learning environments (Luehmann, 2016).

Identity helps explain how and why youth choose to engage with science inside and outside of school and how they develop science-related career aspirations (Archer et al., 2012; Hazari et al., 2010). Research in different countries (e.g., The United States, England, Germany, South Korea, and Israel) shows how informal environments create opportunities for multiple interactions, recognize multiple contributions (Archer et al., 2016; Bamberger & Tal, 2007; Calabrese Barton & Tan, 2010; Hong & Song, 2013; Itzek-Greulich et al., 2017; Mujtaba et al., 2018), and thus afford greater opportunities to identify as science people. For example, Tan and colleagues (2013) studied, through a longitudinal ethnography, 16 non-White, middle-school girls. They followed the girls across formal and informal contexts, showing how out-of-school settings provided the girls with a wide variety of resources and positionings, affording them opportunities to leverage their nonscience expertise to address science issues that matter in their community, positioning them as "community science experts" (p. 1150) and smart and capable participants. For example, one student, named Kay, played a key role in a science club as a "group leader, investigator, interviewer, scriptwriter, narrator, and researcher" (p. 1168) and was publicly recognized by the local mayor for her science-related activities within the community. In contrast, the girls' contributions often went unrecognized by the school science teacher and the structure and expectations of the classroom prevented their positioning as valuable science participants in school science. The authors concluded, "inspiration for STEM-related careers for all of the girls in our study…arose from success in figuring science in out-of-school worlds in ways that positioned them as smart, capable, and powerful girls with relevant ideas and experiences" (p. 1170). They attributed this to "the less hierarchical, more flexible, and youth-centered norms" (p. 1171) of the informal settings. In another study from the same line of research, Calabrese Barton et al. (2013) demonstrated the unique affordances of the informal settings through the case of a middle-school female student whose participation at the science club gradually shifted as she took a more central role in the club, positioning herself and being positioned as an expert and significant contributor. This further shifted her aspiration to be a dancer to an aspiration to combine arts with science. The shift in her identity trajectory in the club also impacted her positioning at school, as her science teacher moved from defining her as a struggling student to recognizing her as a student "they want to clone" (p. 63). The authors suggested that middle school science increasingly recognizes expediency and getting it right, whereas the after-school science club considers other abilities (e.g., artistic ability) as assets to doing science well. This setting thus provides new and varied opportunities for exploring being a science participant and developing a science person identity.

Similarly, through an ethnographic study, Rahm (2008) investigated an afterschool science program for girls only, serving poor, ethnically, and linguistically diverse youth in Canada, and showed how the program allowed students "to experiment with many different positions in science, as somebody who is able to do science, to understand it, value it and own it." Rahm presented the case of a student for whom "the program opened her horizons to the world of science, a world that was foreign to her and hence not a world in which she would have positioned herself as an insider" (p. 115).

Sociocultural research on science identities has revealed not only ways in which structured informal learning environments have the power to foster science identities, but also variation in the support they offer to different learners. For example, Pattison et al. (2020) used a situative identity perspective to conduct an in-depth, qualitative investigation of identity negotiation of five adolescents in an after-school Boys & Girls Club engineering program. They illustrated using this perspective to understand important differences across youth and to tease out moments and interactions that potentially contribute to the development of STEM identities. They focused on "critical moments" (p. 564), such as failure and success moments, that were rich in identity negotiation and thus highlighted situated identities. They observed that almost every youth in the program worked to position themselves, intentionally or not, as *skilled and knowledgeable* relative to the engineering activities and content. Some participants positioned themselves, or were positioned by others, as the *best and most successful* participants, while others as *helpers and collaborators,* some as *confident and resilient*, while others as *unsure or discouraged.* The authors contrasted the cases of Britany and Ariel, showing how the two girls were similar in terms of independent work, engagement, motivation, and persistence, as well as in terms of working to position themselves as skilled and knowledgeable participants. Yet they were strikingly different in other ways. Britany exhibited a variety of identity bids regardless of the social context, in both large- and small-group activities and with a variety of different peer groups, positioning herself as one of the best and most successful participants, and being regularly positioned as one by adults. In contrast, Ariel's positioning appeared to be highly sensitive to the social context, as she was active in her identity negotiation during small group activities, mostly among her siblings, but rarely made any identity bids during large group discussions. Ariel was positioned positively by her peers, primarily her siblings, but in a few instances was positioned negatively by the adults, who gave credit for the team's work to another participant.

A less-studied informal learning environment that plays a significant role in identity development is the home. Drawing on Carlone and Johnson's (2007) conceptualization of identity work, Zimmerman (2012) presented a case of recognition work at home, accounting for the intentions of youth who *do not* want to affiliate with science. Through an ethnographic study, she followed Penelope's home activities and hobby pursuits (mainly around animals) from fourth to seventh grade, showing how they overlapped with scientific practice. The primary recognition Penelope received was from her mother, who supported Penelope's animal practices from fourth grade onward by providing resources and encouraging her to learn about the animals. Penelope's peers also recognized her expertise in hamster caretaking. Yet, as Penelope grew up, she used her talk and activities around animals (which entailed a lot of biology learning) to seek recognition in animal caretaking roles but not in science roles. On the contrary, she sought to be recognized as uninterested in science, to distance herself from school science, from youth who "like science", and from a science career, fearing being labeled as a nerd.

Informal learning environments can also play a significant role in teachers' professional identity trajectory. Luehmann (2016) presents a case study of one teacher's field experiences leading an after-school science club in a master's program nurturing science teachers committed to social justice. This out-of-school experience was characterized by a small student-to-teacher ratio, decreased institutional accountability, extensive opportunities to practice, focus on students' motivation, engagement and enjoyment, and many opportunities to collaborate and receive recognition for success. In this setting, power was shared more equally between teachers and students, enabling them to "escape the roles and rules that normalize, even oppress them, in other social spaces" (Marquez, 2012, as cited in Luehmann, 2016, p. 31). Through this case of out-of-school teaching, using a socio-cultural perspective, Luehmann demonstrates teachers' identity development that, she argues, can happen only outside the constraints of school high-stakes accountability culture.

A different form of field experience with the potential to impact science teachers' identity trajectory is authentic research experience at a science site. Mehli and Bungum (2013), for example, used a socio-cultural framework to examine the benefits of in-service teachers' collaborations with scientists at an authentic research site.

They studied a short-term professional development course consisting of apprenticeship at a space technology site, demonstrating how participating in a scientific community of practice is important for the development of science teachers' disciplinary identity. However, Varelas et al. (2005) found that such experiences can trigger a sense of conflict between the science community of practice and the school community of practice. They studied the identity development of beginning science teachers during and after 10-week summer apprenticeships at a science lab and showed how the teachers came to appreciate certain science practices and dispositions (e.g., messiness and risk taking) and how these shifted their scientist-identity trajectory. However, these science practices and dispositions were incorporated unequally into their *science-teacher* identity, leading to tensions between different facets of their professional identity.

Research on science-identity development in informal learning environments predominantly demonstrates how these environments afford the construction of science identities (Vedder-Weiss, 2018). A few studies have begun to problematize this general notion (e.g., Pattison et al., 2020; Varelas et al., 2005; Zimmerman, 2012). In the following section, we illustrate how we apply a situative socio-cultural identity perspective using linguistic ethnographic microanalytic methods (Rampton, 2007) to examine in detail co-construction of identity in moment-to-moment interaction. Such an approach allows us to offer a more critical perspective on identity development in different informal settings.

12.3 Illustrative Case Study Excerpts: Applying Socio-cultural Identity Theory Through Linguistic Ethnographic Microanalysis

In what follows, we illustrate how we apply situative socio-cultural identity theory to analyze discourse in three informal contexts: a structured informal setting (i.e., a science museum), the home, and an informal teacher professional learning setting. Our use of linguistic ethnographic concepts and methods integrates ethnography's openness and holism with the insights and rigor of linguistics (Rampton et al., 2015). Against the backdrop of the broader and more immediate social and cultural context in which each set of interactions occurs, we undertake fine-grained analysis of the unfolding discourse (Wortham, 2006).

The analysis in each of the cases included repeatedly listening to the discourse recordings and reading and rereading their transcripts, coding for identity themes and/or tensions, which we then consolidated. We then selected illuminating episodes for more detailed microanalysis, which entailed proceeding line-by-line through the conversations, asking questions such as, "What is the speaker doing?", "Why that, now?", "How does this turn at talk respond to what came before?", "What else might have been done here but wasn't?" (Rampton, 2007). We specifically attended to the ways in which participants positioned themselves, the roles they assumed, their bids for recognition and floor, how others responded to these, positioned and recognized them, and resulting conflicts and power relations.

We present three cases: (1) the (re)construction of students' science identities throughout visits to a science museum (Shaby & Vedder-Weiss, 2020), (2) emerging science identities in family everyday life (Vedder-Weiss, 2018), and (3) science teachers' negotiation of identities related to out-of-classroom teaching (Segal et al., 2019).

Transcription conventions we used in the conversations below include: XXX—Indistinguishable speech, ()—Description of prosody or nonverbal activity, []—Authors' translation, Underline—Stress relative to the surrounding speech, ↑—raised intonation, =—cutoff, (.)—silence.

12.3.1 Case Study 1: The (Re)Construction of Students' Science Identities in School Visits ao a Science Museum

Scholars repeatedly have argued and demonstrated that informal learning environments support the development of science identities (Falk, 2016) by offering a variety of cognitive (Rounds, 2006), social (Calabrese Barton et al., 2013), affective (Williams et al., 2018), and physical (Garner et al., 2016) experiences. They have shown that out-of-school settings foster a broader array of interactions and recognize more varied participation modes and roles, as compared to classroom settings, thereby allowing more young people to identify as "science persons" (Carlone et al., 2014). Because of these (and other) benefits, science teachers increasingly are encouraged to take students on fieldtrips to informal learning environments, such as museums, science centers, and outreach labs (NRC, 2009). The following example is part of a larger study published elsewhere (Shaby & Vedder-Weiss, 2020), in which we investigated whether and how school fieldtrips to informal environments support the development of science identities, by examining whether fieldtrips to a science museum offer students interactions and roles different than their school science affords.

The context of this study is a larger research project (Shaby et al., 2017, 2019a, b, c), which followed Israeli elementary school students visiting a science museum in six school field trips over the course of three years (4th to 6th grade, ages 9–12). For this study, we analyzed 18 h of video recordings, tracking the participation of three girls, Peleg, Ori, and Nofar (pseudonyms), across their visits in the different museum settings. We scanned the entire data corpus and wrote research memos summarizing the flow of events throughout all six visits. To explore identification processes in greater detail, we selected, from the entire data corpus, representative activities for in-depth microanalysis. We used linguistic ethnographic concepts and methods, as we described above, employing micro-analytic methods to analyze the sequential unfolding of events. We paid attention to the ways in which each student participated, verbally and physically, the roles she assumed, and how others (peers, teachers, museum educators, and parental chaperones) recognized and positioned her. As secondary ethnographic data, we used student interviews, informal conversations with teachers and parents, and occasional school observations.

Our overall analysis (Shaby & Vedder-Weiss, 2020) shows that the museum reproduced the school's interactions, positioning, and roles. The (non-)science person in school was also the (non-)science person in the museum, and thus, the museum visits failed to shift students' identity trajectories. Ori demonstrated a consistent science-person identity, appearing interested and engaged in all activities throughout the visits, playing the role of, and recognized as, the 'smartest', dominant, valuable, knowledgeable participant. Peleg decreasingly identified as a science person over the years, identifying more as a "good student", participating and contributing as expected. Nofar was overall consistent in her non-science person identification, expressing very limited interest in science throughout the visits, marginally participating and receiving recognition as a negligible contributor who often needs support.

The following episode illustrates the ways in which the three students' identities were constructed in the interaction, and the affordances of this type of analysis for understanding identification processes in such informal learning settings.

The episode took place at the second 4th grade visit, during a riddle-solving competition in an exhibition hall, in which each competing group received a riddle card it had to solve, bring the answer to the museum educator (ME), and, if correct, receive the next riddle card. Ori, Peleg, and Nofar were in the same group along with another student (Shakked) the ME assigned to them. Ori was almost always the one taking the riddle cards from the ME, reading them, and leading the search for the answers. She was eager to win and appeared highly engaged and even anxious. Peleg completed the tasks as expected from a "good student." She was less competitive than Ori but appeared to care about solving the riddles correctly. As the game advanced and their group appeared to lead the competition, Peleg became more enthusiastic and eager to win. Nofar and Shakked followed Ori and Peleg around, often in silence. Ori discussed the riddles predominantly with Peleg, excluding Nofar and Shakked, who did not object. In addition, Ori and Peleg were always the ones presenting the group's answers to the ME, who attended primarily to Ori and handed the riddles over to her, consistently ignoring Nofar and Shakked. With Ori and Peleg jointly leading their group, the group won the game.

In the following excerpt example, the group tried to find the names of scientists on enlarged money bills exhibited on the wall. Ori practically grabbed the riddle card from the ME's hand and read it aloud—be it to herself or for the benefit of the others—while rushing towards the exhibition, followed by the other girls who tried to catch up and have a look at the card from over Ori's shoulder. The riddle they received was: "Leonardo Da Vinci's image appears on money bills. Search for the 'Scientists on Money Bills' exhibition. Find the money bills in the exhibition that belong to the country in which Leonardo Da Vinci was born. How many bills did you count? Tell the ME the name of at least one scientist who appears on those bills." As the group reached the money bills exhibition, Ori consulted the riddle card:

1	Ori	How many do we need to count?
2	Ori	Tell the ME the name of at least one scientist who appears on those bills (holding the riddle in her hand, reading from it).
3		(Peleg stands next to Ori, listening to her. Nofar and Shakked walk together, talking to each other, looking and pointing at bills).
4	Ori	The country he was born in (walking along side with Peleg, looking at the bills)
5	Peleg	No, no, no (standing next to Ori and pointing at one of the bills)
6	Peleg	The country he was=
7	Ori	=He was born in
8		(The group walks and looks at the bills, Peleg and Ori in the front, Nofar and Shakked behind)
9	Ori	(Ori pushes Shakked away with her hand, without looking at her) No, he was born in (.) France
10	Peleg	Scientist that was born in France?
11	Ori	In Italy! Italy!

Ori was holding the riddle card, reading it aloud to herself and Peleg, who was standing next to her, listening (1–3). Thus, Ori took control of the riddle card with no objections from the other participants, positioning herself and positioned by the others as the dominant contributor, not even challenged by her main collaborator, Peleg. Nofar and Shakked did not listen to Ori, walking behind, talking among themselves, looking at the bills and pointing at them (3), while Ori and Peleg did not attempt to include them. By doing so, the four students collaboratively positioned Nofar and Shaked as more peripheral participants in the riddle-solving interaction. Ori and Peleg continued walking along the exhibition, looking at the bills, when Ori consulted the riddle again, "The country in which he was born" (4). At this point, Peleg appeared puzzled (5), and by repeating Ori’s reading (6) she reinforced Ori’s control over the task; while Ori held and read the riddle to the others, the others could only repeat what she read. Before Peleg even had a chance to complete her sentence and make sense of the riddle (7), Ori already suggested an answer - France (9). Peleg repeated Ori’s answer, connecting it to their task, without challenging it (10). Nevertheless, her question might have led Ori to reconsider her answer and excitedly replace it with the correct answer—Italy (11).

The bodily arrangement of the students in this interaction is telling in terms of their relative engagement with the exhibit and each other and their claims for space: Ori and Peleg were in front, reviewing the bills and searching for the answer, facing each other while discussing it; Nofar and Shakked walked further back. When Shakked made a subtle move towards Ori, perhaps trying again to sneak a peek at the riddle card in Ori’s hand, Ori made another physically excluding move by swatting her away as she continued talking to Peleg (9), thus maintaining their exclusive collaboration. Shakked did not object to Ori’s push and moved back.

In this episode (Fig. 12.1), Ori positioned herself and was positioned by her peers and the ME as the leading competent participant, while Peleg was positioned as her

Fig. 12.1 The students' bodily arrangement during the activity

valued collaborator and Nofar as a negligible participant. The design of the activity—a competition they won—served to position Ori not only as the leader of her group but as the most capable student in the entire class.

Microanalysis of this short excerpt illustrates how we use the situative socio-cultural identity perspective to understand identification processes in learning interactions in informal environments. Such analysis allowed us to explore the affordances and limitations of school fieldtrips to informal environments, comparing between different students, different activities, and different points in time. The findings of this analysis, and others in the larger study, challenge the premise that informal environments support the development of science identities also in a schooling context and call for a more critical view of such fieldtrips and their design.

12.3.2 Case Study 2: Identity Work in Family Everyday Life

Family plays an important role in the development of children's science identity (Bricker & Bell, 2014; Tan et al., 2013; Zimmerman, 2012). Scholars suggest that family science-related capital and habitus (Bourdieu, 1984) shape how families engage with science and thus support their children's science identities (Archer et al., 2015; Claussen & Osborne, 2013). Families with rich science capital actively support science engagement through the foregrounding of science in everyday life, for instance, by providing science magazines, watching science-related TV, talking about their science-related careers, and going to science museums (Archer et al., 2012). In these science families, children receive opportunities, resources, and support to develop a sense of ability in science as well as a perception of science as desirable. While Archer et al. (2012) recognize that children in 'science' families do not necessarily develop strong science identity, they do not explore the ways in which such 'incompatible' identities develop. Thus, this study explores how children's science identity emerges through engagement with science in the everyday life of a science family. The following example is part of a larger study published elsewhere (Vedder-Weiss, 2018).

Through a self-ethnography, the study followed one Israeli family during its one-year sabbatical leave in Australia. The family consisted of a mother (the researcher, a science educator, and the first author of this chapter), a father (plant biologist), and three sons (ages 8, 11, 15). The mother–researcher collected data throughout the year, by audio-recording events of family engagement with science content or practice and by writing supplemental field notes. In total, she audio-recorded 305 events, amounting to a total of 26 h and 52 min. Analysis began with an exploratory phase of data review, writing, for each event, a research memo summarizing the flow of affairs, including participants, the setting, scientific content or object, scientific practices, and disciplinary affect. This initial analysis suggested that throughout the year, Shahar (11 years old) and Yoav (8) exhibited different patterns of participation in science. Thus, we reviewed the research memos for events that shed light on aspects of participation, positioning, recognition, and roles. We used linguistic ethnographic microanalytic methods, as we described above, to analyze the sequential unfolding of these episodes, examining the ways in which the children participated and the ways in which others recognized and positioned them.

To illustrate the ways the analysis employed the situative socio-cultural perspective to shed light on how different identities are co-constructed in the same science family, we present one event that took place when Dad, Shahar, and Yoav returned home from a walk in the neighborhood with a bag full of colored fallen leaves they collected. They laid the leaves out on the table as an exhibition, discussing how to "tape the leaves onto sheets of paper." Mom and Dad soon noticed that Shahar disengaged:

10	Dad	(to Shahar) The exhibition doesn't interest you?
11	Mom	The falling leaves exhibition doesn't interest you?
12	Shahar	I'll be happy to see the exhibition. I won't be happy to prepare it. Maybe I can write a few things. But later.
13	Yoav	But how do you know their [the leaves'] names?
14	Shahar	Not about the leaves. About the foliage.

As the family collaborated in preparing the exhibition, Shahar's disengagement stood out to both parents who made a point of recognizing it, thereby legitimizing his disinterest but at the same time signifying that this contradicted their expectations. In response, Shahar clearly sketched the boundaries of his interest: first, in term of actions, he was uninterested in preparing the exhibition—in taping the leaves—but he was willing to write for it and view it. Thus, Shahar distinguished himself from what he may have perceived as a childish artistic activity, appropriate for his younger brother but not for him. The writing—a proficiency in which he had a clear advantage over his brother – is something to which he indicated he might consider contributing; but note he did not commit to it ("maybe"). Second, in terms of timing, Shahar clarified he was uninterested in the exhibition right now, but he reserved the right to get more involved, if he so chose, "later". The other family members did not explicitly object to Shahar's withdrawal and did not, for example, try to persuade him to participate. The only reaction came from Yoav, who questioned Shahar's ability to contribute as he had suggested (13), perhaps reacting to the implicit message that writing is superior to taping. Shahar made his intended contribution clearer (14) and went outside to play ball.

While Dad and Yoav went on with preparing the exhibition, Mom looked at the photos they had taken during their walk and asked Dad:

32	Mom	Dudu, did you however notice that the more exterior leaves on the trees are the first to turn red, while inside [the tree], it [the foliage] is still green
33	Dad	(mumbles) I don't think light intensity
34	Mom	I don't think that makes sense, since as light intensity decreases, the leaf senses more of the winter signal. What characterizes falling leaves is a decrease in light intensity.
35	Dad	(mumbled) No. Definitely not.
36	Yoav	It's the shortening of the day.
37	Dad	(raising his voice) Good job, Yoavi!

Modeling scientific observation and argumentation (in an example of family science habitus), Mom asked Dad about the puzzling color distribution within the same tree. Dad responded absentmindedly to Mom's questions and arguments (33, 35). In contrast, when Yoav jumped in to offer an explanation, even though Mom clearly was addressing her questions to Dad (32), Yoav received loud praise from Dad (35), who by so doing, recognized Yoav for his valuable contribution to the scientific discussion and even positioned Yoav as superior to Mom in his scientific knowledge and understanding.

Mom took photos of Yoav standing next to sheets of papers on which they had taped the leaves, and then they hung the sheets around the house. After about 15 min, during which Shahar was dribbling the ball outside, Yoav and Mom came out to the yard to take photos of Yoav and the leaves from the outer side of the window.

98	Mom	Did Dad explain to you something about the leaves, the foliage, or did you just collect [leaves]?
99	Yoav	Why do they fall, why does this?
100	Mom	Come here.
101	Yoav	Why? how do they know that spring arrived?
102	Mom	Spring?↑
103	Yoav	Why do they fall? Oh the autumn [arrived].
104	Mom	Ahh yes.
105	Yoav	They fall because
106	Shahar	XXX
107	Yoav	Because it's cold in the winter and their leaves can't survive so they go into dormancy. And how do they know eh like they have a biological clock and they have a pigment that identifies the light=
108	Sahar	=The day gets shorter=
109	Yoav	=and that the day gets shorter=

(continued)

(continued)

110	Shahar	=I understood that
111	Yoav	They shed [leaves]=
112	Mom	=What does 'I understood that' mean?
113	Yoav	Dad asked who knows. I said because it gets darker earlier and that's like what I meant.
114	Mom	Right. Come over, stand beside this.
115	Yoav	The day gets shorter.

Cued by Mom to demonstrate the knowledge he gained throughout the day, Yoav repeated Dad's biological explanations about autumn foliage, using scientific concepts (dormancy, biological clock, pigments) and describing biological mechanisms. Shahar continued dribbling the ball, but also tried to join the conversation. His attempts are mostly inaudible in the recording and were probably also inaudible to Mom, who ignored them. While Shahar could have stopped dribbling to express more explicitly his desire to join the conversation, Mom and Yoav also could have stopped their exchange, gotten closer to Shahar, or asked him to repeat what he said. Nevertheless, Shahar explicitly claimed his right over the attribution of autumn fall to the shortening of the day ("I understood that"), and when Mom asked for clarification of this claim (What does 'I understood that' mean?) it was Yoav who responded again, explaining that while Shahar may have been the one to first use the concept "shortening of the day", Yoav was the first to mean it (113).

The analysis of this event, and many others in the corpus, show how the theoretical and analytical frameworks we employed illuminate the repeated co-construction, by all family members, of Yoav as the science person and Shahar as the non-science person (Vedder-Weiss, 2018). The relative positioning of the two brothers consisted of the roles assigned to each of them, and the roles they each took on. Yoav often took on the role of a central science participant, exhibiting interest and knowledge, initiating scientific investigations, asking questions, and sustaining conversations, whereas Shahar was more restrained, often excluding himself from such engagement and exhibiting impatience and disinterest. Yoav was assigned the role of a valuable science participant by his parents, through the recognition he received for his interest, engagement, and knowledge, while Shahar's bids for recognition often were neglected. Such identity work, which included repeated positioning and roles (by self and others), may explain how in the same science family different identities emerge, with one child developing a science-person identity even as the other develops a non-science-person identity.

12.3.3 Case Study 3: Science Teachers' Identity Negotiation Vis-À-Vis Out-of-Classroom Teaching

Reform-oriented science teaching emphasizes inquiry-based teaching and learning. Inquiry teaching aims to develop scientific literacy, skills, and knowledge building, through engagement in authentic scientific practices, including hands-on experiences and related reflection—dialogue, reasoning, and argumentation (Crawford, 2000; NRC, 2012). This approach considers and values not only cognitive dimensions but also affective ones such as student motivation and identity development. Inquiry-based teaching may include teaching in informal environments. Indeed, science teachers increasingly are encouraged, and sometimes even pressured, to include out-of-classroom learning activities in their instruction, that is to take their students on fieldtrips to museums and nature trails, to use the schoolyard and close surroundings as a resource for their teaching, and the like (NRC, 2009; Tal & Dierking, 2014). Elementary science teachers are expected to implement inquiry-based and out-of-classroom teaching (Danielsson & Warwick, 2014; Davis, 2004). However, they are typically generalists (Ardzejewska et al., 2010; Kane & Varelas, 2016) who teach multiple subject areas and often perceive themselves primarily as homeroom teachers responsible for the well-being of the student rather than for his/her science learning. They often have limited disciplinary science training, which means they have not been socialized into the scientific practices and dispositions that underpin inquiry-based teaching in general and out-of-classroom teaching in particular (Gunning & Mensah, 2011). Thus, elementary science teachers face particular challenges employing inquiry-based and out-of-classroom teaching. Such challenges have been studied through the lens of professional identity, but most research to date has focused upon pre-service teacher education or teacher induction, and has utilized primarily interviews, journals, and narrative accounts as research tools and data sources (Avraamidou, 2014). Our study, by contrast, examines the challenges faced by elementary science teachers surrounding out-of-classroom teaching by studying how they construct their professional identities within on-the-job discourse, that is, how they talk to their in-school colleagues about teaching in informal environments. We contend that on-the-job discussions constitute an informal learning environment for the teachers. Given the situated nature of identity, we argue that identity work with colleagues at school is more likely to shape instruction than identity work taking place outside the school. Thus, it is these, embedded in their day-to-day work, loosely structured conversations between teachers through which they learn from one another what it means to be a teacher in their school (Lefstein et al., 2020). This case study thus offers a double glimpse into informal environments: first, the teachers' informal learning environment, in-school teacher team meetings, and second, the informal learning environments they discuss creating for their students.

The context of the research is a design-based intervention research study of a program aiming to foster teacher professional discourse and in-school teacher pedagogical leadership in Israeli schools (Vedder-Weiss et al., 2019). Our research on science teacher professional identity focuses on one in-school teacher team comprised of four elementary (ages of students 6–12) science teachers, including Adi, Sharon, Dara, and team coordinator Noa (pseudonyms). Noa participated in bi-weekly professional development workshops offering tools, ideas, and practices to help her facilitate discourse generative for teacher learning, but the weekly team meeting topics and ways of addressing them were left to her and her team to determine.

We observed and audio-recorded eight of this team's meetings, four of which focused on out-of-classroom teaching and form the data set for the study. We analyzed the data through the lens of socio-cultural theory on identity, using linguistic ethnographic concepts and methods as we discussed above. We examined through these interactions the ways in which the teachers positioned themselves and one another vis-à-vis their professional identities.

Six facets of science teacher identity emerged from the data: *expert in the teaching of science*, *reform-minded science teacher*, *traditional teacher*, *homeroom teacher*, *colleague*, and *organizational policy enactor* (Segal et al., 2019). The following brief example illustrates the ways in which two of these identities were constructed in the discourse, and the affordances of this type of analysis for understanding the teachers' identity-work in this informal professional learning setting.

In this extract, Noa asked the other three teachers to write down the advantages and disadvantages of out-of-classroom teaching. Sharon and Dara shared their ideas, which focused primarily on disadvantages such as lack of structure and control, lack of clear achievement measures, and the potential for children to be injured in the less-closely supervised and freer outdoor setting. Noa, in an apparent bid to steer the conversation towards the benefits of teaching outdoors, offered a personal narrative:

137	Noa	But I want to tell you that my daughter's school, Greenwood, most of the, most of the nature lessons take place outside of the school, because the school is located in a forest.

Noa's opening "but" counters the immediately preceding section, in which Dara presented the perils of taking her first graders outdoors. Noa's narrative is set at her daughter's school; by transposing the setting, Noa was able to present an idealized picture of what is possible. She attributed the school's ability to conduct these lessons outdoors to its location in nature, "in a forest". The teachers' initial response was positive.

138	Sharon	In the scenery, in the forest, how fun.
139	Dara	They go outside?
140	Noa	They always go out and I see the, the enthusiasm.
141	Sharon	The difference.
142	Noa	First of all,
143	Adi	Here we also have Exploring in the Grove.
144	Noa	It doesn't come from me, not regarding [my] personal kids, but she came and she said to me'Mom, you know, we went out and we saw a drimia'. I said 'nice,' like, and then I say wait, but she's seen a drimia with me twenty times.

Sharon responded with delight ("how fun") to the setting described by Noa, adding "in the scenery" to "in the forest" (138). She presented out-of-classroom learning as constant and ongoing ("always"), and as fostering "enthusiasm" among the students (140). "Enthusiasm" is a specific positive effect Noa claimed for out-of-classroom teaching; this is the first mention in this meeting of such a specific benefit. Even before

Noa got to the heart of her narrative, Adi made explicit the implied comparison with their own school (143). That is, just as Noa's daughter explores in the forest, so, too their students explore in the grove. While Adi could not claim that she and her colleagues, like Noa's daughter's teachers, "always go out", her statement contributed to the team's collective identity construction as *reform-minded science teachers*.

Noa continued her story about her daughter's enthusiasm for science fostered by Greenwood school (144), but her colleagues challenged her narrative:

145	Dara	Just a second, but
146	Sharon	And who hit?
147	Noa	And then we got back and drew it and she showed me and so on.
148	Dara	But they go out without accompanying parents?
149	Sharon	Yeah, how do they go out?
150	Noa	No, they have an aide.
151	Dara	Here there's no such thing as that, you don't go out to the parking lot without an accompanying parent.
152	Noa	So that's it, it's different rules.
153	Dara	A different school, a different Ministry of Education.
154	Sharon	How nice.

Bringing the constraints of the real-world teacher to the fore disrupted the idyllic picture Noa depicted. Sharon surmised that the story ended with fisticuffs (146), and she and Dara both explicitly challenged Greenwood's practices on the grounds that they defy Ministry of Education policy about the manpower required to take students outdoors (145, 148, 149). In this exchange, they constructed professional identities of *organizational policy enactors*, who know and implement MoE policies. In this manner, the two professional identities, reform-minded science teacher and organizational policy enactor, came into tension. The teachers worked together to reconcile this tension, in a way that positioned them as bound by systemic constraints in ways that Greenwood teachers are not; after all, Greenwood teachers have the benefit of an aide to accompany them outdoors (150), whereas in their own school, as Dara sarcastically remarked, "there's no such thing as that, you don't go out to the parking lot without an accompanying parent" (151). Thus, while the reform-oriented teacher cares about her students' disciplinary affect (their enthusiasm) and often teaches outdoors, rules and resources constrain the policy enactor. The only way to meet the ideal entailed in combining the two identities is by functioning on a completely different systemic plane ("different rules…different schools…different Ministry of Education," 152–153). Even Noa participated in this reconciliation, which allowed the teachers in the room to position themselves as good teachers operating within the constraints of the system. Sharon then quickly returned to appreciating Greenwood practice, saying "how nice", and again reinforcing the reform-minded teacher identity, that of the teacher who is able to teach outside.

This small example illustrates the kind of fine-grained analysis of identity-in-interaction through which we understand the multiple facets of elementary science teachers' professional identities. Using a fine-grained analysis in an informal learning environment allows us to better appreciate the ways teachers construct their selves and each-others' identity and the ways tensions among these identities emerge and are reconciled.

12.4 The Affordances of Applying Situative Socio-cultural Identity Theory Through Linguistic Ethnographic Microanalysis

Research on science identity predominantly demonstrates how school science constrains identification with science, whereas informal settings afford it (e.g., Tan et al., 2013). By using a situative-identity perspective and linguistic ethnographic methods, our studies call this notion into question, and offer theoretical, methodological, and empirical insights to help develop a more critical, nuanced approach to science identity construction in informal environments.

The cases we present illustrate the affordances of applying socio-cultural theory through linguistic ethnographic microanalysis. First, we show that a more comprehensive understanding of identity construction in school fieldtrips to a science museum requires attention to nuances of interaction, such as who receives the riddle card from the ME and how, who gets to hold and read it, how does this person physically construct exclusive interactions with only some of the other participants, and how do the others react to that. However, the meaning of such nuances we find embedded in a broader social and cultural context, for example, in the relationships between the girls throughout the visits, in the roles they play in school science, and in the norms and expectations of school fieldtrips, all of which we must consider in the analysis. Second, we demonstrate how attuning to the way one child excludes himself from a family science-related activity and the way others react to this, interpreted against the backdrop of the family science habitus, is imperative for the understanding of identity construction in the family context. Finally, we argue that recognizing the different ways a teacher team reacts to an idyllic scenario of out-of-classroom teaching and interpreting these in relation to the current science education discourse and policy, elementary school science teachers' challenges, and the team's specific struggles offer new insights into teachers' identity negotiation vis-à-vis teaching in informal settings.

Based on these examples (and others), we suggest future research in informal learning environments could benefit from using linguistic ethnographic microanalysis to study identity trajectories through a situative socio-cultural lens. Such an approach can expose beneath-the-surface structures and processes that might otherwise go unnoticed, advancing a less idyllic view of learning processes in general and identity development in particular. This approach also can capitalize upon back-and-forth analytical movements between the details of micro-interaction and the more macro-level structures, processes, norms, and discourses (Wortham, 2006). We argue that these benefits are particularly valuable for research into understudied, unstructured learning environments, such as everyday family life and teachers' workplace conversations. As we demonstrate, such environments offer fertile ground for identity work that may be crucial for shaping identity trajectories.

Future research could apply these theories across research contexts to gain an even richer understanding of the nature of identity trajectories and the potential—and complex—roles informal learning environments play in these trajectories. For instance, drawing upon the examples we present from our own research: How do different museum visit designs impact upon identity co-construction in that setting? How do identity trajectories differ for children in families of varying types of habitus and socio-cultural capital? How does teacher identity co-construction play out across formal and informal teacher learning environments (e.g., professional development workshops as opposed to the type of on-the-job conversations we studied)? Closely examining identity work in and across such settings, incorporating the fine-grained details of interaction with more macro-level features, through a critical lens, can advance our understanding of how people learn across the different contexts of their lives.

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Part IV
Sociocultural, Socioscientific, and Social Entrepreneurship

Chapter 13
Sociocultural Theory: Intergenerational (Family) Sociocultural Dialogic Patterns and Spaces at an Aquarium Stingray Touch Tank

Patricia G. Patrick

13.1 Introduction

Sociocultural theory is a framework for defining how people learn across informal science learning spaces (Phipps, 2010). The theory postulates individuals should be studied within the context of their culture and learning is a social process. Within social situations, people interact with others and these exchanges shape their thinking (Miller, 2011). Additionally, driving sociocultural ideological principles are notions that (1) society respects ability, (2) to learn people actively must engage with the world, (3) experiences are a valuable ingredient of learning, and (4) meaning is an artifact of learning (Wenger, 2009). Vygotsky described learning as, "Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first between people (interpsychological) and then inside the child (intrapsychological)" (Vygotsky, 1978, p. 57).

Seminal work by Allen (1997), Bell et al. (2009), Falk and Dierking (2000), and Jakobsson and Davidsson (2012) tout the use of sociocultural theory as a framework that allows researchers to describe learning in informal science learning environments. Falk and Dierking (2000) termed the need for sociocultural interactions in out-of-school settings the sociocultural context. They describe the sociocultural context as within-group sociocultural mediation or mediation others facilitate. A sociocultural perspective of learning in out-of-school contexts situates learning within patterns of collaboration, communication, experiences, and participation within a community (Bell et al., 2009), such as an intergenerational group (Idema & Patrick, 2016a, 2016b; Patrick, 2014; Uzick & Patrick, 2018).

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Miller (2011) describes sociocultural as a cultural matrix that includes behavior. The cultural matrix has levels of social and physical settings, physical and historical influences, and "shared beliefs, values, knowledge, skills, structured relationships, ways of doing things (customs), socialization practices, and symbols systems (such as spoken and written language)" (p. 172). Changes within one level of the cultural matrix influence occurrences in another level. Language is a significant part of learning. Vygotsky considered language an important process in developing higher-order thinking skills (John-Steiner & Mahn, 1996). The use of language during social interactions facilitates the co-construction of knowledge and develops cultural understanding (Scott & Palincsar, 2006). The ways a group uses language influences how members interpret the world, communicate with others, and denote significance. To specify the importance of language in informal science learning spaces, I put forth the new terms sociocultural dialogic space and sociocultural dialogic patterns. The sociocultural dialogic space where language exists, and interactions occur is the stingray exhibit. The sociocultural dialogic space includes the biotic and abiotic parts of the exhibit and visitors, which all serve as catalysts for dialogue. I use Angel's (2016) definition of dialogue, which states dialogue is cooperative and is an exchange of information for building relationships. The resulting dialogue among intergenerational groups presents sociocultural dialogic patterns. I explain these concepts more in the discussion.

A sociocultural perspective of learning in informal science environments requires methodological considerations conducive to collecting data on group interactions with the environment and dialogue about the activity. Identifying discourse in groups should focus on each individual in the group for analysis, because each member may contribute to the learning of the group (Borun et al., 1996; Idema & Patrick, 2019; Jakobsson & Davidsson, 2012). Dialogue is a sociocultural activity because the background of group members influences the content and focus. Dialogue in informal settings provides valuable knowledge and insight about the group's culturally held beliefs, values, and thoughts (Schauble et al., 2002), and individual thoughts of group members. Identifying what people discuss is important for formal and informal educators developing pedagogical practices and epistemological perspectives.

Research should focus on the multifaceted complexity of learning science outside the classroom. Research in science learning outside the classroom should investigate social and cultural intervening factors encompassing: the role of dialogue, social learning, cultural aspects, and the consideration of individual and group as components of investigation (Rennie et al., 2003). Sociocultural theory forms from the social constructivist paradigm, which states knowledge is constructed socially through interaction and shared by individuals (Bryman, 2001). In this view, learning and development embed within social events and occur as a learner interacts with other people, objects, and events in the collaborative environment (Vygotsky, 1978).

A better understanding of how sociocultural influences created in informal learning spaces, such as an aquarium, will support opportunities for developing assessments and scaffolding learning. Sociocultural ideologies afford an infrastructure for challenging the pedagogical methods of informal science educators and the exhibit designs informal science learning institutions employ. Moreover, the sociocultural framework allows for a rich analysis of visitor experiences in informal science learning institutions (Jakobsson & Davidsson, 2012; Shaffer, 2021) by focusing on naturally occurring interactions and dialogue (Erlandson et al., 1993; Haden, 2010; McClain & Zimmerman, 2014; Uzick & Patrick, 2018). Dialogue in these institutions and in other out-of-school science learning contexts represents moment-by-moment learning and necessitates analysis (Allen, 2002; Borun et al., 1996; Massarani, 2021; Riedinger, 2012).

13.1.1 Intergenerational Groups

Bell et al. (2009) state learning occurs during, "a joint collaborative effort within an intergenerational group of children and significant adults" (p. 33). Intergenerational groups learn together, because their interactions grow from sociocultural beliefs, which lead to the internalization of social and cultural perspectives (Matusov, 2015). Based on Miller's (2011) interpretation of cultural levels, when intergenerational groups interact with each other and the exhibit, they influence the development of cultural levels and learning.

Rogoff (2003) identifies the importance of face-to-face social and cultural cues and interactions and their influence on learning. Additionally, she describes a transformation of participation in sociocultural activities as occurring when, "People contribute to the processes involved in sociocultural activities at the same time that they inherit practices invented by others" (Rogoff, 2003, p. 52). The process includes listening and observing (Rogoff, 2003; Rogoff et al., 2003). Rogoff (1995) describes sociocultural learning as three processes: apprenticeship, guided participation, and participatory appropriation. Apprenticeship occurs in the community plane when less-experienced individuals participate with others in a cultural activity. The purpose of apprenticeship is to develop participation in the future. Guided participation takes place in the interpersonal plane. Adults teach children while interacting in a culturally valued activity. Guided participation consists of two processes that are the mutual bridging of meanings and mutual structuring of participation. When adults bridge meaning to a child, they incorporate verbal and non-verbal interactions. This process leads to a common understanding among intergenerational groups (Kelly & Ocular, 2021; Kelly et al., 2020; Patrick, 2014; Patrick & Moorman, 2021; Tunnicliffe, 2000; Uzick & Patrick, 2018; Zimmerman & McClain, 2014a, 2014b; Zimmerman et al., 2013). Bridging of meaning takes place even when adults do not have an intention to teach. The second process is structuring participation. During structured participation, adults determine in which activities children participate and how they interact. However, children do control the interaction within the structure provided. Participatory appropriation materializes in the personal plane. This plane reflects the changes occurring in the first two processes. The individual becomes an active participate in cultural activities. The processes occur simultaneously and influence each other, but we can study them independently.

Uzick and Patrick (2018) identified the three processes of Rogoff's sociocultural learning theory as concentric circles and steps from the broadest plane of apprenticeship (culture) to guided participation (social interactions) to personal appropriation (individual). Even though extant research identifies families and dialogue as important aspects of science learning (e.g., Ash, 2003a, 2003b, 2003c; Ash, 2004a, 2004b; Ellenbogen et al., 2007; Borun et al., 1995, 1996, 1997; Hike, 1989; Povis & Crowley, 2015; Riedinger, 2012; McClain & Zimmerman, 2014; Uzick & Patrick, 2018; Zimmerman & McClain, 2014a, 2014b; Zimmerman et al., 2013), the application of Rogoff's sociocultural theory to intergenerational group interactions and learning is a vital contribution to understanding learning outside the classroom. Specifically, analyzing intergenerational dialogue reveals what group members perceive during interactions and how they group-process the information (Ash, 2004a, 2004b, 2003a, 2003b, 2003c; Kelly & Ocular, 2021; Kelly et al., 2020; McClain & Zimmerman, 2014; Uzick & Patrick, 2018; Zimmerman & McClain, 2014a, 2014b; Zimmerman et al., 2013). Additionally, an intergenerational group shares a set of values, vocabulary, comprehension, and assumptions (Ellenbogen et al., 2004; Wenger, 2009). Group members understand and interpret individual actions and interactions and give specific meaning to the interactions and dialogue based on the culture of the group (Ellenbogen et al., 2004; Patrick & Moorman, 2021). This chapter is not meant to ignore the work of others who have completed similar. Instead, this chapter adds to the conversation of employing sociocultural theory in informal science education and learning research and adds new terms to the discussion: sociocultural dialogic space and sociocultural dialogic patterns.

13.1.1.1 Dialogue

Dialogue is an important aspect of learning science in informal settings, such as arboretums, homes, museums, parks, and zoos. My chapter builds on previous conversation research (Ash, 2004a, 2004b, 2003a, 2003b, 2003c; Collins et al., 2021; Conrad et al., 2020; Idema & Patrick, 2016a; Kelly & Ocular, 2021; Kelly et al., 2020; McClain & Zimmerman, 2014; Patrick, 2014; Patrick & Tunnicliffe, 2013; Tõugu, 2021; Tunnicliffe, 2000; Uzick & Patrick, 2018; Zimmerman & McClain, 2014a, 2014b; Zimmerman et al., 2013), while explaining research within the sociocultural lens. Conversation research in these institutions focuses on social dialogue between group members, students, and intergenerational groups. The data indicate dialogue is social and educational. Learning grows from the social interactions and the cultural dynamics of the group, which are conversation rich (Hutson et al., 2011; Patrick & Tunnicliffe, 2013; Tunnicliffe, 2000; Uzick & Patrick, 2018; Zimmerman & McClain, 2014a, 2014b; Zimmerman et al., 2013). For learning to occur, groups should participate in meaningful dialogue with a science focus. "The science process discourse should consist of questioning, hypothesizing, predicting, observing, finding evidence, and evaluating" (Patrick & Tunnicliffe, 2013, p. 130–131). Determining what groups discuss provides valuable insight about visitors' attitudes, beliefs, and values and thoughts about the institution.

13.2 Application in the Literature

The literature touts sociocultural theory as an approach to understanding how people learn outside the classroom (Andre et al., 2017; Ellenbogen et al., 2004; Shaffer, 2021). Numerous papers describe sociocultural theory as a context for developing models of learning, but do not apply the theory in empirical studies with participants. Below, I provide five examples.

Example 1: Uyen Tran and King (2007) described the importance of sociocultural theory as a tool to explain professional development. They manipulated the theory to develop a framework, which we could use to understand the professional development of museum educators.

Example 2: Peacock and Pratt (2011) couched how informal educators should construct learning spaces within sociocultural theory. Their work asserts informal educators should bridge the communities of school culture, home culture, and the learning space culture.

Example 3: Jahreie et al. (2011) expounded on sociocultural theory by considering the relationship between play and school. They described the use of play-based tools and the experiences of a professional group. Their article provides exemplars of connecting scientific concepts between classrooms and informal learning experiences.

Example 4: Rahimi (2014) employed the theory to build a sociocultural interaction model. The model accounts for the creation of strong sociocultural interactions between people and places within museum space. The model implies sociocultural interactions are the outcomes of three basic factors: motivation, context, and actuation. Motivation and physical context link and drive the inclination to interact effectively.

Example 5: Kim et al. (2016) reviewed 25 articles focused on learning outside the classroom. They used sociocultural theory to determine if scholars were describing their findings with social and cultural tones. Even though Kim et al. found evidence of social and cultural discussion, they suggested the application of the theory in out of classroom learning was not well articulated in pedagogical practice.

The literature above posits sociocultural theory as a worthy framework for situating research in learning outside the classroom. In 2017, Andre et al. completed a content analysis of 44 articles related to children learning in museums from 1999 to 2012. They discovered the theoretical framework cited most often was sociocultural theory. Since 2012, extant studies rely on the sociocultural perspective to underpin empirical studies focused on learning outside the classroom, such as in aquariums (Kelly & Ocular, 2021; Kelly et al., 2020), science museums and centers (Voigt et al., 2020; Dawson et al., 2020; Zimmerman & McClain, 2014a, 2014b), and zoos (Idema & Patrick, 2016a; Patrick, 2014; Tishler et al., 2020), and during and after science events (Idema & Patrick, 2016b). Instead of employing sociocultural theory as an overall view of learning, I concentrated on Rogoff's (2003) perspective of guided participation to look solely at the intergenerational language between group members interacting at a stingray touch tank.

13.3 Aquarium Study

13.3.1 Introduction

Worldwide, aquariums attract millions of people (https://www.aza.org/partnerships-visitor-demographics?locale=en) and are an important source of biodiversity knowledge (Jensen et al., 2017; Moss et al., 2014, 2015, 2017). Aquarium research recognizes the importance of prior knowledge (Falk & Adelman, 2003) to learning during a visit and identifies aquariums' potential for promoting learning during field trips (Bonderup Dohn, 2011; Kim, 2012; Kim et al., 2007). Even though some studies focus on learning impacts of aquariums within intergenerational groups (e.g. Briseño-Garzón et al., 2007a, 2007b; Kelly et al., 2020; Kelly & Ocular, 2021; Kopczak et al., 2013; Rowe & Kisiel, 2012), we need research to define the nuances of conversations between group members with a focus on children. Defining the interactions intergenerational groups develop during an aquarium visit is important, because over time families with nurturing interpersonal relationships foster ecological caring (Mayer-Smith & Peterat, 2016; McNamee, 1997).

Even though some research focuses on dialogue among intergenerational groups in informal science learning settings (Ash, 2003a, 2003b, 2003c; Ash, 2004a, 2004b; Kopczak et al., 2013; McClain & Zimmerman, 2019; Tunnicliffe, 2000; Patrick, 2014; Idema & Patrick, 2016a, 2016b; McClain & Zimmerman, 2014), few separately code the individual comments of adults and children. Aquarium research would benefit from the study of intergenerational interactions during a hands-on touch tank experience. Identifying the processes of intergenerational dialogue to maximize learning potential is important as aquariums (and other museums) design and improve their institutions. To better understand intergenerational interactions at a hands-on aquarium exhibit, I observed and recorded dialogue between adults and children as they verbally interacted with each other in a stingray exhibit to answer the following questions: (1) What Learning Levels occurred among intergenerational groups at the stingray exhibit? (2) What were the levels of questions intergenerational groups asked at a stingray exhibit? (3) What were the roles of adults and children? (3) I describe Learning Levels, Question Levels, and roles in the data analysis section.

13.3.2 Methodology

I completed a descriptive case study (Baxter & Jack, 2008; Stake, 1995) that provides an entry point for expressing research design based on theory. The intergenerational groups visiting an aquarium stingray touch tank bound the case. I defined intergenerational groups as at least one child and one adult. Exploring the sociocultural dialogic space of the touch tank allowed me to investigate how the tank influenced the dialogue among intergenerational groups. I describe the overarching insights produced from the study, which allowed me to speculate on the social and cultural roles members of an intergenerational group play. Using the results of the study, I address the following: (1) sociocultural theory as a frame for the study, (2) the relationship between results and theory, and (3) implications for using the theory in informal learning contexts.

13.3.2.1 Location and Participants

I collected the data at an aquarium located in the southern United States of America, which has a yearly visitorship of approximately 800,000. The stingray touch tank is roughly 10,000 gallons and is in a room with smaller fish tanks located on the wall. The sampling method I used to select groups for this study was a random convenience sample (Zimmerman et al., 2013) of intergenerational groups speaking to each other at a location at the edge of the stingray tank. Over three weekdays from 9:00 am to 12:00 pm, I observed and recorded 62 intergenerational groups as they interacted and conversed with each other at the tank. The groups included 371 participants (140 adults/231 children).

13.3.2.2 Data Collection

I placed a digital recorder in one location in the stingray exhibit; therefore, I did not record all dialogue occurring around the exhibit. I recorded the dialogue at a place in the exhibit based on previous observations of where groups most often gathered. I collected 2 h, 32 min, and 16 s of audio. Groups spent from 1 min 9 s to 5 min 12 s at the exhibit location with the average being 1 min 34 s. I observed the groups and recorded the time a group arrived and left the recording area. I used this information to match each group with their transcript.

13.3.2.3 Data Analysis

I transcribed the dialogue and assigned each group member a nonidentifying code. For example, Family 1 consisted of 2 adults and 3 children. I coded the adults Adult 1a, Adult 1b, and the children Child 1a, Child 1b, Child 1c. I recorded a child as someone appearing to be under age 12. I did not record gender or race, because I captured the data using audio and visual data. I analyzed the dialogue between members of the family group, but the analysis did not include when a family member interacted with aquarium staff and discourse unrelated to the exhibit, such as, “Let’s go, Brandon!”.

The analysis took place in four phases, and I recorded each occurrence of the data in a group. However, I recorded once the social role a group member displayed.

Phase I: I coded the dialogue using the Learning Levels coding framework, which identifies increasing levels of complexity (Borun et al., 1996; Uzick & Patrick, 2018; Zimmerman et al., 2013). Identifying, Level 1, occurred when a group member identified or named an organism. Level 2, Describing, occurred when a member of the group described, with adjectives, adverbs, or verbs, the physical characteristics or actions of an organism. In Interpreting and Applying, Level 3, group members made connections to everyday life and to prior knowledge or described systems, processes, functions, and relationships of an organism. Phase II: Question Levels, I classified using Patrick's Recording Sheet (Patrick, 2014), which is based on Bloom's taxonomy (Bloom et al., 1956), as: knowledge, comprehension, application, analysis, synthesis, or evaluation. Non-exhibit-related questions, I did not record, such as, "When are we leaving?" Phase III: I coded once the roles of group members based on Uzick and Patrick's (2018) social roles of Explorer, Protector, and Rememberer. For example, once I recorded a group member as an Explorer, I did not record them as an Explorer again. Explorers take risks and interact with their surroundings outside provided guidelines. Protectors care for the surroundings, including organisms, and step in when they see anyone doing harm. Rememberers recall past experiences and incorporate shared and unshared experiences into the dialogue. Stage IV: An education doctoral student reanalyzed the data. We matched on 95% of the codes. We discussed the discrepancies and agreed on the remaining codes.

13.3.3 Results

Below, I follow the outline of Uzick and Patrick's paper (2018) to present the results. The data are for all groups and for all mentions of the Learning Levels and Question Levels. However, for the roles of group members, I report when a group member took on dual roles and report their role only once. For example, I report if a child took on the role of an Explorer and Protector, but I do not provide how many times the child displayed the role.

13.3.3.1 Learning Levels

The 62 intergenerational groups engaged in 1795 Learning Levels of dialogue related to the exhibit. Of the 1795 utterances, 64% (n = 1148) occurred at Level 1, which were Identifying comments. The remaining 36% of utterances were at Level 2 (Describing) and Level 3 (Interpreting and Applying), 25% (n = 449) and 11% (n = 198) respectively. The following quote represents a family using a name (Level 1), describing what they see (Level 2), and a child applying previous knowledge and experiences

(Level 3). Adult 25a stated: “It’s a stingray [Level 1]. It looks like a kite [Level 2]. Look at the shape.” Child 25a responded: “Yeah. I made a kite at school. It looks like that [Level 3].”

13.3.3.2 Question Levels

The 62 intergenerational groups asked a total of 496 questions: 82% (n = 406) Knowledge, 18% (n = 90) Comprehension, Application, and Analysis together, and 0% Synthesis or Evaluation questions. The dialogue among intergenerational groups indicated children asked questions most often and at the Knowledge level. Child 1a represents the most common Knowledge question, “What are they doing?” Comprehension questions included, “Why do they keep going around and around?” Application questions most often focused on the physical features, “Wow! Does it still have a stinger?” Analysis questions concentrated on actions, “Do you see their stinger? Do you think they use it to kill the food in here?” Below, I present additional example questions from each level of Patrick’s Recording Sheet (Patrick, 2014; Uzick & Patrick, 2018).

Knowledge (82%)

> Adult 32a: Come here! What is this?
> Child 5e: Where did it go? I can’t see it… it disappeared.
> Comprehension (11%)
> Child 22c: Is that the same one? He went around there. Is it the same? Does it have the same dots as the other one?
> Child 4a: Are they all the same size? See that one and that one and that one. Are [they] all the same?

Application (4%)

> Child 53d: We saw one in the Bahamas. You remember… we swam with them… Is it the same here? Don’t they look [like] the stingers [stingrays] in the Bahamas?

Analysis (3%)

> Child 61a: We caught one… at the beach. We threw it back in the ocean. It was wild. Is this one wild?
> Adult 61b: Yes.
> Child 61a: How do you know?
> Child 39e: They don’t have stingers. They can’t sting you. It’s… is it OK… to cut it off? What happens when you cut it off?

Roles. Similar to Uzick and Patrick, I found group members took on and moved in and out of roles during their interactions: Explorers, Protectors, and Rememberers. Explorers investigated the exhibit using their senses. Protectors cared about the welfare of the organisms. Rememberers expressed previous experiences and mentioned prior knowledge. I termed this role Alarmer, because group members were concerned about personal welfare and safety of others when interacting with the exhibit and organisms. Below, I provide examples for each role.

Explorers

Explorers in the stingray exhibit left the group to see other areas of the exhibit and encouraged others to join them. Additionally, they wanted to touch parts of the exhibit that were not stingrays. In the following example, Child 32b is trying to touch the bottom of the tank. He explores the tank and encourages Adult 32c to join.

Child 32b: Look! Touching the bottom of the tank. (Child is not touching the bottom.)

Adult 32c: You're not touching [the bottom].

Child 32b: [I] want to touch the bottom. What is it? What's [it] feel like?

Protectors

Protectors cared about the welfare of the exhibit and the organisms. They stepped in to ensure the stingrays were safe. Protectors denounced others when they thought they were touching the stingrays in a harmful manner. Adults were usually Protectors and redirected children when they were splashing the water or trying to poke the stingrays. In the following example, Adult 41b is explaining to a child why it should be gentle with the stingrays. Child 41a is splashing the water with its hands and trying to catch the stingrays as they go by.

> Child 41a: Come here! Come here! I want to catch it!
> Adult 41b: Stop! Stop! You're scaring it! Stop!
> Child 41a: I want to hold it.
> Adult 41b: Stop! You're not catching it. Stop hitting the water. You're scaring it. When you stop hitting the water it might come back. Give it a minute. It's scared. You can't hold it. You can touch it when it comes by. If you catch it … you hurt it."

Rememberers

Rememberers recalled past experiences and prior knowledge and included them in their discourse. Children were likely to recall seeing stingrays in media. Adults told stories about interacting with stingrays or stories they heard from other people. Below, Child 13a tells Adult 13a about a YouTube show, but the adult is not familiar with the show.

> Child 13a: They were on Wild Kratts [PBS YouTube]. Stingrays.
> Adult 13a: What is that?
> Child 13a: YouTube.
> Adult 13a: Don't know it.

Alarmers

During the data analysis, the doctoral student and I discovered an additional role: Alarmers. Alarmers showed fear of the exhibit or the organisms. Group members displayed a fear of touching the stingrays and/or being close to the exhibit. Children were afraid of the organisms and refused to approach the exhibit. Moreover, Alarmers were afraid their children would suffer harm. In the following example, Child 61c runs to the exhibit with Adult 61a closely following behind.

Child 61a: Stingrays!! I love them! They're my favorite.
Adult 61b: Don't put your hand in there! They bite. Don't do that.
Child 61a: But… I want to pet it.
Adult 61b: No… you don't know what they got. They might carry diseases.

13.3.3.3 Adults Versus Children

To discern the social interactions of group members, I used multiple data sources and analyses suggested by Uzick and Patrick (2018). However, for a clearer view of the social interactions among intergenerational groups, I recorded the number of Adults (n = 140) and Children (n = 231) mentioning each Learning Level and Question Level and what Role they assumed. The discourse of Adults and Children shown in Table 13.1 reflected some similarities and dissimilarities. The percentage of Adults and Children who spoke at Learning Level 1 (Adult 96%, Children 92%) was similar. Even though Adults spoke at Level 2 and Level 3 more often than Children, nearly half of Children engaged in discourse at Level 2 and 30% at Level 3. The Questioning Levels data revealed Adults and Children were equally likely to ask Knowledge questions, while Children were inclined more to ask Application questions (Adults 6%, Children 9%) and Analysis questions (Adults 2%, Children 7%). Application and Analysis questions usually went unanswered. For example, when a child asked an adult a higher-level question, the adult ignored the question or responded, "I don't know." The data revealed adults and children interacted socially and talked about the organisms and abiotic factors in the exhibit, which supports Uzick and Patrick's work. Children were Explorers (82%) most often and adults (17%) took on this role the least often. Instead, adults were Protectors (63%) and Remembers (66%). Interestingly, adults (27%) and children (29%) showed fear of the exhibit organisms. Below, I discuss the findings and situate them in the sociocultural framework.

13.4 Relating the Results to Sociocultural Framework: Sociocultural Dialogic Space and Patterns

Rogoff's (1995, 2003) sociocultural theory was beneficial in defining the interpersonal interactions taking place at the stingray exhibit. The results support the exhibit as a catalyst for intergenerational groups bridging science meaning and structuring participation. The stingray exhibit is a sociocultural dialogic space. The interactions within the sociocultural dialogic space, or exhibit, resulted in dialogue linked to the

Table 13.1 Adults and children whose dialogue included Learning Levels, Question Levels, and Roles

	Adult[a]		Child[a]	
	n = 140	%	n = 231	%
Learning Levels				
Level 1	129	92	223	96
Level 2	119	85	113	49
Level 3	89	63	69	30
Question Levels				
Knowledge	106	76	177	77
Comprehension	25	18	53	23
Application	8	6	22	9
Analysis	3	2	18	7
Synthesis	0	0	0	0
Evaluation	0	0	0	0
Roles				
Explorer	24	17	189	82
Protector	89	63	25	11
Rememberer	92	66	121	52
Alarmer	41	29	63	27

[a]The totals do not equal n, because group members spoke and asked questions at various levels and took on multiple roles

cultural and social perspectives of group members. I term the verbal interactions occurring among visitors at informal science education institutions sociocultural dialogic patterns. The sociocultural dialogic patterns occurring among visitors are a result of the space the group shares (e.g. exhibit type and place—aquarium, camp, park, zoo). The data showed intergenerational group interactions at a stingray exhibit are multifaceted and multilayered. Group members engaged in science related sociocultural dialogic patterns at different learning levels and low questioning levels. The dialogic patterns reflected the various sociocultural roles taken on by group members (Patrick, 2014; Uzick & Patrick, 2018; Zimmerman et al., 2013). Even though the findings suggest touch tanks support sociocultural dialogic patterns of learning at lower learning levels, they promote higher-level questioning among children. The results call attention to the notion children are interacting at a higher level by asking higher-level questions, which mostly go unanswered (Uzick & Patrick, 2018).

Although differentially distributed, group members took on various roles during the visit. Children were more likely to be Explorers and Rememberers, while parents took on roles of Protecters and Rememberers. Rememberers most often mentioned out-of-school events (Uzick & Patrick, 2018). Children mentioned television shows and parents described seeing stingrays or interactions with stingrays outside the aquarium. Just over one-fourth of adults and children took on roles of Alarmers and displayed a wide range of negative emotions toward the stingrays, from cautioning someone about touching the stingray to fear of being close to the exhibit. Even though I was unable to locate exhibit studies recording fear among intergenerational groups at a stingray exhibit, the results do support that parent—child sociocultural dialogic patterns may encourage fear in children (Conrad et al., 2020). Alarmers who showed less anxiety eventually engaged with the exhibit. The adults who displayed trepidation did not want their children to interact with the organisms and discouraged their child. Children who were afraid did not interact with the organisms even when adults did and encouraged the child to touch the stingrays. Adults modeled for the children by placing their hand in the water to show the child the stingrays were harmless—an example of bridging meaning or showing cultural acceptance. Adults recognized children were afraid and tried to comfort them and modeled behaviors to encourage children to interact with the organisms. These interactions intertwine with science engagement and care for the organisms, which may lead to later conservation-based decisions or behaviors. Group members appeared to take on roles of Explorers, Protectors, and Alarmers based on emotions and perceived need. Explorers were excited while Protectors and Alarmers showed concern.

The exhibit influences the sociocultural dialogic patterns and intergenerational group interactions, e.g., who starts the dialogue and to whom they speak about the exhibit (Patrick & Moorman, 2021). This study adds to the significance of Patrick and Moorman's work by underscoring the magnitude of understanding what role the exhibit plays in how members interact with the exhibit, because the interactions influence sociocultural dialogic patterns. Exhibits promote dialogue about prior experiences and knowledge. The exhibit is part of a triadic sociocultural dialogic pattern, which promotes dialogue between the adult and child. This triadic dialogue reflects the bridging of meaning between the exhibit and the group. However, adults do not build the triadic dialogue solely. Children experience the exhibit, build dialogue, and guide the dialogue of the group. Rogoff (1990) describes sociocultural communication from adult to child. However, the contact between the exhibit and children promotes child-driven dialogue in which the child attempts to bridge meaning between the exhibit and past experiences and they share these with adults and other children. Similarly, adults used past experiences and personal meaning-making to aid children and other adults in understanding the exhibit.

Adults and children depicted their thoughts through dialogue and a display of their comfort with the stingray exhibit, which represented a concrete action group members could mimic. For children who were afraid of the stingrays or the water, the action was important for transforming a child's fear to an interaction with the exhibit. When children were afraid to interact with the exhibit adults utilized the exhibit (e.g., putting their hand in the water as an example) as a tool to illustrate its safety. The exhibit became a catalyst for adults and children to interact, discuss, and share, which represents guided participation through sociocultural dialogue. The results indicate the stingray exhibit encouraged interactions with the stingrays and sociocultural dialogue about stingrays. The exhibit stimulated meaning-making and the dialogue reflected the thinking of participants in real time, which is not reproducible, but dialogue does depict reality as it occurs. The conditions of the exhibit permit the development of teaching and learning opportunities for intergenerational groups—children teaching adults and adults teaching children. Consequently, according to the findings, adults and children can encounter new situations and information, share prior knowledge, show fear, and feel comfortable exploring. However, we should determine the sociocultural dialogic patterns for each exhibit as not all exhibits are the same and encourage the same types of dialogic patterns. For example, the roles of family members in an arboretum described by Uzick and Patrick (2018) added to the roles of family members reported by Zimmerman et al. (2013). Likewise, this study added an additional role, Alarmer, for intergenerational groups at a stingray exhibit.

13.5 Implications for Research in Informal Learning Contexts

Identifying and understanding sociocultural dialogic patterns are important because family members serve as role models and influence children's science engagement (Aschbacher et al., 2010; Bricker & Bell, 2014; Dick & Rallis, 1991; Gilmartin et al., 2006; González et al., 2006; Idema & Patrick, 2019; Patrick, 2019; Tan et al., 2013; Tenenbaum & Leaper, 2003; Zimmerman, 2012). Specifically, Rogoff's learning processes (2003) allow researchers to situate the dialogic patterns within sociocultural theory. In conjunction with similar research (Uzick & Patrick, 2018; Zimmerman et al., 2013), the results of this study express a need for employing sociocultural theory as a guide for defining sociocultural dialogic patterns. To understand how intergenerational groups interact in informal science learning environments, we must identify the variability of exchanges occurring across various types of settings even within an institution (e.g. aquariums, arboretums, science museums, parks, zoos, etc.).

An awareness of the ways group roles intertwine with their learning dialogue is important. These roles and moment-to-moment interactions are an important aspect of developing science engagement and developing science identity (Vedder-Weiss, 2018). Researchers and informal educators should consider how informal science learning environments promote intergenerational interactions and how these interactions play out within the space. Additionally, researchers must develop a better understanding of the dialogic patterns of children (Vedder-Weiss, 2018) and take into consideration children's experiences separate from adults (Heras et al., 2020; Idema & Patrick, 2019; Patrick & Moorman, 2021). Identifying what children say, their questions, and the roles they take and how adults respond is a necessary process for developing better exhibits and informal science education programs.

The preferential exhibit design and organisms reflect institutional beliefs. The tools employed by the institution in exhibit design reflect the voice of the institution (Patrick & Tunnicliffe, 2013) and will influence the sociocultural dialogic patterns. Exhibit designers should take into consideration the usability and friendliness of the exhibit for intergenerational groups (Borun & Dritsas, 1997) and its potential to create the triadic sociocultural dialogic patterns. Therefore, developing an understanding of the sociocultural dialogic patterns is critical to determining best exhibit design processes and best practices for educators interacting with visitors. Informal science educators can fill in the blanks left when the sociocultural dialogue patterns among intergenerational groups are not progressing in a way that affords learning. Sociocultural theory justifies questioning the primacy of dialogic patterns in all visitors, especially intergenerational groups. Exhibits and informal science educators should create sociocultural dialogic spaces that encourage higher-level dialogue and questions and develop normally occurring group roles.

13.6 Importance of Sociocultural Theory

Sociocultural theory provides for a social and cultural examination of learners in an informal science learning context, not just intergenerational groups. When informal science educators understand the sociocultural dialogic patterns occurring in these spaces, it better prepares them to develop pedagogical practices and strategies that may promote learning. Adults and children collaborate in informal science learning settings by experiencing, discussing, interacting, and negotiating meaning. Applying sociocultural theory allows for educators to reflect on the importance of social collaboration, the cultural context in which collaboration takes place, the backgrounds of diverse learners, and the importance of group interactions and dialogue. Informal science educators and researchers should consider: (1) sociocultural dialogic patterns developing in the space, (2) learners taking on different roles and how the roles change, (3) adults and children may not have similar experiences in the same space, and (4) children can be experts who apprentice adults (even though the adults may appear to ignore the children).

Sociocultural dialogic patterns develop with the support of others. Learners within a group develop individually while interacting with others. The physical interactions within the context of the space are an important catalyst for dialogue. The goal of informal science institutions should be to encourage groups to apply knowledge and discuss experiences, which may lead to guided participation, bridging science meaning and structuring participation.

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Chapter 14
Socioscientific Issues and the Potential for Fostering Engagement Through Exhibits

Jenn L. Idema and Kristy L. Daniel

14.1 Introduction

With declines in species and natural resources, surges in pollution, and climate changes (Cafaro, 2015), the anthropogenic pressures humans have placed on the Earth have led to the creation of complex, socially embedded, scientific problems not easily solved. Aptly known as socioscientific issues (SSI), these issues are often controversial and largely problematic because their open-ended nature is influenced by the multiple socio-cultural dimensions and entities involved (Sadler, 2004; Zeidler & Keefer, 2003). Finding solutions to address SSIs has increased the need for a more scientifically literate society (Roberts & Bybee, 2014); however, creating this type of society is challenging. Less than five percent of the average person's life is spent in a formal science classroom (Falk & Dierking, 2010) and the need for reaching people outside of the classroom in the spaces they frequent to learn about science continues to grow (Bell et al., 2009; Yun et al., 2020).

More than 700 million people worldwide visit zoos and aquariums each year, placing them in the position to educate and connect their visitors with science information and the natural world (Godinez & Fernandez, 2019). Zoos and aquariums can direct the experiences of their visitors through, "real objects, people, places, or animals; learning is voluntary and is stimulated by the needs and interests of the learner; and they provide a very learner-centered experience which involves exploring and examining, making choices, making personal connections, developing one's own way of understanding, and controlling one's own learning environment," (Packer & Ballantyne, 2010, p 25). Essentially, informal science institutions (ISI) function as

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mirrors of our societies. They reflect back to their visitors the world's natural histories and cultures, preserving what our societies believe to be worth saving, as well as presenting visitors with information about the current issues impacting today's societies in formats that are easy to comprehend and engaging (Bell et al., 2009). As a result, ISIs are prime places for presenting and learning about SSI as through artifacts and/or species these institutions can illustrate and connect visitors with the impacts of SSI on different species, the environment, and society.

One of the largest ways ISIs such as zoos and aquariums reach visitors is through exhibits. Once defined as collections of species housed in glass tanks and barred cages (Hutchins & Smith, 2003; Patrick & Tunnicliffe, 2013), the exhibits of the twenty-first century look vastly different than their predecessors. The exhibits of today mimic natural habitats where visitors can observe species interacting with each other and engaging in natural behaviors similar to in the wild (Patrick & Tunnicliffe, 2013). This type of exhibit design sends a message to the visitor that habitat conservation is integral for species (Hutchins & Smith, 2003). Exhibits strengthen conservation messages further through the use of interpretive signage and interactive hands-on components visitors can manipulate to learn more about an issue and/or the species within the exhibit (Bruce & Bryant, 2008; Serrell, 2015; Shani & Pizam, 2010). Through engagement with the exhibit, visitors can generate personal meaning for the information and species presented (Bacher et al., 2007; Beck & Cable, 2002). Beyond initial costs and maintenance, exhibits can be one of the most cost-effective ways ISIs can engage visitors (Bitgood, 1989; Graham, 2020), as visitors can access information, interact with species, and learn science with or without an informal science educator. The zoos and aquariums of today strive to create and uphold the image that they are centers for conservation, education, and learning, claiming success through the number of educational experiences and opportunities to connect with the natural world they offer to visitors (Carr & Cohen, 2011; Patrick & Tunnicliffe, 2013). Exhibits play a large role in these educational experiences and opportunities.

14.1.1 SSI and Exhibits

Traditionally used in the formal classroom, the Socioscientific Issues Framework (SSIF) is an instructional-based framework that utilizes concepts from the fields of developmental psychology, sociology, and philosophy as a way to describe the processes in which an instructional resource facilitates learning about science content embedded in socially relevant situations (Zeidler et al., 2009). The SSIF examines the epistemological growth of the learner and the potential for development of character as they engage with socioscientific-based instruction (Macalalag et al., 2019; Zeidler et al., 2009). The SSIF's main purpose is to create scientifically literate citizens who can use evidence-based scientific content knowledge to make morally conscientious decisions about real-world SSIs (Zeidler et al., 2005). It is important to distinguish between a SSI and SSIF, in that SSIs encompass presenting or discussing issues, but may not follow all of the defining characteristics of the SSIF. Through meaningful discussions, debates, and argumentative thinking, the SSIF aids those who engage with it in thinking about the complex science issues our societies face and how those issues personally relate to them.

SSIs with an environmental focus are often relevant to and integrated into zoo and aquarium exhibits. Common SSIs found in ISI exhibits include pollution, invasive species, illegal wildlife trade, overharvesting of natural resources, destruction of habitat, climate change (CC), or an impact attributed to CC (Idema, 2021). However, these issues often appear as only a brief mention buried deep within exhibit interpretation or on stagnant signage, causing the SSI to seem more like an afterthought or a tangential connection to the exhibit message and science content conveyed (Idema, 2021; Yun et al., 2020). While acknowledgement of a SSI is a step in the right direction, we must integrate the SSI in a meaningful way following the SSIF if the goal is to have visitors engage with SSIs at levels that hope to foster positive conservation actions (Zeidler et al., 2009)—supporting the mission of most ISIs. Instead of just introducing a SSI in an exhibit and expecting visitors to be able to navigate its complexities on their own, the SSIF is a tool designers can use to create SSI-integrated exhibits supporting visitor exploration of science content, understanding the viewpoints of different stakeholders, confronting personal bias, as well as opportunities to formulate new perspectives.

Given that we already know SSIF instruction in the formal classroom is effective in engaging students in science learning grounded in real-world contexts (Eastwood et al., 2012; Herman, 2018; Kinslow et al., 2019; Sadler et al., 2016), we can expect exhibits at ISIs would be strengthened by using the SSIF. ISIs may even illustrate SSI impacts on nature better than the formal classroom through their ability to provide greater opportunities for emotional experiences that enhance appreciation for species (Prevot & Clayton, 2018). For example, an aquarium can create a permanent exhibit inviting visitors to explore the SSI of marine pollution through the eyes of a sea turtle. While such an interaction technically may be possible in a formal classroom, it is incredibly difficult to achieve at this scale and would likely be cost prohibitive. Furthermore, adapting the SSIF as a tool for ISI exhibit design can help create a shared language around SSI instruction grounded in empirical research and theory. Currently, we have many different terms for SSIs (e.g., critical issues-based science, hot-button topics, hot science, issues-based science, sociocultural science, science in contexts), making it difficult to find appropriate literature to support ISI practitioners plan and design exhibits and programming (Yun et al., 2020). The SSIF has the potential to ensure ISIs are able to navigate the complexities of SSIs and use SSI as a way to open dialogue about difficult topics.

14.2 The Socioscientific Issues Framework

The SSIF has been used successfully in the formal science classroom to engage students in science learning (Sadler, 2011), while increasing their science understanding through the development of skills like questioning, argumentation, empathy, and moral reasoning (Sadler & Zeidler, 2005; Zeidler et al., 2009). We can think of the SSIF as a series of concentric circles. At its core, the SSIF has three main parts centered around a particular SSI—*Design Elements*, *Learner Experiences*, and *Teacher Attributes*—which are influenced by social constructs and key players found within the *Classroom Environment* and *Peripheral Influences* (i.e., the school/district, local and regional communities, and state/national policies) (Presley et al., 2013).

14.2.1 Design Elements

Four essential features make up the *design elements* component. First, we must identify a compelling SSI rooted in the institution's science curriculum to build instruction around it (Presley et al., 2013). Second, we must present the SSI at the beginning of instruction as opposed to an ending thought that follows the lesson. Presenting the SSI up front provides a grounded, real-world context for the learner to think about as they explore the different aspects and key players involved in the issue (Presley et al., 2013). Third, the lesson should provide scaffolding opportunities (e.g., Shabani et al., 2010) that promote and lead to higher order practices (Anderson and Krathwohl 2001) such as argumentation, reasoning, and decision making (Presley et al., 2013). Finally, the lesson ideally will provide the learner with a culminating experience that helps the learner to synthesize and integrate new knowledge they acquired about the SSI with their prior knowledge and experiences (Presley et al., 2013). Design elements set up critical guidelines for presenting SSI-based lessons that support learner experiences.

14.2.2 Learner Experiences

Learner experiences are a crucial part of the SSIF as they describe the involvement, interactions, and exposure learners experience as they engage with SSI-based instruction. Within the SSIF, we must provide learners with opportunities to engage in higher order practices that involve but are not limited to reasoning and argumentation, as well as decision making (Presley et al., 2013). Additionally, we must present learners with opportunities where they can confront scientific ideas, theories, and misconceptions related to the SSI studied. As part of their experience, learners have opportunities to collect and analyze scientific data pertinent to the issue and explore the different social dimensions associated with it (Presley et al., 2013). Additional recommended *learner experiences* include engaging learners with ethical aspects surrounding the issue studied, as well as consideration towards appropriate nature of science themes (Presley et al., 2013). Learner experiences call to attention needed cognitive pieces within SSI interactions crucial for supporting higher-level processing.

14.2.3 Teacher Attributes

In addition to *design elements* and *learner experiences*, a teacher should exhibit important characteristics to help ensure their SSI lesson is effective. First, the teacher must be familiar with the SSI presented. This familiarity should include a background knowledge of relevant science content and an awareness of the social dimensions (e.g., political, ethical, economic) connected to the issue (Presley et al., 2013; Zeidler et al., 2009). Second, teachers must act as a facilitator and a learner, placing themselves in the position of a knowledge contributor on the issue as opposed to the sole authority. Third, teachers should be flexible and to some degree be comfortable with improvisation when handling the possible uncertainties that arise from using SSI-based instruction in the classroom. Because of the open-ended nature of SSIs, classroom discourse will not always follow a predictable pattern. Therefore, teachers adept at capitalizing on opportunities of uncertainty are more effective at SSI-based instruction (Herman et al., 2018; Presley et al., 2013; Zeidler et al., 2011). Teacher attributes form the ideal baseline for how to help educators act as model learners in SSI-based instruction that is important for helping to set the tone for collective learning.

14.2.4 Classroom Environment

To create an effective SSI *classroom environment*, teachers should start by setting high expectations for learner participation. Without learner participation, there is little chance for thought-provoking, higher order learner experiences (Presley et al., 2013). High learner participation is more likely to happen if the learner views the classroom environment as a safe place to share and discuss their ideas about the SSI studied (Presley et al., 2013). Hand-in-hand with the need to feel safe sharing in the classroom is the importance of respect. SSIs are often controversial (Zeidler et al., 2005) and the discussions that occur through engagement with SSIs can be difficult due to their polarizing nature. Therefore, teachers and learners must respect each other and the differing perspectives that discussing a SSI can bring (Presley et al., 2013). Teachers may approach creating a safe classroom space that cultivates mutual respect in many ways (e.g., Harless, 2018; Robinson & Kakela, 2006). To help ensure classroom environments have high learner participation and learners feel safe sharing, teachers can provide ample opportunities for collaboration amongst learners. Collaboration serves as a way for learners to build trust amongst each other and significantly influences student buy-in for participation (Presley et al., 2013). The learning environment is a critical consideration for SSI instruction as the environment influences emotional connections to the content and indirectly can engage or disengage the learners.

14.2.5 Peripheral Influences

Entities beyond the classroom environment, *peripheral influences*, can influence SSI instruction. Influences such as administrative personnel, school board, surrounding community members, regional, state, and/or national policies can dictate the who, what, when, where, and how often teachers use SSI in the classroom (Herman et al., 2018; Presley et al., 2013; Zeidler et al., 2011). Developing strategies that provide support and encourage teachers as they create and/or incorporate existing SSI curricula into their classroom environments is essential for successful SSI-based instruction (Presley et al., 2013). Access to quality existing curricula as well as supporting materials is also necessary for successful SSI-based instruction. Many teachers do not have the time, experience with, and/or confidence in creating their own SSI-curriculum (Bossér et al., 2015); therefore, the SSIF encourages schools and districts to provide their educators with existing high-quality curricula that are flexible and support and encourage SSI instruction in the classroom (Presley et al., 2013).

The different communities (e.g., churches, scout groups, neighborhoods, organizations, ISIs, and regional government) that are a part of and encompass a school district often influence what is taught in the classroom. When community members believe a SSI is inappropriate for the classroom, they can pressure teachers and administrators to remove the lesson or avoid the topic (Presley et al., 2013). To help alleviate community pressure, teachers and administrators should familiarize themselves with local issues and viewpoints to address community concerns, should they arise. Arranging meetings with parents and community members to explain the need for teaching a SSI creates transparency providing peace of mind, while avoiding the spread of misinformation (Presley et al., 2013).

State and national policy often govern science curriculum taught in the classroom. Current science education reforms reflect a movement centered around student evaluation, teacher accountability, and a standardized science curriculum (e.g., Next Generation Science Standards [NGSS]). The likelihood these movements will affect SSI-based instruction is almost certain as teachers may be disinclined to incorporate an SSI-based lesson if they think it strays too far from the curriculum objectives outlined in their teaching evaluations (Presley et al., 2013). As a result, it is imperative that teachers and curriculum developers work together to create SSI content and lessons that are usable in the classroom and align with state and national standards (Presley et al., 2013).

14.2.6 Adapting the SSI Framework for ISI Exhibit Design

The SSIF is a useful lens for exploring teaching and learning practices in science, technology, engineering, and math (STEM) (Chowdhury et al., 2020; Herman et al., 2018; Presley et al., 2013; Sadler, 2011; Yun et al., 2020; Zeidler et al., 2009) given the cross disciplinary nature of STEM content and societal impacts of the content. Given that so much of STEM learning takes place out of formal classroom environments (Falk & Dierking, 2010), it would make sense to apply the SSIF to STEM learning in these informal educational environments. However, the language used to describe the original SSIF components is not fully inclusive of the various types of learning environments typically found in ISIs. Because the original SSIF is classroom-based, much of the literature focuses on the role of the teacher as they facilitate learning about SSI in a formal learning environment (Presley et al., 2013). However, in ISIs educators are often not present; therefore, it is up to an exhibit to fulfill the learning environment role for visitors. To make the SSIF more inclusive of informal learning environments, resources, and experiences, we updated the language (Fig. 14.1) of the core characteristic known as teacher attributes to instructional resource attributes, changed classroom environment to education environment, and provided updated descriptions for how SSIF components may apply to exhibit design in ISIs. We include exhibit and interpretation design principles (Tilden & Craig, 2009; Veverka, 2011) to address exhibit needs in design elements not found in formal classroom education.

14.2.6.1 Design Elements in ISI Exhibits

In this revisited SSIF, design elements still provide critical guidelines for presenting SSI-based education messaging to support learner experiences. However, in exhibit-based ISI contexts, these elements are focused more on the underlying design process that led to creation of the exhibit experience. SSI-based instruction, whether facilitated through an exhibit, program, or curriculum, features a relevant social issue connected to science. Without a foundational educational message built around a SSI, instruction is not classified as SSI-based; but instead the instruction merely includes a SSI example (Presley et al., 2013; Yun et al., 2020; Zeidler & Nichols, 2009). Distinguishing between the two types of instructional structures is important as they each serve a different educational role and can have different impacts on learner engagement. Developing an entire exhibit using the SSIF has more potential for visitor engagement over one that briefly mentions a SSI in context with other science information (Everett & Barrett, 2009; Serrell, 2020; Veverka, 2011).

Any content and messaging should align with the institution's mission and goals as well as state and/or national education standards. Much like an SSI-based classroom lesson (Herman et al., 2018; Presley et al., 2013), the SSIF suggests introducing visitors to the SSI early and integrating the SSI throughout the exhibit message. Such integration of the SSI would make the intention of the exhibit's purpose clear for

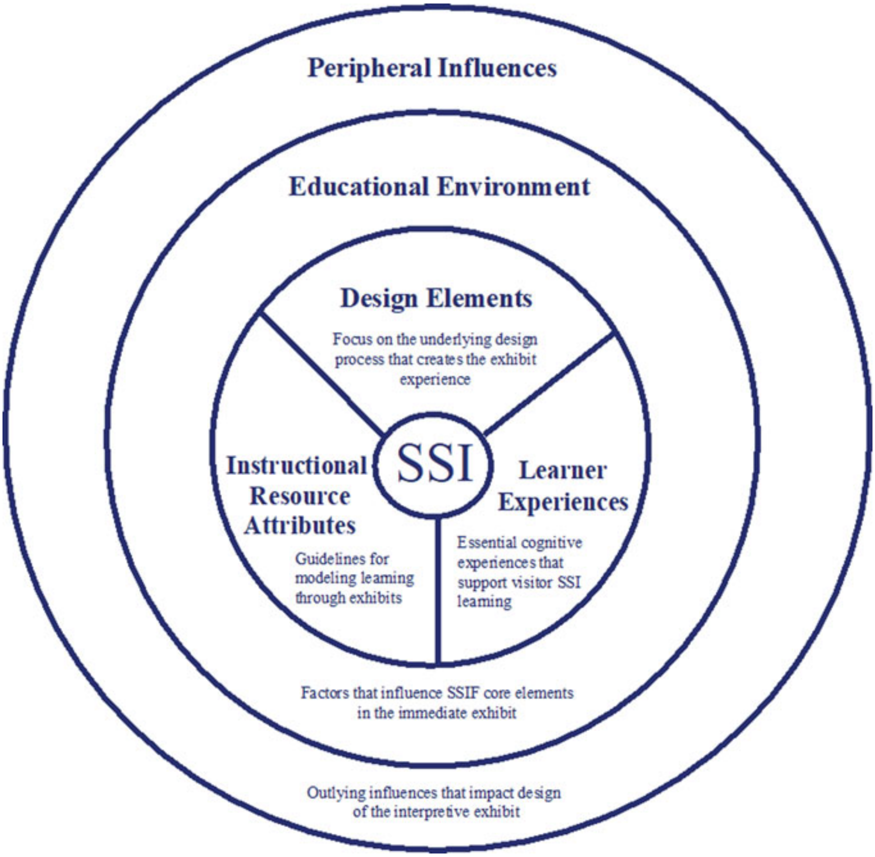


Fig. 14.1 The Socioscientific Issues Framework core aspects for exhibit design. *Note* Here, teacher attributes become instructional resource attributes, the classroom environment becomes the educational environment, and characteristics of these aspects reflect how an exhibit can take on the role of instructor when an educator is not present. Adapted from "A Framework for Socio-scientific Issues Based Education," by M. L. Presley, A. J. Sickel, N. Muslu, D. Merle-Johnson, S. B. Witzig, K. Izci, and T. D. Sadler, 2013, *Science Educator, 22*, 26–32

the visitor. For example, aquarium exhibits that mention CC often present the issue in the form of one or two sentences on a sign describing how CC impacts a particular species such as coral or penguins (Idema, 2021). This treats the issue almost as an afterthought because it buries the information within husbandry information, fun facts about the species, and Convention on International Trade in Endangered Species (CITES) status (Serrell, 2015; Yun et al., 2020). In exhibits that use video screens as signage, CC is often the last screen that appears for 30 seconds or less in a five-minute video/slideshow (Idema, 2021). Given the average amount of time spent at an exhibit varies dramatically pending visitor interest, group type, and motivation (Bell et al., 2009; Falk et al., 2007; Serrell, 2015), they may miss out on

CC information as it flashes by on a screen. Instead, a CC exhibit may be more effective if it incorporates interpretation principles (Tilden & Craig, 2009) to ensure grounding of the SSI message in relevant, real-world contexts that introduce, inform, and help shape visitor thinking about the different socio-scientific dimensions tied to the SSI (Clayton & Myers, 2015; Presley et al., 2013). Exhibit messaging should move beyond the presentation of science facts (Tilden & Craig, 2009) to content that has scientific concepts localized and made relevant for the visitor (Melber, 2007; Skydsgaard et al., 2016). Hence, implementation of the SSIF is a logical fit for such ISI settings.

Just as SSI-based instruction in the formal classroom must provide scaffolding opportunities that lead to higher order thinking (Anderson and Krathwohl 2001; Herman et al., 2018; Presley et al., 2013; Sadler, 2011; Zeidler et al., 2009), so too should these opportunities be a part of SSI-based exhibit design. Scaffolding for SSI-based exhibits can come in many forms (e.g., Hints [Zurek et al, 2014], such as prompts [Siegel, 2007] and overarching thematic questions [Boche & Henning, 2015]). For example, an interactive exhibit could stimulate visitor thinking by embedding prompts in signage to help adults encourage dialogue and debate between their visitor group and/or other visitors (Krange et al., 2019). Ideally, scaffolding ultimately will help visitors analyze different perspectives associated with the SSI as they work towards forming their ideas about the issue (Presley et al., 2013). Ultimately, the visitor's exhibit experience should culminate in opportunities for reflection, practice, and the desire to take action.

One element missing from the original SSIF is the consideration of cognitive load of the SSI lesson. Interpretive exhibits vary in their cognitive load–the amount of physical and psychological time and energy an exhibit requires a visitor to expend as they interact with the exhibit and elements (Veverka, 2011). Regardless of motivation for a visit, learners enter an ISI with a set cognitive level of 100%. As they move through the ISI, this level reduces as the learner expends cognitive energy interacting with the information and components found within exhibits (Veverka, 2011). Visitor interest in an exhibit drops with more saturation with information and stimuli (Veverka, 2011). Lower cognitive load exhibits are more passive in nature and visitors may gloss over them without retaining any content. Higher cognitive load exhibits are extremely interactive, requiring the visitor to expend more mental and physical energy, causing the visitor to reach mental fatigue faster. Interacting with multiple high cognitive load exhibits in a row can end with the visitor leaving prematurely (Veverka, 2011). A SSIF exhibit has more cognitively taxing potential for learners because of the cross and interdisciplinary nature of the contexts. Underloading or overloading a lesson or ISI exhibit potentially could interfere with the learner experience and hinder learning outcomes.

14.2.6.2 Learner Experiences in ISI Exhibits

In any SSI-based instruction, the learner should engage in essential experiences related to the SSI presented, allowing them to engage in higher order thinking and practice, confront prior ideas, collect and analyze related scientific data, and navigate the complex sociocultural dynamics of the issue (Presley et al., 2013; Yun et al., 2020). With games or role play, we can engage visitors in higher order thinking and practice through an exhibit, or with the use of prompts to foster dialogue or provoke thinking (Idema & Patrick, 2019; Krange et al., 2019; Silseth, 2012; Skydsgaard et al., 2016; Tilden & Craig, 2009). For example, a SSI-based exhibit focused on sustainable fishing could assign visitors with different roles (such as fisherman, restaurant owner, biologist, etc.) as they enter the exhibit. By having visitors role play how different stakeholders may act in a given scenario, we provide them a way to engage with the content using a novel perspective. In the formal classroom, learners collect and analyze scientific data as part of their experience (Presley et al., 2013); however, this may not be feasible in every SSIF exhibit. Instead, ISIs can provide visitors with takeaways such as packets (Marty, 2020), mobile applications (Delen & Krajcik, 2017; Soller et al., 2014), and/or QR codes that provide information and access to community science and conservation projects in which they can participate. Participating in community science and conservation projects can help solidify knowledge gained from interacting with the exhibit, extending the lesson and visitor motivations for action (Ballantyne et al., 2011). With few exceptions, SSIF learner experiences are comparable in any learning environment, formal or informal.

14.2.6.3 Instructional Resource Attributes in ISI Exhibits

Teacher attributes serve as a baseline guide for shaping how educators can serve as model learners in the original SSIF. However, in ISI settings, teachers are not a common player. Instead, interpretive exhibits often serve as the primary facilitator of science learning for visitors (outside their own visitor groups) (Patrick & Tunnicliffe, 2013). As such, in this modified SSIF, we update how *teachers* are viewed and described to be more inclusive of the available instructional resources in both formal and informal learning environments. *Instructional resource attributes* in this modified SSIF share many of the same descriptions as the original teacher attributes previously described.

During the planning phase of a SSIF-designed exhibit, designers should be familiar with the SSI along with related relevant science content knowledge and social dimensions tied to the issue (Presley et al., 2013; Zeidler et al., 2009). In ISIs, the context surrounding the SSI may be expressed or integrated more creatively than a teacher might have the opportunity to elaborate upon in a formal classroom setting. While in-person teachers or interpreters have the luxury of acting as a facilitator and a learner in SSIF, this step can be a challenge when considering the role of an ISI exhibit. For an exhibit to avoid serving as a sole authority on an issue, exhibit design must allow learners to interact and engage with the content and access prior ideas brought with them. Thus, exhibits should rely not on text-heavy signage, but rather present foundational information required to understand scientific concepts involved with the SSI and leading into interactive components, such as scaffolded activities described prior. ISIs can leverage family units or learner groups that visit exhibits and find ways to encourage parents or advanced peers to help scaffold dialogue. Offering material that is more familiar to adults helps them ask more conceptual questions to their accompanying children (Melber, 2007). Instructional resource attributes is the most challenging adaptation to shift from a teacher to an exhibit. Again, in-person teachers and interpreters have the luxury of being flexible and integrating improvisation into their instruction; however, exhibits are a more static feature in ISIs (Yun et al., 2020). Still, exhibits can maintain a level of flexibility through regular updates and revisions by designers. New SSIF exhibit construction should have regular revision in mind, through direct, electronic, or supplemental resource updates. This revision is beyond regular maintenance, but rather an ability to update content, alter interactive activities and prompts, and transform dialogue topics to leverage current events, prior visitor interactions, if possible, and changes in how we consider the SSI. We note that flexibility may come with associated costs that ISIs must consider, either through higher upfront costs to support updateable technology or back-end costs to fund exhibit revisions.

14.2.6.4 Educational Environments

Expanding the SSIF to include informal *educational environments* also expands the types of audiences considered as learners. Most classroom settings require students to attend and participate. The teacher is more informed as to the likely prior knowledge of their students given standardized learning objectives within the K-12 curricula. In ISIs, learners may represent one of five types of audiences: explorers, facilitators, professional/hobbyists, experience seekers, or rechargers (Falk et al., 2007), and come with larger variance in prior knowledge. A way to reach all visitors regardless of varying prior knowledge is to localize the SSI (Yun et al., 2020; Zeidler et al., 2009) and draw explicit connections to help make the content relatable (Pedretti, 2004; Tilden & Craig, 2009). Given the variety of visitors to any given ISI, it can be difficult to identify an appropriate level of expectation for learners. In our modified SSIF, we suggest that exhibits offer multiple levels of objectives to better attend to the needs of learners in terms of audiences and age range, and these objectives should push visitors to apply higher order thinking skills as an expectation. Teachers have more control in formal classrooms versus informal education settings to create safe spaces and mutual respect. Being explicit about cultural appropriateness in how we present SSIs is one way that ISIs can create these spaces. Encompassing cultural diversity in exhibits through examples or stories and designing exhibits in a manner that allows visitors to develop their own educated opinions without judgement are other ways to show respect for visitors.

14.2.6.5 Peripheral Influences

Consistent with the original SSIF used in formal settings, *peripheral influences* such as administration and surrounding communities often influence SSI instruction in ISIs (e.g., Reyes, 2020). For example, Administration contributes to SSIF-based exhibit design success by facilitating access to relevant resources supporting exhibit development. Surrounding communities influence programming and exhibits in ISIs much the same way as they can impact classroom curriculum (Maynard, 2018; Patrick & Caplow, 2018). Unlike in formal settings, funders influence ISIs, whether private contributions, grants, and/or visitors' entrance and program fees. If an SSI has no community support, inclusion of such an issue within an exhibit may negatively impact revenue-generating potential of the ISI through visitor protest or funding rejections (Koster & Schubel, 2007). Thus, there is a need to promote community support and willingness to engage in exploring perspectives to relieve pressures surrounding polarizing SSIs (Maynard, 2018; Presley et al., 2013). Exhibit designers and ISI administration can prepare themselves for possible pushback from communities by familiarizing themselves with local issues and the differing viewpoints (Presley et al., 2013). ISIs even could involve different businesses and organizations within communities in the planning process (Christensen et al., 2016; Pirani, 2011), giving community members a voice in how SSIs impact them. By explicitly connecting a SSIF exhibit to local communities, ISIs increase the likelihood for community buy-in and deepen the relevance of SSIs for visitors. ISIs could consider hosting previews of an SSIF exhibit to address potential community concerns (Yun et al., 2020).

The same standards used in formal educational environments indirectly influence ISIs, given that most ISIs offer field trip programs for neighboring school districts as part of formal-informal educational partnerships. As such, ISIs are bound to standards-driven considerations when developing educational materials, including exhibits. Ownership of the ISI can influence focus on SSI within exhibits. While some ISIs are state or federally managed, many ISIs are owned privately through nonprofit foundations or corporations, with a few belonging to publicly traded companies. Thus, ISIs are not as restricted by government policies in the same ways as formal education. Instead, ISIs tend to be governed more by accrediting boards (e.g., American Alliance of Museums, Association of Zoos and Aquariums [AZA], European Association of Zoos and Aquaria, etc.) that require them to meet and maintain industry standards for education.

Schools have Individual Educational Plans to support students with accessibility issues, but ISIs often do not have such formal structures in place and must consider accessibility needs (i.e., blind, deaf, hearing impaired, autism spectrum, physical access) for exhibit and programming design. SSIF exhibits may involve adaptive tools that visitors can request upon entering an ISI to assist the visitors' experiences. Designers may choose to highlight individuals in SSIs that represent members of different genders and/or come from a mix of cultures, races, and ethnicities (Dawson, 2014). There is power behind seeing diverse role models engaging in STEM activities.

14.3 Application in the Literature

Previous implementation of SSIF in informal settings is understudied (Yun et al., 2020) and lacking in empirical research (Burek, 2012). While prior research found ISIs may use a SSI to begin communication about science and conservation, they do not all utilize the SSIF to build instruction (Yun et al., 2020). There is a need for more aquariums and science centers to use SSIF programming and exhibits to improve scientific relevance (Koster & Schubel, 2007; Yun et al., 2020) and create a more scientifically literate society (Yun et al., 2020). Much of existing research (e.g., Bandelli & Konijn, 2015; Pedretti, 2004; Skydsgaard et al., 2016) examines characteristics of design elements found in the SSIF through exhibits and programs. Museums can foster scientific citizenship through activities allowing the public to engage with scientists, participate in debate and dialogue forums, and special programming targeted for adult visitors (Bandelli & Konijn, 2015). SSI exhibits can challenge visitors in intellectual and emotional ways by personalizing and increasing the relevancy of exhibit messaging (Pedretti, 2004). Furthermore, evidence suggests SSI exhibits can stimulate dialogue and debate amongst visitors (Pedretti, 2004). Implementing four exhibit design principles (curiosity, challenge, narratives, and participation) can support SSI facilitation of visitor reflection and discussion (Presley et al., 2013; Skydsgaard et al., 2016). Curiosity can support the SSIF goal of creating compelling messages promoting discussion and reflection. When visitors are curious about a subject, they are more likely to seek out additional, relevant content to further their exploration of the content. Challenge is a way to create opportunities for visitors to reflect on their reactions and previously held ideas about the science information they encountered. Narratives involve using stories to make science contextualized, relatable, and relevant. Participation through elements such as manipulatives (Price et al., 2018), like touch screens and physical artifacts, can facilitate increased visitor engagement at an exhibit.

The other elements of the SSIF discussed in previous research include instructional resource attributes (Cameron, 2012), and the educational environment (Christensen et al., 2016; Esson & Moss, 2013) in ISI exhibits and programs. Museums communicate science from differing perspectives, do research, and provide visitors with information on actionables and resources aiding behavior change (Cameron, 2012). As such, museum exhibits that integrate scientific information with real-world connections help visitors understand broader notions about SSIs like what being healthy means (Christensen et al., 2016). Even if ISI exhibits include "disturbing" illustrations and content as part of temporary exhibits, visitors tolerated the messaging and expressed comfort with reflecting upon and indirectly debating these issues with other visitors using message boards and post-it notes (Esson & Moss, 2013). While the research explored elements of the SSIF, none looked at the SSIF in ISI exhibits from a holistic approach.

Studies investigating the SSIF in a holistic manner have used a place-based approach to informal learning but have not explored the SSIF in ISI exhibit settings.

Currently, holistic investigations of the SSIF offer implications suggesting engagement with SSIF instruction in informal environments may lead to increases in compassion toward people and nature (Herman, 2018; Herman et al., 2018), contextualized nature of science understanding (Herman et al., 2019), development of critical thinking and problem-solving skills (Burek, 2012; Ervin & Sadler, 2008), science content knowledge (Burek, 2012; Kinslow et al., 2019), and a willingness to take action (Herman et al., 2018). If these are qualities that ISIs want visitors to build as a result of engaging with their exhibits and programming, then ISIs should consider utilizing the SSIF when designing their exhibits.

14.4 Exploring the SSIF in Aquarium Exhibits

As one of the places people go to get science information outside of a formal science classroom, aquariums are an important point of study (Bell et al., 2009). While limited research has explored the SSIF in ISI (e.g., Yun et al., 2020), even fewer studies focus on a holistic look at SSIF in aquarium settings. Through a series of three sub-studies, we explored how a SSI is communicated through an aquarium exhibit (Idema, 2021; Reyes, 2020). To guide our exploration, we used the outlined parts of the updated SSIF to create a checklist for identifying what elements of the SSIF (Fig. 14.1) are already integrated in existing exhibits (Idema, 2021). Our first two studies focus on identifying which SSIF characteristics are present in aquarium exhibits that introduce visitors to the SSI of climate change. Our third study explores what SSIF characteristics are present as well as visitor interactions and interpretations of an exhibit that features the SSI water sustainability.

14.4.1 In-Person Exhibits About Climate Change

We identified the primary features of the SSIF for each of the three core characteristics (*design elements*, *learner experiences*, and *instructional resource attributes*) and used this list as a guide to analyze 420 climate change exhibits from 50 aquariums across nine countries. Of the 420 exhibits observed, only three featured CC messaging throughout the exhibit, while 30 mention CC or a human-induced impact associated with CC at least once. In Fig. 14.2 we provide an example of signage from an exhibit classified as mentioning CC and/or a human-induced impact associated with CC at least once. In the example, we identify two of the characteristics of design elements—includes a relevant social issue tied to science and grounds the message in localized real-world contexts. Based on the adapted SSIF characteristics for exhibit design, no exhibits used all the characteristics in ways to warrant classification as representing the SSIF instructional approach, suggesting a disconnect between the SSIF and practice in ISIs. The most common characteristic found was the ability to ground the SSI in related science content under instructional resource attributes. Aquariums tended to include text-heavy, factual science information. While including relevant science information in CC exhibits is important, if signage is too text heavy, visitor engagement declines (Bitgood, 1989; Serrell, 2015). Scaffold opportunities promoting higher order thinking and cognitive load planning were absent from the observed exhibits (Idema, 2021). Most noticeable was how few exhibits (n = 3) attempted to ground the CC message in localized and relevant contexts. These three exhibits offered learner experiences through exploration of different social dimensions tied to CC. While using different perspectives to convey the impacts of CC on people within a community can be a powerful tool for engaging visitors in SSI learning (Presley et al., 2013), this tool becomes more powerful when used with the other learner experiences characteristics of the SSIF (Herman et al., 2018). We noted that only one of the three exhibits to feature CC messaging throughout the exhibit included an additional learner experience of collecting and analyzing data on the effects of ocean acidification (Idema, 2021). All exhibits showed evidence of background knowledge about CC and related science content garnered from instructional resource attributes. However, we found an overall lack of interactive components. By incorporating interactive components over text-heavy signage, ISIs can increase visitor engagement through opportunities to manipulate elements of the exhibit as they learn more about the SSI (Allen & Minion, 2020; Price et al., 2018; Roe et al., 2014). As we consider restructuring CC exhibits, we should ensure we do not overlook characteristics to support successful SSI-based learning.

14.4.2 Virtual Exhibits About Climate Change

The Covid-19 global pandemic presented ISIs with unprecedented challenges including a need to make their content virtual for visitors sheltering in place (Graeber, 2020). We describe virtual exhibits as a combination of themed content, messaging, and species arranged on an online platform for public viewing. Content-wise, virtual exhibits are like in-person exhibits with photographs, live streams, and/or videos of species taking place of viewing organisms in-person. These virtual exhibits can be available through ISIs' websites and offer visitors a way to access and engage with ISI content around the clock (Graeber, 2020; Song et al., 2004). In Fig. 14.3, we provide an example of what signage in a virtual exhibit can look like. Utilizing virtual exhibits allows ISIs to reach broad audiences with frequently updated content and more cost effectively than in-person counterparts (Decker, 2015; Semczyszyn, 2013; Song et al., 2004). Unfortunately, research on virtual exhibits is limited (Foo, 2008; Kim, 2018). We explored CC messaging using a SSIF lens in 256 virtual exhibits from aquariums across the US and Canada (Idema, 2021). We found that only 21 virtual exhibits across both countries mentioned climate change or a human-induced impact associated with CC.

Similar to in-person exhibits, none of the observed virtual exhibits used all of the expected SSIF characteristics adapted for exhibits (Idema, 2021), but they did share

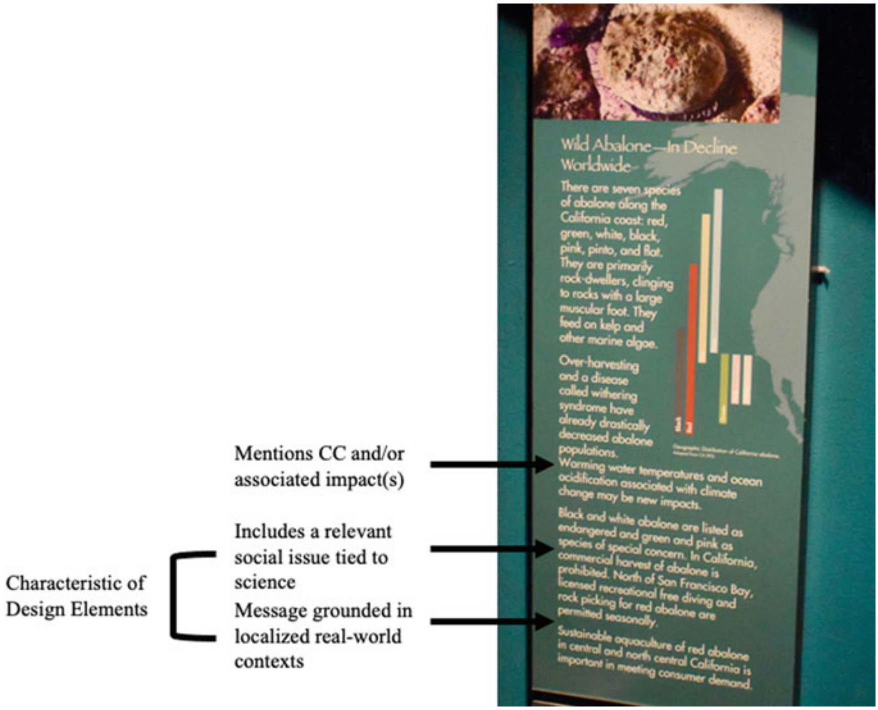


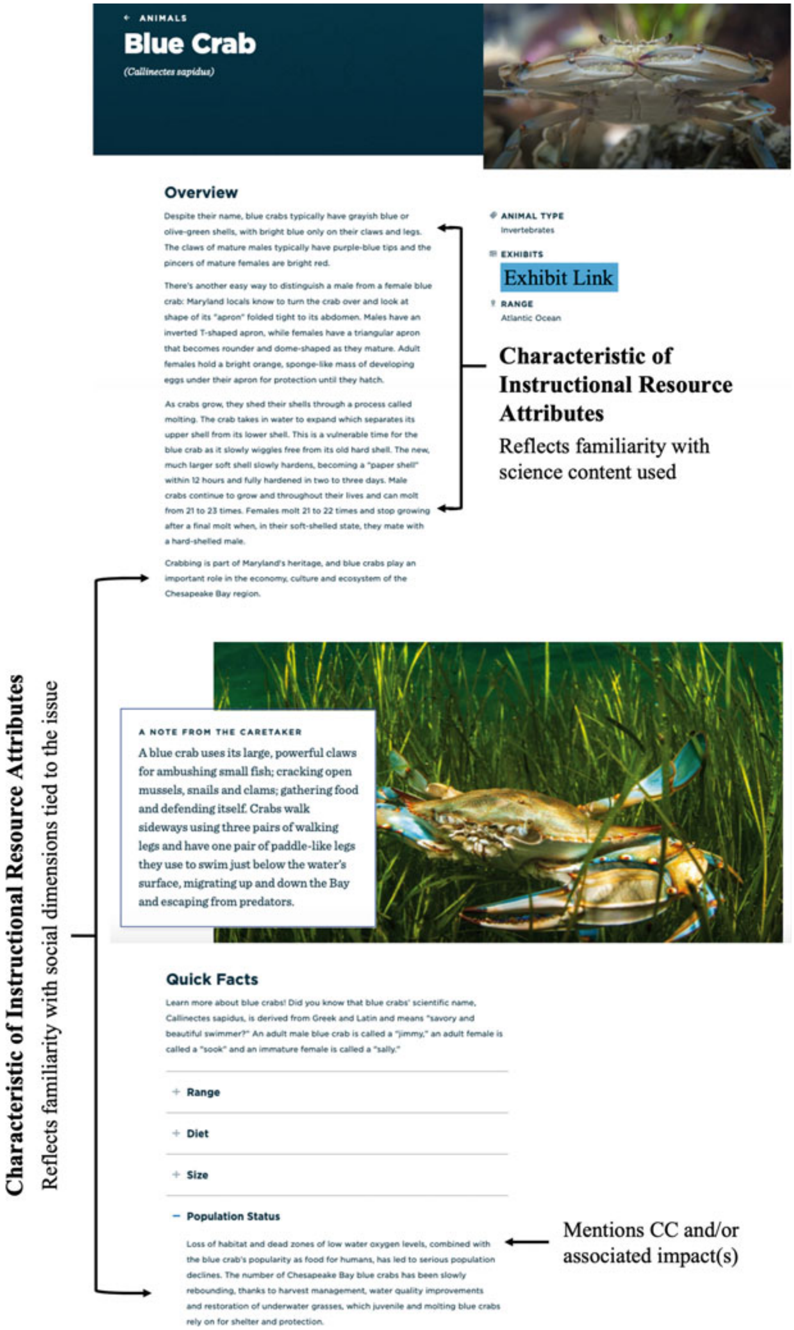
Fig. 14.2 Examples of design element characteristics found in an in-person exhibit. *Note* Here we show signage from an exhibit at a California aquarium that was classified as *mentions CC and/or an associated impact.* Our example illustrates two SSIF design element characteristics. First, the sign includes a relevant social issue (consumer demand of abalone) tied to science (decreasing abalone populations due to environmental and human impacts). Second, the message is grounded in localized (description of species native to the California coast where the aquarium is located) real-world contexts (the need for sustainable harvesting and aquaculture practices). It is important to note that we counted SSIF characteristics across multiple signs included in an exhibit's boundaries. This example reflects SSIF characteristics found on one sign within a California coast exhibit

many of the same common core characteristics. For example, six virtual exhibits grounded the CC message in local and relevant contexts. Design elements are critical as people may feel removed from climate change and its impacts because it can be difficult to see the immediate effects (Clayton et al., 2014) and they do not know how climate change may impact their everyday life (Moser, 2010). In contrast, within the virtual dimension, we found two virtual exhibits integrated scaffolding and five virtual exhibits explicitly attended to cognitive load balance (Idema, 2021). The ideal exhibit grabs visitor attention as well as provokes thinking and interest in the featured topic through creative, unique ways (Beck & Cable, 2002; Tilden & Craig, 2009; Veverka, 2011). Virtual exhibits that incorporate the SSIF in their design exemplifies ideal exhibits by prompting open dialogue and encouraging the development of moral and ethical reasoning that leads to better environmental decision making (Sadler et al., 2007). However, we found only seven of the observed virtual exhibits supported ideal learner experiences and included opportunities for visitors to engage in higher order practices, confront prior ideas, theories, and misconceptions, explore different social dimensions tied to CC, collect and analyze data, learn about ethical/moral issues tied to the SSI, and/or consider nature-of-science themes connected to the SSI (Idema, 2021). Learning from an online platform may be difficult if information and visuals are stagnant (Song et al., 2004). Therefore, virtual exhibits should incorporate interactive components such as games, videos, links to citizen science opportunities, or virtual pets (Dillahunt et al., 2008). However, we found a lack of interactive components (i.e., games, interactive maps, activities, etc.) in virtual exhibits (Idema, 2021). Still, the most common instructional resource attributes found in all CC exhibits reflected a familiarity with the SSI and the science content as well as potential to update content frequently to include current events. Figure 14.3 provides an example of instructional resource attribute characteristics that can be found in a virtual exhibit.

14.4.3 Interpretations of a Socioscientific Issue Exhibit

Reyes (2020) explored how families interacted with an SSI exhibit focused on water sustainability. Reyes interviewed staff responsible for exhibit design and used eye-tracking to capture family interactions with the exhibit in real time. Reyes (2020) found the theme of water sustainability present throughout the exhibit via signage, videos, interactive touch screens, and tanks with native and endemic species. According to the staff participant, the intent behind the exhibit's design was to make it interactive and accessible for all visitors using touch screens and other digital displays, as they "attract people's eyes more than paper information sheets" (Reyes, 2020). By incorporating different design elements, the exhibit attempted to balance cognitive loads (Veverka, 2011) but still relied upon text-heavy signage. Too much text can inhibit visitor engagement (Serrell, 2015) even if it is interactive (Veverka, 2011).

Building on the work of Reyes (2020), we found the water sustainability exhibit did not include scaffolding opportunities to foster higher order thinking and practice (Reyes et al., in progress). Learner experiences in the SSIF are influenced largely by scaffolding opportunities in the exhibit design elements and need support through higher order practice. When these opportunities are missing, engaging visitors in higher order thinking and practice becomes more of a challenge (Patrick, 2014). However, the exhibit did provide visitors with some opportunities to explore different social dimensions through short videos about a native species life cycle and the different ways humans use water from the local aquifers and rivers (Reyes et al., in progress). The exhibit presented visitors with moral and ethical aspects tied to water sustainability through videos and signage. However, the staff explicitly opted to focus the exhibit on a water sustainability message instead of CC to present a less controversial issue, less likely to upset visitors (Reyes et al., in progress). ISIs do not


ANIMALS
Blue Crab
(Callinectes sapidus)
Overview
Despite their name, blue crabs typically have grayish blue or olive-green shells, with bright blue only on their claws and legs. The claws of mature males typically have purple-blue tips and the pincers of mature females are bright red.
There's another easy way to distinguish a male from a female blue crab: Maryland locals know to turn the crab over and look at shape of its "apron" folded tight to its abdomen. Males have an inverted T-shaped apron, while females have a triangular apron that becomes rounder and dome-shaped as they mature. Adult females hold a bright orange, sponge-like mass of developing eggs under their apron for protection until they hatch.
As crabs grow, they shed their shells through a process called molting. The crab takes in water to expand which separates its upper shell from its lower shell. This is a vulnerable time for the blue crab as it slowly wiggles free from its old hard shell. The new, much larger soft shell slowly hardens, becoming a "paper shell" within 12 hours and fully hardened in two to three days. Male crabs continue to grow and throughout their lives and can molt from 21 to 23 times. Females molt 21 to 22 times and stop growing after a final molt when, in their soft-shelled state, they mate with a hard-shelled male.
Crabbing is part of Maryland's heritage, and blue crabs play an important role in the economy, culture and ecosystem of the Chesapeake Bay region.
ANIMAL TYPE
Invertebrates
EXHIBITS
Exhibit Link
RANGE
Atlantic Ocean
Characteristic of Instructional Resource Attributes
Reflects familiarity with science content used
A NOTE FROM THE CARETAKER
A blue crab uses its large, powerful claws for ambushing small fish; cracking open mussels, snails and clams; gathering food and defending itself. Crabs walk sideways using three pairs of walking legs and have one pair of paddle-like legs they use to swim just below the water's surface, migrating up and down the Bay and escaping from predators.
Quick Facts
Learn more about blue crabs! Did you know that blue crabs' scientific name, Callinectes sapidus, is derived from Greek and Latin and means "savory and beautiful swimmer?" An adult male blue crab is called a "jimmy," an adult female is called a "sook" and an immature female is called a "sally."
+ Range
+ Diet
+ Size
− Population Status
Loss of habitat and dead zones of low water oxygen levels, combined with the blue crab's popularity as food for humans, has led to serious population declines. The number of Chesapeake Bay blue crabs has been slowly rebounding, thanks to harvest management, water quality improvements and restoration of underwater grasses, which juvenile and molting blue crabs rely on for shelter and protection.
Mentions CC and/or associated impact(s)
Characteristic of Instructional Resource Attributes
Reflects familiarity with social dimensions tied to the issue

◀**Fig. 14.3** Examples of instructional resource attributes characteristics found in a virtual exhibit. *Note* Here we show signage from a virtual exhibit classified as *mentions CC and/or an associated impact.* While the signage does not directly use the words climate change, it does present visitors with an associated impact (dead zones of low water oxygen levels) that can be attributed to the SSI. Additionally, we present two characteristics of instructional resource attributes. The virtual exhibit signage reflects a familiarity with social dimensions tied to the issue by providing visitors with statements about the role blue crab populations play in Maryland's ecosystems, economy, and culture. The virtual exhibit also reflects a familiarity with the science content used as it draws connections between blue crab physiology, how dead zones of low water oxygen levels affect the species, and conservation efforts to improve this ecologically and economically important species. Like their in-person counterparts, SSIF characteristics were counted across multiple webpages designated within a virtual exhibit's boundaries. The examples of instructional resource attributes characteristics we show are just some of the SSIF characteristics found within a virtual exhibit about Maryland's coast

want to alienate the visitors and entities that fund their programs. However, the SSIF is purposely designed to facilitate controversial messages by encouraging visitors to explore different social dimensions tied to the SSI and promote institutional and community support.

We found that participants spent an average of four minutes interacting with the exhibit (Reyes et al., in progress). Adult participants mainly focused on digital signage. In contrast, child participants focused their attention on the live animals in the exhibit. Both groups focused on physical signage the least. While most family participants identified a theme closely aligned with the exhibit's intended message, none identified the exhibit's intended message in its entirety–to help visitors understand that the conservation of water is important because the overuse of water and nonpoint pollution within the watershed can harm local endangered aquatic species (Reyes et al., in progress). We found participant interpretations aligned with their engagement focus. Adult responses were more reflective of information found in the videos and interactive touch screens while child responses talked about the need to protect aquatic species and their habitat or actions they could take to protect species (Reyes et al., in progress). Participants' experiences and exhibit message interpretations are reflective of the idea that visitors enter an exhibit with varying levels of prior knowledge, motivation, and interest (Bell et al., 2009; Falk et al., 2007). As such, ISIs may want to consider integrating multiple learning objectives into SSIF exhibits to address the needs of the different visitor groups engaging with their exhibits to ensure intended SSI takeaways. Even though the focus of our research is on two particular SSIs (CC and water sustainability), our findings provide takeaways and suggestions for how ISIs can utilize the SSIF to engage visitors in learning about SSIs.

14.5 Importance to the Research

The SSIF is a tool ISIs could use to design and evaluate exhibits. Figures 14.2 and 14.3 reflect how SSIF characteristics can be used in the evaluation process. ISI staff could use the SSIF to identify missing SSIF characteristics in existing exhibits and develop solutions addressing those characteristics, making exhibits more effective. In this capacity, the SSIF can aid ISIs in recognizing exhibit strengths and opportunities for improvement.

Trends in the SSIF usage reveal a lack of scaffolding, presentation of SSI in local and relevant contexts, and the inclusion of text-heavy signage (Idema, 2021; Reyes, 2020). Scaffolding is essential as it fosters higher order thinking and practice that leads to a better understanding of science (Sadler et al., 2016), ethical and moral reasoning (Sadler et al., 2007), and behavior change (Burek & Zeidler, 2015). In the formal science classroom, an educator leads scaffolding opportunities (Presley et al., 2013). However, in ISIs an informal educator is not always present. During these times, the exhibit takes on the role of educator and a lack of scaffolding can hinder opportunities for deeper learning with SSIs (Krange et al., 2019; Presley et al., 2013). In this respect, ISIs can benefit from theory-driven best practices used in formal education to improve effective exhibit design.

ISIs use exhibits to introduce a SSI (Idema, 2021; Reyes, 2020); however, failing to expand on this introduction is a concern. SSIF exhibits address why an SSI is complex and introduce visitors to varying social dimensions tied to the SSI. Furthermore, there is a need to present SSIs in localized and relevant ways to visitors (Clayton & Myers, 2015). Coral reefs and polar habitats are important within the context of CC, but most visitors have limited interactions with these ecosystems beyond a zoo/aquarium visit. Connections needed to ignite conservation action are challenging if visitors feel removed from the SSI (Clayton et al., 2014; Moser, 2010). Using native and endemic species as well as engaging visitors in learning about local social dimensions affiliated with the SSI may increase the personal relevance of the issue and ultimately help visitors understand impacts of their actions.

Some research argues that a vast majority of visitors do not read exhibit signage (Churchman, 1985; Screven, 1992; Serrell, 2015; Shiner & Elwood, 1975), while others say at least 95% of visitors read some signage (Barriault & Pearson, 2010; Davis & Thompson, 2011). Regardless, ISIs cannot place too great a dependence on exhibit signage to engage visitors in SSI learning as not all visitors use physical signage in the same way (Roe et al., 2014). While interactive signage may hold visitor attention longer (Davis & Thompson, 2011; Holland et al., 2015; Roe et al., 2014), cognitive fatigue can occur if there is too much text (Veverka, 2011). SSIF exhibits have the potential to be taxing mentally due to the amount of cognitive energy expended (Shaby et al., 2017). Due to the high amounts of cognitive energy used in SSI-based learning, not every exhibit in an ISI should be an SSIF exhibit.

In the formal classroom, the SSIF effectively has engaged students in dialogue while helping them develop critical thinking and reasoning skills (Sadler et al., 2007; Zeidler et al., 2009). ISIs frequently work in tandem with school districts to ensure their program curriculum meets the standards schools need to justify field trips to said institutions (Patrick & Tunnicliffe, 2013). Because the SSIF employs provisions for meeting industry and educational standards at state/national levels, future uses for the SSIF could assist with ISI curriculum design. This chapter introduces the SSIF for exhibit design and provides a foundation for examining SSIs in ISIs. As ISIs continue their quest to create more scientifically literate citizens, the SSIF serves as a vessel for generating exhibits, programming, teaching practices, and research that takes us there.

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Chapter 15
Complementing Informal STEM Education with Social Entrepreneurship

Najmeh Keyhani and Mi Song Kim

15.1 Introduction

During the Cold War tensions, through competition, Eastern and Western Blocs started putting in extra efforts to excel at science and technology. In 1957, the Soviet Union inaugurated the Space Age by launching Sputnik, the world's first artificial satellite. This event led to public fear about the possible technological gap between the United States and the Soviet Union and fueled existing attacks on public schools, immediately resulting in the United States recruiting specialists from various scientific fields to develop new curricula (Null, 2008). The hype continued for about 16–17 years (Helgeson, 1977) and during this time curricula in the United States and Great Britain developed quickly and spread to other countries (Weinstein et al., 2016). In the 1990s, similar interest resurfaced when the Assistant Director of the National Science Foundation's Education and Human Services Directorate, Judith Ramaley, coined the acronym STEM to underline the coherent nature of Science, Technology, Engineering, and Mathematics, and to promote these skills to the public (Marx, 2017). Subsequently, STEM education gained much attention and prominence in other countries and is now a fundamental concern for policy makers worldwide (Marginson et al., 2013). This holds true for Canada, which has opened space for many investments in STEM initiatives. For example, the Hibernia Project in Newfoundland and Labrador holds STEM-related professional development and teacher education programs, the Wise Atlantic program in Nova Scotia dedicates to getting young kids, particularly girls, involved in STEM, Youth STEM in Ontario encourages education and careers in STEM fields, the Imperial Oil Foundation in Alberta supports STEM-related studies at the University of Calgary, and the Saskatchewan Cradleboard Initiative in Saskatchewan supports STEM education for ages 5–14 (DeCoito, 2016). The 2018 budget of the federal Canadian government

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indicates Canada's ongoing support for STEM fields through allocation of funds to various STEM research and commercial grants (Department of Finance, 2018).

Most of the attention STEM education is receiving is due to promotional efforts emphasizing economic and national security objectives (Gonzalez & Kuenzi, 2012). Consequently, concerns arise that neoliberal intentions guide STEM initiatives (Weinstein et al., 2016). Through a discourse analysis of the United States' Next Generation Science Standards (NGSS), Hoeg and Bencze (2017) found prioritization of specifically reproducible and measurable initiatives related to STEM education. In addition to this career-centered focus, Garibay (2015) found the perception of STEM areas as very technical and irrelevant to morality or social value. In response, there have been many calls to connect social value to STEM areas (Amadei & Sandekian, 2010; Sriraman & Steinthorsdottir, 2007; Vaz, 2005; Vieira & Tenreiro-Vieira, 2014), and to take on an interdisciplinary approach to STEM education by incorporating more of humanities and social sciences to make resolving society's issues more possible (Collins, 2018; Yamada, 2018). Hytten and Stemhagen (2019) emphasize the need to reinfuse a democratic-civic vision and mission into STEM education to create a balanced and just society. The development of topics such as Socio-scientific Issues (SSI) and Science, Technology, and Society (STS) outline a history of efforts highlighting the importance of social value in STEM education (Sadler, 2004; Yager, 1996) with an even stronger emphasis in recent years (Letizia, 2017; Marx, 2017; Storksdieck, 2016; Sun, 2017). However, studies still point out the need for more. Although the level of social agency in STEM students is not homogenous throughout all STEM fields and student demographic categories, Garibay's (2015) study of over 6300 STEM graduates shows the majority of them still have low or medium levels of social agency or sociopolitical involvement (Garibay, 2018). Garibay's mentioned studies reveal that despite existing efforts, lack of social responsibility among STEM students persists.

15.2 Learning Theory and Application in Literature

In this chapter, we bring to light the potential value in complementing STEM education with social entrepreneurship. Social entrepreneurship is, "a process involving the innovative use and combination of resources to pursue opportunities to catalyze social change and/or address social needs" (Mair & Martí, 2005, p. 3). Social entrepreneurs carry out similar tasks to commercial entrepreneurs who focus on business creation and are the ones most commonly talked about in non-scholarly discourses when the word entrepreneurship is used. However, as opposed to financial gains, social entrepreneurs are also (and sometimes mainly) motivated by social value as an end goal. A popular example of social entrepreneurship is the case of the Grameen Bank (Yunus, 1999). In 1972, Muhammad Yunus realized there were many poor families in Bangladesh's village of Jobra who struggled as a result of not having small amounts of working capital. Bankers refused to give them loans as the poor had no collateral. In 1976, he took a loan himself and distributed the money to the villagers in need.

All villagers paid him back, so he repeated this process in 100 other villages with the same results. His results still did not convince bankers, so he created his own bank (the Grameen Bank) for the impoverished through which he gave small loans to mostly women whose incomes were at less than half the poverty line. Women were required to apply in groups to offer each other support, pay back their loans in weekly meetings, and memorize and repeat 16 resolutions about social practices (e.g., controlling family size) and hygiene and health (e.g., consuming clean water). The Grameen Bank is a for profit institution which guarantees its sustainability while clearly working to reach greater social value.

The reason behind our proposal to bring social entrepreneurship concepts into STEM education, is the characteristics of both of these areas. The first characteristic common among both fields is their language of use. As we mentioned before, the language surrounding STEM education and STEM initiatives is an economic and career-related language (Science Technology and Innovation Council, 2015). Similarly, social entrepreneurship communicates well through a commercial language, as it is a discipline that emerged from inside the business field (Worsham, 2012). The second characteristic relates to the existence or lack of existence of a social concern. Based on the definition of social entrepreneurship we mentioned above, social value motivates social entrepreneurs, meaning they strive to benefit the society in some form (Peredo & McLean, 2006), and this social concern, as we mentioned earlier, is what STEM education and STEM students lack. Therefore, we believe, with the help of this familiar language, social entrepreneurship can appeal to STEM enthusiasts and introduce social responsibility.

For three reasons, the most proper place for this connection to happen is in a pre-university-level informal environment. First, in an informal setting, we target those who already expressed interest in STEM fields, whereas a formal school setting may include students with no STEM interests. Second, minorities who have shown to have higher social responsibility levels (Garibay, 2018), are typically less present in such informal settings (Vallett et al., 2018), which narrows the target population even more to those we would like to reach. Third, informal settings are not pressured by standard curricula and assessments (National Research Council, 2009) and this flexibility provides a safe environment for exploring new initiatives.

Use of commercial entrepreneurship in formal STEM education is common, as both areas (commercial entrepreneurship and formal STEM education) pursue economic development and growth (Nichols & Armstrong, 2003). However, in the literature, it is not easy to find the use of social entrepreneurship to complement informal STEM learning. Still, some have touched upon the merits of such a combination. For example, the 2015 Kumbhthon was a technical hackathon dedicated to STEM students carrying out social entrepreneurship projects to address the city needs of Nashik, India (Hecht et al., 2014). A total of 150 students from different disciplines participated in this 72-h event in teams mentored by educators, engineers, and entrepreneurs from India and the U.S. Teams received pre-brainstormed assignments to look for potential solutions for the assigned problem and begin designing that solution during the workshop. Students practiced rapid prototyping, testing their work, and using social entrepreneurship models to design how to move the idea forward.

The main purpose for this combination was the need to teach STEM through experiential learning and project-based approaches while responding to the wealth of opportunities for social change in the populous country. Marshall (2009) also developed a conceptual design for specialized STEM academies that would incorporate social entrepreneurship into their practice, to nurture "*decidedly different*" students (p. 48). This would happen through an emphasis on empathy, developing knowledge and skills in systems thinking, public advocacy, and an attempt to create "change in principle, policy, or practice" (p. 56). For example, teams would meet with investors interested in their entrepreneurial ideas and set out to procure resources and bring their ideas to life. The goal of bringing social entrepreneurship into the mix was to help nurture socially responsible change agents who engage in social activism and problem solving, which is very much in line with our claim for the need to bring social entrepreneurship into STEM education and our reasons for it.

In summary, we believe the business-like language of social entrepreneurship can help attract STEM enthusiasts (e.g., through promotional efforts) to an environment that can help introduce them to social value. Then, it is suggested that social entrepreneurship concepts be used as a source of inspiration or a helpful basis/framework for designing informal STEM educational experiences. We would like to leave the specific choice of concepts to the curriculum developers to make based on their unique situations and needs. However, we propose the stages of entrepreneurship and the elements of innovation, opportunity, resources, and social value as a beneficial combination of concepts to consider. As an example of other potential social entrepreneurship concepts that can be used, we also incorporated empathy, which is considered to be an important antecedent to social entrepreneurship.

15.3 Example of Author Use

The context of our example is a graphic design and coding course designed for elementary students (ages 6–9) at a non-profit STEM centre in Canada. The course included four weekly sessions that consisted of designing game elements (characters, background, etc.) using various graphic design software and creating a game or a number of mini games using those elements in SCRATCH, a drag-and-drop coding platform for kids. We used a well-known antecedent to social entrepreneurship and the process and main elements of social entrepreneurship to shape this course. One of the main antecedents to social entrepreneurship is empathy (Urban & Teise, 2015) that leads to prosocial behavior (Batson, 1987), and empathy is a trait STEM education needs. Design thinking and problem-solving approaches already use empathy (Mahil, 2016; Parmar, 2014) in STEM literature but the need for much more persists, for creating more inclusive and welcoming STEM environments (Daily & Eugene, 2013; Yore et al., 2014). For this study, we defined empathy using Olson's (2013) words, as putting oneself in other people's shoes to see what they feel, "to encompass a constructive prosocial response to this moral emotion" (p. vii). In response to expectations of fun (Keyhani & Kim, 2020) and engagement (Allen & Peterman, 2019) in informal STEM learning environments, we avoided possible negative feelings that may arise from empathy with a real-world character facing challenges. The STEM centre was a start-up in its growth stage and we were not in a position to experiment with ideas that potentially could influence students' experiences in a way that ultimately could have affected their retention rates. Hence, we decided to have students empathize with a virtual character throughout the sessions, as literature had shown us that developing empathy through virtual reality experiences is possible (Bachen et al., 2012; Tong et al., 2020).

Apart from our use of empathy, to break down our sessions and activities, we used Thompson's (2002) four stages of social entrepreneurship, *envisioning, engaging, enabling, and enacting*. One recognizes an opportunity in the envisioning stage, engages the opportunity by searching for solutions in the engaging stage, starts actual work in the enabling stage by acquiring resources and taking action, and moves forward to a satisfactory result in the enacting stage. It may be useful to note that in general, these stages can be advanced, either by one person (the social entrepreneur), or a group/institution. We chose this process to provide enough flexibility and simplicity for our work with young students, while still including important elements of social entrepreneurship such as opportunity, resources, and taking action. Finally, for the main elements of social entrepreneurship, using the definition Mair and Martí (2005) offered, we ensure the presence of innovation, opportunity, resources, and social value.

In the first session, we asked students to gather in a circle, close their eyes, and imagine a place where it rains. Then we told them to look more closely as the raindrops were not water. The teacher asked them each to picture exactly what was raining from the sky, open their eyes, and name what they saw. The teacher explained that in this imaginary land, people did not come out of their houses because nobody had an umbrella for that particular kind of rain. At this point, students went back to their workstations and, using one of the graphic design software we chose for the class, they started to design a character who would be the one to build the umbrella everyone needed so urgently. Throughout the whole session, the teacher went from student to student asking them about their design choices and why they thought that specific shape, color, etc., was useful or appropriate in relation to the type of rain they had in mind. In the end, students took their characters into SCRATCH and chose a backdrop (background) for them, again using the same reasoning and justification processes.

As a result, with the help of storytelling and imagination, the students started by *empathizing* with the characters they had in mind. Then, they deepened their connection to this character by designing the character themselves, gradually thinking about all its body parts, colors, shapes, and how the character lives, moves, and acts in that environment. Regarding the social entrepreneurship elements and process, in this session the teacher and students went through the *envisioning* and *engaging* stages. They clearly identified and envisioned the *opportunity*, which is in this case the lack of an umbrella. Then they got to know the surrounding situation and started engaging with the umbrella idea through engagement with the character who eventually would build that item. The use of students' imaginations to create characters and worlds that did not exist before also guaranteed our use of *innovation.* They briefly touched on *social value* as they considered the vision of their land and people improving with the help of an umbrella.

In the second session, the teacher explained to the students that because nobody went out under the rain, their characters had been unable to find any friends and they felt too sad to build an umbrella on their own. The teacher then asked students to consider their main character and design a pet or friend for their character so that they could become best friends. Students used new graphic designing software initially to design this pet/friend and a second application to turn it into 3D. Once students finished their new designs, they took both characters into SCRATCH to participate in a racing game and become friends.

In continuation of the first session, *empathy* went to a deeper level. Students now had to put themselves in their character's shoes to think about their emotional needs. Having one week in between the first and second sessions to think (consciously or unconsciously) about their characters made this easier. Basing imagination on the character's personality and appearance, which they had decided themselves, and the character's living conditions on the rainy land, students imagined what type of pet/friend the character would want potentially to help create the umbrella as well. Like the previous session, they were still in the *envisioning* and *engaging* stages as students became more familiar with the characters and the environments in their stories. Even though students started thinking about a friend for their characters, they still were considering the bigger opportunity to create an umbrella, as they imagined the possibility of this new friend also being a useful resource in the social entrepreneurship process.

For the third session, the teacher told the students that their characters were to finally build the umbrella. However, at this point the virtual characters did not know how or with what to build the umbrellas. First, students imported their characters into SCRATCH and added a backdrop as the characters' home environments. At this point, on the classroom table, the teacher laid out 30 pieces of paper on which random object names were written. Then students were to choose 5 resources their characters could use to build an umbrella. Three of these resources could be anything they wanted, but the students must choose two from the papers on the table. Students then inserted their chosen resources into their SCRATCH games and had their characters glide from one resource to another, in the order required to build an umbrella. Again, the teacher asked students about their resource selections and how their characters were to create an umbrella with those specific resources. After game characters finished gliding to all resources, students had them glide to an umbrella icon, which meant the characters had succeeded in building an umbrella. This final event triggered the backdrop to change to a new game environment.

Students continued to practice *empathizing* with their characters as they imagined what resources were useful to the characters, considering their traits and personalities. In this session, students entered the *enabling* stage of social entrepreneurship, in which they set out to acquire the resources by choosing from a series of *limited* *resources*, similar to real life. They entered the *enacting* stage as they start building the umbrellas and making their ideas come to life. At this point, they received more serious encouragement to think of the role of the character's pet/friend in the design.

In the fourth and final session, students designed a new backdrop which visualized a rainy outdoor environment in which their characters would be using the umbrella. This new environment was programmed to appear on screen once students' characters glided to the umbrella (designed in session three). Students created the environment by choosing a base backdrop and adding their own *raindrops*. They then brought in the umbrella and coded it to move around the page with arrow keys. An added code also made sure that every time a drop of rain hit the umbrella, students' characters gained a certain amount of money, which enabled them to build more umbrellas. Once they had enough money to build 10 more umbrellas, the backdrop would change to a celebratory one. In this stage, students took photos of themselves in front of a green screen and inserted those photos into their games. Students then made themselves the mayor of their cities, who handed out a gift to the characters in the game and gave a short speech on how the city had changed with this umbrella.

In this session, students finished their work in the enacting stage, in which they put their umbrella to use, started gaining income from the use of the umbrella, which would allow them to build more (and redesigned/enhanced) umbrellas, and experienced the concept of sustainability, which is essential to the continuation of any entrepreneurial initiative. In this session, students continued to reflect on resources, now that they had money as an available resource, and possibly new friends. In addition, with the mayor's small speech at the end of the session, they got a chance to think deeper about the *social value* and change brought about because of their actions.

At the end of each session, students' parents came into the classroom to see their students' developed designs and heard about students' ideas, plans, and goals. We believe this interaction created an opportunity to have a positive effect on the parents' perceptions regarding STEM education and *social value*.

15.4 Importance to Research

Through this study, we attempted to link social value to STEM education in a way well aligned with the goals of STEM education itself. We explored constructive grounds for an interdisciplinary study between the fields of social entrepreneurship and informal education, which is not a common event as there exists a certain level of resistance to similar ideas (Despres, 2003). Our work opens the door to more interdisciplinary research of this kind, which will enable and motivate scholars to explore further, to learn from and to share knowledge with other fields. This is especially true for the field of informal education and outside of the formal classroom environments because of the flexibility they provide for such explorations to take place.

Our work introduces a language to communicate easily with STEM enthusiasts, without taking away the elements of STEM particularly important to them. One can use this language of social entrepreneurship through content, promotional work, policies, and research to appeal to students, parents, politicians, and scholars. For example, research on informal STEM education design and assessment can use the elements and process of social entrepreneurship to establish more widely accepted STEM activity designs and expectations to implement and assess in both practice and theory. Similar studies to ours can focus on combining real-world and virtual-world social issues and ways to take advantage of the potentials of both. Studies can take place on long-term perceptions of students who do attend informal STEM environments that focus on social entrepreneurship. Scholars can focus on opportunities that arise because of the economic language common among STEM and social entrepreneurship and the possible ways to take advantage of such commonality. Researchers can turn the perspective around and see how informal STEM education theory and practice can help enhance the field of social entrepreneurship.

15.5 Conclusion

There are numerous calls to add a component of social responsibility to the education of all STEM areas (Amadei & Sandekian, 2010; Sriraman & Steinthorsdottir, 2007; Vaz, 2005; Vieira & Tenreiro-Vieira, 2014), as they continuously connect to economic and business discourses or are very technical and separate from moral issues and concerns (Garibay, 2015; Science Technology and Innovation Council, 2015). We took an interest in adding this social component to STEM education in an informal setting because of the unique characteristics of such environments, especially their flexibility and openness for exploration of new ideas (National Research Council, 2009) and integration of concepts (Burrows et al., 2018). We worked to complement informal STEM education with social entrepreneurship, which is rich in social concern and empathy and can relate to STEM education well as it uses a similar commercial language. For this purpose, in this study, we designed and carried out an informal STEM course using the social entrepreneurship process and its relevant elements. We believe scholars from both the disciplines of social entrepreneurship and informal education can carry out different variations of our work, build on our work to develop their fields' designs and outcomes, and experiment with the components of informal STEM education and social entrepreneurship in various settings to discover new possibilities.

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Part V
Systems Theory

Chapter 16
Bringing Barad into Outdoor Learning: A Reflective Case Study Concerning Quadrats and Agential Cuts in Ecology Education

Dawn Sanders and Paul Davies

16.1 Introduction

As teaching and learning moves from the classroom to outdoor settings, teachers and students often make shifts between socio-material planes of action from the indoor to outdoor classroom, the ecological setting, and the investigative tools they use. One such tool common to ecological science is the quadrat, a square frame mostly used for measuring plant populations in diverse habitats. Karen Barad's theories (2003, 2007) on new materialism have influenced our thinking about exploring these shifts. Her theories of material agency emerge from her background in physics and draw extensively on the work of Niels Bohr. For Barad, material objects enact changes, so, rather than seeing matter as inert, she argues matter intra-acts, resulting in new phenomena emerging. Few attempts have been made to ground her theories in science education practices, especially in relation to educational spaces and materials, as Hetherington et al. (2019, p. 20) note: "…as of yet, Barad's frame has not been brought to bear directly on the pedagogical interactions/intra-actions in school laboratories". Drawing on our educational experiences developed with teachers and students in the cities of Gothenburg and London, we make public an extended reflective conversation on what happens and what might happen if one used a Baradian perspective to consider an outdoor science activity focused on ecology. In these reflections, we examine the quadrat as a critical tool for framing layers of understanding through the lens of "agential cuts", both on the part of the teacher and the students during acts of noticing and identifying the biodiverse forms and interactions within the quadrat.

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Thus, the theoretical focus in this work concerns the use of Barad's "agential cuts" as a didactical frame on moving between the classroom and outdoor settings. Within this, we consider the conceptual and material possibilities the quadrat tool offers teaching and learning. Here we focus on the choices the teacher makes in relation to the materiality of both the quadrat as a didactical tool, the ecological concepts within the teaching, and the affordances for inquiry through 'noticing' and 'playing with' scale, geological deep time and ecological relationships. In so doing, we explore the emergence of Barad's "intra-actions" and how these manifest in what she describes as "worlding", where the world for the teacher and student is not simply 'there' but constantly coming "into being" through material agencies. Baradian thinking is not easily transposed to school science (see for example discussions in Hetherington et al., 2019; Scantlebury & Milne, 2019), but a growing group of researchers, particularly in science education, are attempting to draw on Barad's work to formulate deeper reflections on the ways in which our teaching processes and materials 'intra-act'.

Although we grounded this work in the education of teachers and situated it in a formal context, the reflections and theoretical concerns have applications across learning settings and can apply equally to so-called 'informal contexts', such as field-centres and botanical gardens (Braund & Reiss, 2006). We understand the usefulness of defining learning contexts as 'formal' and 'informal' but we agree with Dillon's (2021) assertion that "learning is learning is learning" no matter the context and, as such, believe that border-crossings (Akkerman & Bakker, 2011) between classroom-based settings and those beyond the classroom are of value in understanding the material and conceptual complexities of making such journeys. Thus, a conscious 'blurring' of definitions of 'formal' and 'informal' learning shapes our work in this chapter. As Kostogriz (2006) argues, we should not view sociocultural spaces with a notion of "sameness or difference" but as a "lived-space characterized by border-crossing events" (p. 118). Doing this, he asserts, helps reveal the "emergence of new identities and shared experiences" (p. 118).

Bringing Barad into outdoor biology learning is a challenge with which we have engaged for five years. Although difficult, we have found the challenge to be worthwhile and formative. Indeed, for both of us, our pedagogical use of the quadrat and related materials in our lessons has been extended in multiple ways, as discussed in this chapter. Such work, we believe, is a contribution to the gap Hetherington et al. (2019) recently noted, "there are many as yet unexplored possibilities for integrating the material world into pedagogical practices in science" (p. 17).

16.2 Application to the Literature

In this section we consider our approach in relation to relevant literature in both biological science and social science research, including, but not limited to, education studies. The following section explores ideas about spaces and objects—specifically the quadrat and the work of Karen Barad.

16.2.1 Scientific Spaces

Science is a complex socio-material space of disciplines and practices in which ideas, theories, objects, phenomena, experiments, and field work function in networks of actors (Latour, 1987, 2005). Within this culture of multiple participants is the added layer of diverse scales and the challenges of making sense of the invisible elements of science. For education, these ways of knowing and understanding place demands on teachers to: (a) make meaning from the abstract to the concrete for their students and (b) make decisions on the representations and tasks they use in their lessons. The diverse identities that the bodies of science knowledge represent, Biology, Physics, and Chemistry, add to this complexity through their differing epistemologies/ontologies, i.e., what it means to know in these disciplinary contexts (McGregor, 2004).

16.2.2 Quadrats in Ecology

Quadrats come in two forms, the frame and point frame. The quadrat most common in pre-university biology education settings is the frame quadrat. This is normally metal arranged to form a square or known area. The square sometimes is subdivided into smaller sections (see Fig. 16.1). The quadrat is a familiar scientific tool for measuring plant populations (Crawley, 1986). Thus, within ecological science it has a specific identity as a situational tool for measuring. Typically, the quadrat is used to focus and 'frame' a field of view where the researcher then can count or estimate percentage cover of the plant species present. As with all ecological sampling methods, the data generated within the quadrat are then extrapolated to provide an estimate for the entire study area. An advantage of the frame quadrat is that it is easy to use, even by young children, and allows for the rapid collection of data. Its use requires no specialised knowledge and provides limited risk to the user. It might be this ease of use that has led to the quadrat being such a common tool in ecology and, possibly, why researchers have given less thought to its affordances. This does not mean however others have not considered the *role* quadrats play in plant ecology and the history of biology research.

As early as 1920, Gleason provided an elegant appraisal of the affordances of the quadrat. He demonstrates that even over 110 years ago some ecologists were asking questions about what a quadrat actually can tell us and, importantly, what it cannot. For Gleason, while the quadrat frame provides a useful focus, it also means the researcher misses much. But, unless carefully used, often with associated statistical analysis, it can tell you little about variation in abundance of plant species across a large study area and provides limited insight into immigration and migration patterns. For Gleason, the tool is useful, but researchers have portrayed it as a 'panacea' to solve all problems in determining plant distribution, which it is not. He argues the proper use of the tool is alongside an evolving narrative of what the researcher observes, the

Fig. 16.1 A typical frame quadrat (from Wiki Commons)

relationships between what the researcher observes and the meaning the researcher attaches to these observations. He points out, too, the pitfall into which the quadrat leads the observer if they simply look at each plant individually, 'ticking it off' as they go. For him, the true essence of plant ecology is relationships, those between the plants, the plants and other organisms, and the non-living aspects of the environment. Essentially, Gleason argues researchers should use the quadrat to enhance notions of communities and relationships in plant ecology and not simply for spotting species.

The more modern, seminal text, *Plant Ecology* by Crawley (1986) explores this idea of shifting from the measuring tool to seeing what the tool can afford. In the preface of the book, Crawley makes it clear plant ecology is not about the tools but about the plants. He worries that "Traditional quadrat-based measures like 'percentage-cover' consign individual plants to oblivion, and discourage thinking about the evolutionary ecology of individuals" (Crawley, 1986, p. xv). Crawley goes on to introduce his book by saying "The plant-centred view of ecology is intended to rectify some of these defects by focusing attention directly on the interactions between a plant and its immediate neighbours, and between plants and their mycorrhizal associates, pollinators and natural enemies" (Crawley, 1986, p. xv).

For both Gleason (1920) and Crawley (1986), the quadrat has come to dominate the focus of investigating plant ecology. This is something we noted in our work with pre-service teachers and high school students. The emphasis, when exploring plant ecology, very much had a focus on the tools and techniques for measuring populations, and statistical analysis, rather than what the researchers did and did not observe. The literature well documents content and assessment approaches dominate school curricular in many countries (for example, see Wiliam, 2011), marginalising the space for creative teaching and learning (Baer, 2003). This concerns us as educators and drives from us a desire for teachers and students to recognise the role the individual plays in constructing their own, personal knowledge and the way a skilled teacher can weave learning experiences that allow this in their students.

Charles Darwin and his experimentation, thinking and imagining of other worlds, influences our teaching ideas. In his weed-plot experiments on his lawn at Down House in Kent, Darwin conducted experiments between January and August 1857 as Sanders (2015) describes,

> Darwin's weed-plot experiment brings alive the everyday dramas of our pavements, walls and back gardens. A patch of common plants becomes a miniature jungle where the struggle to survive is paramount, and competition rife. Darwin saw the struggle for existence as ruthless, universal and ceaselessly shifting, no less so with seed germination. (p. 27)

The woven fences (to keep large animals out) form a quadrat shape and are of a similar scale to the quadrat frame and so, in Darwin's work, the quadrat is both a framing tool for collecting data on the seedling survival rates and a narrative structure for thinking about what is going on in this space and the competitive factors at play.

16.2.3 Boundary Crossing and Boundary Objects

Drawing on Akkerman and Bakker's literature review (2011), we recognise that 'boundary crossings' can involve unfamiliar territories and navigating transitions into different sociocultural spaces. In the study of transitions between contexts, the literature emphasises the significance of objects (Akkerman & Bakker, 2011; Lee, 2007; Star, 1989, 2010; Star & Griesemer, 1989). Among the different notions of the concept 'boundary object', Star and Grisemer (1989) provide a description useful for the purposes of this study. They argue that boundary objects "are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (Star & Grisemer, 1989, p. 393).

The idea of "common identity across sites" was a significant one, which informed and provoked our discussions concerning quadrats. As these conversations continued, it emerged that whilst objects might have a common identity in one role, for example as a measuring tool, they can have other roles, such as a frame for meta-narratives concerning ecological relationships. This became important to us when we considered how teachers use a frame quadrat to explore plant ecology concepts. In addition, one of us developed ways to use *Das Grosse Rasenstück* (The Great Piece of Turf), Fig. 16.2, from 1503, as a representation with which to open up the world of plants before students enter the material world of the botanic garden and engage with the 'toothpick safari' quadrat we discuss later in this chapter. Using the painting in class introductions is an 'agential cut' to focus student teachers' ecological thinking. In this sense, we can view Dürer's painting as a quadrat-like frame that looks into a clump of plants rather than looking down on them. In this way it makes life as plant visceral and as such we can see the painting "resonate with the vibrancy of lived life" (Aloi, 2019, p. 57).

Fig. 16.2 Great Piece of Turf by Albert Dürer (1503). Wikimedia commons: The Google art Project

16.2.4 Baradian Thinking and the Quadrat

In framing the world, Barad (2003) argues we cannot understand phenomena in isolation. Instead, everything interacts with everything else. This is what Barad calls the idea of 'intra-action'. For her, you cannot understand the world by looking at all the intra-actions simultaneously; it is too complex. In order to understand this complexity, it is necessary to make 'cuts', which Barad (2007) describes as "agential cuts", note the role of the 'agent' and 'agency' in this term, to examine the nature of the complexity, involving analysis at multiple levels. Furthermore, Barad argues to make these cuts you must focus on the act of the cut itself and the associated decision-making. This temporal separation of 'the cut', from her perspective, allows us to define the process of enquiry through what Barad calls a process of "making it visible".

So, why might Baradian theory be useful to our thinking concerning teaching biology with the quadrat? Barad's (2007) work has emerged, in part, through her theoretical reflections on Niels Bohr and his work on the quantum model of the atom in her book *Meeting the universe halfway*. Bohr rejected the notion of Newtonian physics that 'things' exist as independent entities, and those systems being measured could be separated from the measuring apparatus. Instead, he argued objects were inseparable from the measurement approaches taken to investigate their position and behaviour. For Bohr, the unit of investigation is *not* the independent object and its boundary, but instead the phenomena (Barad, 2003). Taking Bohr's work further, Barad developed this idea to argue against the 'nature-culture' binary of Michel Foucault and Judith Butler in her theory to explore 'intra-action' and the role the human has in making decisions about where to focus their attention. Using this lens on the world, she sees apparatuses as dynamic and "reconfiguring the world" (Barad, p. 816). Furthermore, she sees apparatuses as having no boundaries and constantly being "reworked" (p. 817) for different purposes. In doing so, she furthers Bohr's notion that apparatus are, 'mere laboratory set-up' (Barad, 2007, p. 141), and argues the apparatus themselves are part of a material-discursive process. As Hollin et al. (2017) note, Barad exemplifies this well with her telling of the Stern-Gerlach experiments in physics. This series of experiments only yielded useful data because one of the experiments smoked a certain brand of cigar that produced sulfurous fumes that allowed the experimental effects to become visible. As Hollin et al. note, Barad (2007) explains this as follows:

> Apparatuses are not static laboratory setups but a dynamic set of open-ended practices, iteratively refined and reconfigured. [In the Stern-Gerlach experiment] … a cigar is among the significant materials that are relevant to the operation and success of the experiment …. Not any cigar will do. Indeed, the cigar is a 'condensation'—a 'nodal point', as it were—of the workings of other apparatuses, including class, nationalism, economics, and gender, all of which are a part of this Stern-Gerlach apparatus. (Barad, 2007, p. 167)

As we note above, Baradian thinking can be complex to engage. During our reflective discussion, we searched for solid examples applying Barad's theories in practice. A good example comes from the doctoral work of (Yoshizawa, 2014) who sets out a fairly straightforward analysis of Barad using Barad's example of a brittle star, a type of echinoderm closely related to sea stars. This unlikely example opens up the true meaning of Baradian thinking by placing her theory in concrete terms. To explain, Yoshizawa begins by saying agential realism is more than "knowing". In this theory, "knowing is a matter of part of our world making itself intelligible to another part" (Barad, 2007, pp. 185). Brittle stars do not have functional eyes; they possess receptor pores, which allow them to detect changes in their environment. These allow the animal to seek food, discern potential predators, and find mates. These discernments, Barad (2007) explains, are agential cuts as they cause differences in the brittle star and the world it inhabits, for it to survive. Knowledge of these cuts comes from humans making meaning through examination and experimentation with brittle stars but, importantly, this knowledge is human-made and constructed *about* the brittle star while the animal has nothing to do with this knowledge construction—it simply is living. For Barad (2003), this means agential realism is post-humanist because this way of thinking involves no separateness of anything. Instead, it makes sense of the world through agential cuts, which humans and non-humans make, and the effect of these cuts.

For Barad, the purpose of the observer reveals new ways of seeing or "worlding". As she argues, this opening out or new possibilities comes from the apparatus a scientist uses as being 'material-discursive', at one time opening up new opportunities of understanding while simultaneously excluding others. Returning to our quadrat, this tool focuses the viewer on a specified space and the plant specimens within, likewise Dürer's painting is a close-up of a seemingly insignificant group of common plants at a specific time in their life cycles. Baradian theory concerning "the cut" allows us to think beyond a simple framing of plant populations and instead to make multiple "cuts" across time and space. Thus, the quadrat is a tool that affords a richer ecological narrative of inter- and intra- relationships on ecological levels beyond individual plant species and their distribution (Crawley, 1986). Barad argues the complex, connected way everything entwines with everything else means any observation makes a "cut" between the included and the excluded from the considered. This means nothing is fundamentally separate from anything else, but separations temporarily enact so one can examine something long enough to gain knowledge about it.

Quadrats are tools familiar to biologists, typically placed on the ground and used to frame an area of investigation, which allows counting of individual plant populations or determining their distribution cover. Having a fixed area, the quadrat allows for quantitative analysis of the ecosystem and provides a convenient method for extrapolating raw data to estimate biodiversity. A typical school experiment using a quadrat would involve students comparing one area of grassland with another or investigating how plant communities change from one area to another. The quadrat literally frames the focus of this type of investigation; things inside the quadrat are of interest, those outside are not. The teacher will have made decisions about the area the students investigate; this represents the first agential cut. The students might then make decisions about where they place the quadrat, another cut. Then there are decisions about what plants to count or not to count, a third cut. Each of these decisions forms the boundary of what to observe—some things are inside, some things outside. So, the object (the quadrat) and the human (the agent) together define the phenomena. It is here at this point that knowledge is revealed.

This approach to using the quadrat is fairly commonplace. However, as we considered the use of the quadrat in learning biology, we started to recognise the physicality of the frame afforded many other opportunities for learning, most of which link to noticing. Noticing in ecology is more than just looking; it is about seeing what is there (Eggemeier, 2014). In the case of plant distribution, it is about identification, layering, and scale. For example, the observer of the quadrat may be drawn to larger plants; more obvious and easier to record, they attract immediate attention. However, the boundary of the quadrat can encourage the observer to look 'within' and fully explore. This approach to using a quadrat requires the observer to explore randomly and consider the layering of plants and other organisms, their relationship to one another, and the place of soil. Small, previously 'invisible' plants now come 'into being', what Barad (2007) describes as 'the visible with material entangled with the other', and demand attention. As students look within the frame, new intra-actions occur and new phenomena arise; for example, evidence of herbivory on different leaves can provoke thinking about invertebrate grazers and their mouthparts, 'cutters' and 'graters', which can extend reflections on life as plant beyond nutrient cycles and primary producers into plant defences and the use of volatiles, poisons, thorns, and sclerophyllous leaves. These phenomena also can cause questions to arise about ecological relationships between the plants, size and scaling, and biodiversity.

The observer asking questions is one we highly value in science education. Noticing what is within and beyond the quadrat frame encourages students to do just this. Harrison (2014), well established the role the generation of authentic data plays in learning science, and the phenomena that emerge as students intra-act with a quadrat encourage investigative approaches. Scientific discoveries reveal scattered examples of serendipitous events, often when the scientist is 'looking the other way', or appearing to be 'mooning', as in Darwin's case.

Barad (2007) and Latour (2005) would argue the quadrat is not simply a metal frame; its meaning comes from both use and the nature of interactions with the user. So, to the biology teacher it might be 'a tool for measuring plants', it might also be 'a tool with a specific area that allows calculation of distributions' or when it lies in a classroom it could be 'just a piece of plastic or a metal square'; such diversity in interpretation brings to mind Miller's philosophical work on functioning objects (Miller, (1982). In relation to curriculum and assessment procedures the quadrat might become 'a thing we have to show the student for the exam'. The use of such objects in biology education creates teaching decisions to provide a content focus, such as making sense of a quadrat within the idea of ecology. But why the teacher makes these decisions is complex. Some of the decision-making comes from the curriculum, 'what are the students meant to learn?', and some comes from the teacher's experiences of their students, 'what do they know about quadrats and measuring species diversity?' It also can come from teachers thinking about the wider context of the curriculum, for example Gilbert's work on teaching science in the Anthropocene and asking, 'what is science education for?' in a 'post-normal' world (Gilbert, 2015). What then happens in the lesson and what students might learn and experience reveals the realisation of the foci of the teacher's "agential cuts" (Barad, 2007).

16.3 Understanding the Use of Quadrats Through Baradian Thinking

We framed our enquiry by a meta-reflective process, conducted over nearly five years, focused on our socio-cultural spaces as teacher trainers in biology. In so doing, we consider our common praxis of teaching plant biology in sites beyond the indoor classroom. An ERASMUS[1]-funded exchange between Gothenburg, Sweden, and London, U.K., has enabled, in part, our work together.

This exchange has given us the opportunity to interact at four reflective-practice levels:

- To co-teach student secondary/high school biology teachers during an introductory week in which both teachers worked together in London (London, 2015)
- To share specific readings on Barad, socio-materiality, boundary crossings, and boundary objects and critically reflect (September 2015–December 2020)
- To engage in documented meta-reflective conversations in relation to our theoretical positions and practice as teacher-trainers within biology education (September 2015–January 2021) and discuss our individual work with teacher-students in each city
- To share our work and receive feedback from critical friends in both Gothenburg (the natural sciences and technology teaching group, the mathematics teaching group) and London (with a Professor of science education).

During this time, we participated in an iterative reflective research cycle (Kemmis, 2009). Thus, we embraced the "densely woven mats" (Schatzki, 2002, p. 87) of "sayings, doings and relatings that compose our practices" (Kemmis, 2009, p. 467) in the sociocultural spaces of professional identity in which we encountered each other. We framed our reflections by questions arising from working with specific didactical objects, such as quadrats and microscopes, in 'boundary crossings' between indoor and outdoor teaching contexts.

16.3.1 Development of Our Thinking

Before deciding to carry out this study, we discussed the nature of teaching training courses in the UK and Sweden during a group meeting in The Linnean Society of London as part of an ERASMUS-funded visit (see footnote) between science and technology educators from The University of Gothenburg and University College London in which we were participants. Most pre-service teachers in the UK follow a short (9-month) programme, which involves a mixture of university-based and in-school training. These experiences receive some criticism as not giving the pre-service teachers times to develop professional knowledge and skills or experiment with different approaches and strategies before qualification, and with it, all the responsibilities of an employed teacher. For years there has been a call to see teacher

[1] ERASMUS is a European Union scheme that funds exchanges of teachers, and students, between countries in the EU. As the UK has now left the EU these exchanges between EU and UK academics will no longer be funded by the European Union.

training as a long-term activity with newly qualified teachers supported in their development for the early stages of their career and beyond (Perryman & Calvert, 2020). Unfortunately, this vision never has been realised fully and despite both government and local-level interventions most early-career teachers state their training, whilst useful, was too short and once qualified they have little time fully to develop their practice in ways they would like (Perryman & Calvert, 2020). In Gothenburg, student teachers studying science education experience a four-year course during which time they develop both subject content knowledge and didactical training. They receive teaching in a variety of spaces including a science centre with a living rain forest, and, as such, they receive exposure to materially rich environments with multiple affordances (Nyberg et al, 2019). In our early discussions, we both came to realise we wanted to seed ideas about imaginative teaching and learning with the pre-service teachers (training to work with students aged 11–18 years) with which we work in the hope this would encourage them to carry these approaches to science education throughout their career.

An obvious link we saw in our work was the topic of ecology. Central to biology, we both view this as a topic that can provide learners with a deep understanding of the living world. Ecology encompasses several Big Ideas in Biology (Harlen, 2015), encapsulated within the notion of *interdependence*. Interdependence is a key concept in biology. It describes and explains the way living organisms depend upon one another and, in doing so, requires knowledge of energy transfer, evolutionary biology, and ecological cycles. These ideas are complex, involving abstract thinking and ideas about scale and deep time, ways of thinking that challenge learners (Kusnick, 2002; Millar & Brewer, 2010). Energy transfer requires knowledge of the laws of thermodynamics, behavioural science, autotrophic and heterotrophic nutrition, and human impact on the environment. Deep time concerns large periods of time, a way of thinking essential in 'origins thinking', which involves an understanding of the origins of the Universe, life on Earth, and species. This last point is a key aspect of evolutionary biology and something learners find difficult, both because of its abstract nature (Nehm & Reilly, 2007; Yates & Marek, 2015) and challenge to alternative worldviews (Reiss, 2007). Like deep time, scale is another idea learners struggle to grasp (Decker et al., 2007). When studying ecology, learners must grapple with both the micro and macro scale. At the micro end of the scale are ideas like ions and molecules recycling and the invisible relationships between microscopic things. At the macro end of the scale, the challenge lies in thinking about communities and ecosystems, succession, and population biology. As these observations show, ecology is not a straightforward topic to learn and, by extension, teach.

Studying ecology has another important aspect to personal learning in that it forms an important understanding about humans and their influence on the environment. Ideas about climate change, pollution, human use of energy or materials all grow from an appreciation of ecology. If one of the roles of education is to help learners become engaged and critical thinkers, then ecology must play a central role.

Having decided on our primary focus, we began iterative discussions, which informed the approaches we wished to take with the pre-service teachers. Part of the teacher training process in London involved the pre-service teachers participating in reflective workshops. These have a specific theme, which the science education teaching team designed; in biology, for example, this might be photosynthesis or inheritance. The workshop where this study focused was an introductory session, running on the first day of the teacher-training course. The design of the session had, historically, been as a chance for the students to get to know one another and start to reflect on their reasons for deciding to train as biology teachers. As our discussion continued, we decided an activity that questioned the student's ideas about biology education, including its purpose, how it is presented within school settings, and their knowledge and understanding about 'Big Ideas', would be more profitable. Much writing exists about the influence of initial teacher education on teacher attitude, self-concept, and views about teaching and learning (Glackin, 2016).

Having this flexibility in the approaches we took in the workshop meant we could design a learning opportunity that could explore the ideas we felt were important about ecology and introduce the pre-service teachers to innovative examples of practice that we hoped would encourage reflection and creative thinking. The workshop ran for two hours, a length of time that allowed a range of activities and discussion. During our reflective discussions we began to formulate the nature of the workshop and thought carefully about how we wanted to present information and how we wanted the pre-service teachers to engage with the learning opportunities. The idea of using a quadrat as part of the workshop was an easy one. As discussed, the tool has an important role in biology and, to us seemed a useful tool with which to encourage the pre-service teachers to consider many aspects of biology. We were also cognizant that the quadrat would be familiar to the students and a tool they most probably had encountered in the traditional uses we previously discussed. What we came to think about was how we could shift the student's thinking from one of 'sampling and counting' to one of 'exploration'. By exploration, we meant how to use the quadrat to transform the student's perceptions of its use but, more importantly, the affordances it would provide that would allow them to notice and consider the complexity of the living world. Having started to engage with Baradian thinking, we were also keen that the students should shift their thinking about the quadrat as a 'tool' or object towards conceptualising it as a window into something that allowed interaction between the observer and the observed (and unobserved). This, we felt, was an important aspect of what they might encourage in their own students and, being an approach that allowed serendipitous learning, encouraged a creative and sophisticated way of approaching the topic of ecology (Harris & De Bruin, 2018).

It would have been easy to ask the students to place the quadrat on the ground and explore but we felt this would not provide enough focus for them actually to *look* at the living and non-living aspects of what was within the quadrat. We also were aware that as teacher educators we were modelling how the pre-service teachers might work with school students, especially considering how much support children may need to have meaningful learning experiences. It was this thinking that led us to develop the 'Toothpick safari' activity.

16.3.2 The Toothpick Safari Study

The ‘Toothpick Safari’ was an activity that evolved from our discussions. The activity involved taking the pre-service teachers (n = 25) to an area of managed grassland and asking them to place a $0.25m^2$ quadrat in an area of ecological interest. We randomly assigned the pre-service teachers to groups (consisting of 4–5 people) and asked them to create a ‘Toothpick Safari’. The Toothpick Safari involved the students placing toothpicks (with small flags with numbers written on them) throughout the quadrat to mark interesting features (living and dead plants, bare ground, animals or remains of animals such as snail shells, litter, etc.). Working in groups, the students had to make decisions about what they wanted to ‘flag’—we limited them to five flags to encourage careful decision-making. We then required the pre-service teachers to develop a narrative—‘the safari’—to explain the conceptual journey from one flag to the next. So, albeit a simple activity to set up and run, it required the pre-service teachers to work hard, ask questions, notice, reflect, discuss, and consider the complexity of the ground on which they were standing.

During the activity, we circulated amongst the groups taking on the role of observer (Fenwick et al., 2011). This approach involved a variety of approaches:

1. Listening
   (a) What was said?
   (b) Who said what?
   (c) Who responded?
   (d) What was the nature of discussion, for example, collaborative, disruptive?
2. Noticing
   (a) Who did what?
   (b) How did they organise tasks?
   (c) Group dynamics (leadership and roles)
3. Probing
   (a) Asking questions (for example: ‘Why did you put that flag there?’, ‘What is the relationship between these flags?’)
   (b) Encouraging discussion and collaboration (for example: asking the pre-service teachers to explain their role in the group, asking how they were making decisions)
   (c) Encouraging cognitive conflict (for example: challenging the pre-service teachers on their decisions, setting up alternative hypothesis and explanations)
4. Recording field notes to supplement the observations and capture interesting and important aspects of the activity for later discussion between the both of us.
5. Photographs of the completed safaris.

We gave the pre-service teachers 15 minutes to complete the tasks between which we asked each group in turn to talk through their safari narrative. We followed this with a series of questions from other pre-service teachers and us, to seek clarification, encourage reflection, and probe decision-making. We recorded field notes to support discussion.

Following the activity, we began to develop reflective discussions about what we observed. The first and in some ways most obvious observation was the toothpick safari appeared to cause unrest for some students, as the 'agential cuts' (Barad, 2007) we had encouraged were unexpected and differed from pre-service teachers' preconceptions of how to use quadrats. As discussed above, the typical use of quadrats involves direct counting of plant species. The safari had a very different focus and outcome. In addition, we deliberately kept instructions to a minimum, hoping this would give the pre-service teachers confidence to take agency for the decisions they made. This is also an atypical approach to teaching and learning in science in high school, where instruction often is directed and can deny the learner autonomy. We observed the pre-service teachers being slow to begin the activity, finding it hard to "know where to start" or decide on "what to look for". We were conscious that, being the first day of the training programme, the pre-service teachers were nervous of one another and us, but the reluctance of some did not match the keenness with which they had engaged with the 'ice-breaker' activities earlier in the day.

The groups of pre-service teachers used different approaches when organising themselves. Some took what we felt was a democratic approach with a general discussion before the placing of the flags began, and some attempted to reach consensus. Other groups divided up the tasks, such as looking at the ground within the quadrat, preparing the flags, and placing the flags. As is common in group-work activities, these roles and approaches emerged through discussion and seemed related to confidence within the group setting (Williams & Svensson, 2020).

The narratives different groups developed when describing their safari varied. Some groups focused solely on plant species, weaving a story that developed ideas about interdependence and relationships, others explored ideas about micro- and macro-scale biology, and some considered evolutionary biology. One group also considered the relationships between biodiversity and human interaction with the environment. In the next section, we provide examples of each agential cut the groups carried out.

16.3.2.1 Agential Cuts and Interdependence

A good example of considering the relationships between the living and non-living components was the way one of the PST groups explored the way pollination occurs and the role of different types of inflorescences. Their flags highlighted compound flowers and grasses, identifying diverse pollination strategies (wind, insect, and attachment to animal fur dispersal). Their safari took the learner on a journey, which promoted questions about the relationship between inflorescences and function, for example colour and shape of petal. The group members were keen that the learner must consider how the inflorescence structure, particularly of compound flowers, linked to insect pollinators. They asked the question, 'What might the quadrat look like to a bee?' This encouraged discussion about co-evolution between plants and animals and promoted thinking about how plants distribute energy resources in order to build petals, pollen, and nectar, and the balance between this and other essential life processes. The 'drive' for reproduction was a strong feature of the group's thinking in this area.

Another group took a different approach to exploring interdependence. For them, the relationship between the 'seen' and 'unseen' parts of the plants was important. Their flags linked to plant structures, such as stems, leaves, shoots, and roots. For the most part, they attached their flags to aerial parts of the plants, but they discovered some roots dislodged from the soil and some stolons, which they included in their safari. The narrative they developed was one of how the plant structures link to essential processes, such as exchange, transport, and photosynthesis. They wanted the learner really to *explore* the quadrat, moving plants aside and investigating layering. They promoted thinking about the unseen part of the plant by linking flags to the dislodged roots with questions about where the roots might go and what they might look like. They extended this thinking but also posed questions about how other organisms might link to the roots; this included the role of mycorrhiza and other soil microbes. The plotting of the flags promoted useful discussion in this area from the group, with one PST particularly knowledgeable about this aspect of biology.

16.3.2.2 Agential Cuts and Ideas of Scale

Two groups considered scale in biology through their safari. The first used the flags to highlight interesting aspects of the micro-scale. The group made a decision early to examine carefully a small section of the quadrat. This approach gave them the opportunity to look carefully and *notice* what they might normally miss. Their flags drew attention to a mixture of living and non-living material, including tiny buds, a small section of beetle elytra, insect eggs, and small moss plants hidden between broad leaf plants. Their narrative focused on what we can miss if we examine biology through human eyes (and scale) alone. They used the phrase "An ant's-eye view" to make this point powerfully, imagining the ant describing the narrative of the safari. This use of analogy and metaphor has a long history in science education (Taber, 2017) and is a very useful pedagogical approach. Not without its criticism (Tucker, 2017), it allows the learning to imagine abstract or invisible in a tangible way. For the pre-service teachers, it was about opening up new worlds to the learner and exposing them to biology at a different scale.

16.3.2.3 Agential Cuts and Evolutionary Biology

Evolutionary biology is theory that holds biology together, without which it is hard to make sense of complexities of the living world (Dobzhansky, 1973). A really good example of how one group embraced this way of thinking in their safari was how they used their flags to create a narrative of the phylogeny of plant groups. They identified a range of plants within the quadrat, which linked early plants, such as mosses, with later plants, including grasses and angiosperms. Their safari took the learning on a journey through time with questions that encouraged thinking about evolutionary development, such as identification of roots, inflorescence, and leaf structure. Examination of their structures encouraged the learner to consider differences and similarities between plant groups but also relationships between structure and function, especially around essential life processes such as exchange, transport, and reproduction. During discussion, they thought the safari might be misleading in promoting a teleological approach to evolution or even anagenesis, but the pre-service teachers gave good suggestions about how to address this through the addition of supplementary material for the learner to explore. Another feature lacking was a tangible sense of time. The pre-service teachers felt they could have added geological period dates to the flags to support this. During the discussion, it also emerged that the pre-service teachers serendipitously had encouraged exploration of ecology succession, something that flags linked to soil and decomposers would have promoted a different aspect of the safari. This resonated well with us as a good example of agential cuts and the boundaries they place around what is, and what is not, important, as well as the intra-actions between the viewer and the "thing". The pre-service teachers made a purposeful 'cut' to focus on evolution; this excluded ecological succession. However, through alternative intra-action, ecological succession emerged from the same safari. This proved powerful to us, illustrating exactly what we wanted the pre-service teachers to experience.

16.3.2.4 Agential Cuts and Human Influence on the Environment and Looking Beyond the Quadrat

Consideration of the role that humans play in the environment came from one group of pre-service teachers who focused part of their safari on the management of the grassland they were exploring and evidence of human presence. Some of their flags developed the narrative of mowing (flags attached to grasses recently cut) and the possible use of agrochemicals (the relationship between abundance of monocotyledonous and dicotyledonous plants). The groups also flagged some litter as an object of significance. In their discussions, the group wanted to draw attention to how humans influence the ecosystem. They were one of the few groups to consider ideas beyond the quadrat. When talking about agrochemicals, the pre-service teachers made links to the recycling of nitrogen in the environment, noticing plants such as clover in the quadrat and discussing nitrogen fixation (thinking about nitrogen from the atmosphere) and human improvement of the soil through the application of fertilisers and approaches such as intercropping. This aspect of the safari elicited some interesting links between the 'unseen' aspect of the quadrat (such as the root nodules of clover plants and the invisible gases of the atmosphere) and the tangible, material nature of what was present in the visible aspect of the quadrat.

One thing that struck us in our reflective discussions was the lack of counting and frequency measurements observed by the pre-service teachers. Though they included abundance of plant species in some of their narratives, no group made this a major focus of their safari. The toothpick safari, it seemed, had stimulated a different way of thinking about the quadrat.

16.4 Importance to Research

In this reflection on our teaching of biology in outdoor contexts, we intentionally focused the quadrat away from its typical use as an ecological measuring tool to one in which the students must view the curriculum topic 'ecology' from a narrative-based perspective concerned with differing worldviews and scales. Thus, moving from the stance of one group of pre-service teachers who said: "In our quadrat we have a daisy, some clover, and lots of grass", to other groups developing a storyline identifying, for example, soil and living and dead organisms from a nutrient-recycling perspective. In this second instance, we see the teacher-students recognising how their knowledge and skills could combine in new ways to reveal something about broader biological concepts, an example of Barad's (2007) 'agential cuts' in action.

In our use of the concept 'boundary objects', we begin to integrate the work of Lee (2007) and her assertion, 'artifacts can be used to push boundaries' (p. 308), thus extending boundary objects to 'boundary negotiating artifacts'. This concept is particularly appropriate in the case of the 'toothpick safari' and the use of Dürer's painting (Das große Rasenstück), and our students' emergent notions of frame quadrats as didactical objects rather than simply situational tools for measuring plant populations. Baradian theory enabled us, as teachers, to unfold the domain of scientific tools into a space in which our students can see the quadrat as something that allows you to open up worlds within worlds through deepening levels of inquiry. It also provoked us to think about the 'agential cuts' we make in our translation of the curriculum concerning plants and their ecological place in the world. In doing so we added art works to the material possibilities in recognition that the quadrat frame mirrors in the boundaries of painted plant life and both afford windows onto the world.

Through our reflective discussions, our awareness of the work of others in allied areas heightened. As is often the way with collaborative research, the more one speaks about one's ideas, the more ideas flow and develop. Two recent examples of work that really resonated with us are Chandler-Grevatt (2021) and J. Hale (personal communication, June 18, 2020). Chandler-Grevatt designed his work on the 'moss safari' to allow students access to the invisible world of interdependence between mosses and other organisms. His work encourages students to develop a narrative that explores these worlds and encourages the asking of questions and personal reflection. Hale's work is an excellent example of how a teacher becomes a practitioner-researcher. He has developed a sequence of learning experiences where students explore sand dune succession with traditional line transects, placing quadrats in a systematic way and recording plant species. Following this experience, students take part in a game that requires them to reflect on how the transect generates data and the nature of these data, before revisiting the transect. This activity takes a meta-approach to thinking about gathering and interpreting ecological data and, his research suggests, encourages a deeper understanding of both the nature of the evolving landscape and the role the tools and approaches to exploring the landscape affect what might be seen and unseen.

We are keen to continue our work. The next stage of our research is to both 'remake' (Kemmis, 2009) our current sociocultural spaces in the light of these situated reflections and to consider further questions. In so doing, we wish to engage more deeply in teacher/researcher discourses concerning tools we commonly use in our teaching, such as quadrats, magnifying glasses, and microscopes, to negotiate didactical boundary crossings that enable our pre-service teachers to attend to 'the nature of nature' (Østergaard, 2014), particularly in urban contexts. Our broader aim is to extend the teaching of biology beyond normative framings of science education and create new material affordances for open ecological enquiry beyond the classroom. We feel that Barad's view of materiality offers much to research on informal science education. While her theoretical positions and writings are complex in nature, our work has convinced us of the benefits of perseverance and looking for connections between her ways of thinking, mainly focused on the physical sciences, and other science, specifically biology. Viewing teaching and learning episodes through the lens of Baradian materiality has offered us new, and exciting opportunities for exploring our own ideas about studying ecology. This has convinced us that thinking in this way will open up new approaches to understanding the roles of tools in learning biology and how teacher and student interactions can be better understood. Viewing the use of scientific equipment as intra action between tools, what is being studied, and teachers and students, has much to say about meaning making and how decisions in teaching and learning guide, as well as constrain experiences. Thus, we suggest that a Baradian lens into the border crossings between indoor and outdoor, 'formal' and 'informal' teaching and learning spaces, and their related objects, affords researchers new possibilities to examine educational practices in outdoor learning. We hope this reflective case study provokes future investigations.

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Chapter 17
General Systems Theory and Boundary Crossing: Exploring the Relationship Between Zoo Educators and Elementary Educators

Patricia G. Patrick and Jillian Weinstein

17.1 Introduction

A field trip is "a trip arranged by the school and undertaken for educational purposes, in which the students go to places where the materials of instruction may be observed and studied directly in their functional setting" (Krepel & DuVall, 1981, p. 7). Field trips have a positive student impact because they (1) promote learning of facts and concepts (Bamberger & Tal, 2006, 2008; Jose et al., 2017; Miglietta et al., 2008; Rudmann, 1994), (2) improve short-term cognitive knowledge (Farmer et al., 2007; Knapp & Barrie, 2001; Prokop et al., 2007); and (3) increase understanding and comprehension of a topic (Jose et al., 2017; Sturm & Bogner, 2010), especially if the formal educator prepares for the visit and revisits the topic in the classroom using pre-visit, during visit, and post-visit activities (DeWitt & Storksdieck, 2008; Eshach, 2007; Patrick et al., 2013).

A wealth of research supports pre-visit, during-visit, and post-visit activities as important for increasing student knowledge (e.g., Behrendt & Franklin, 2014; Jose et al., 2017; Patrick & Tunnicliffe, 2013; Patrick et al., 2013). Patrick and Tunncliffe (2013) refer to pre-visit, during-visit, and post-visit activities as a tripartite zoo sandwich—the zoo is the filling, and the pre- and post-visit activities are the bread. Ideally, educators should use a variety of instructional strategies that increase the impact of learning scientific concepts (Hofstein & Rosenfeld, 1996). Pre-visit activities should set the stage, pique curiosity, and introduce the learner to the concept(s) and relevant vocabulary. Pre-visit activities are to prepare the learner for the lesson (Tal et al.,

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2012), build background knowledge, and provide an educational focus (Noel & Colopy, 2006). Post-visit activities are to encourage the learner to reflect on and explore the information introduced during the field trip, apply the concepts in their lives, and further explore the topics (Noel & Colopy, 2006; Patrick & Tunnicliffe, 2013; Patrick et al., 2013; Tal et al., 2012). Even though during-visit activities should stimulate student interest, promote future connections to the topic, offer experiences, and link students to the field trip site (Alon & Tal, 2017; Coughlin, 2010; Ernst et al., 2015; Jose et al., 2017; Noel & Colopy, 2006; Patrick et al., 2013), pedagogical practices of informal educators, such as show and tell, may lead to passive student observers (Tal et al., 2012). During-visit activities are important and more educationally effective when paired with proper planning and inclusion of pre-visit and post-visit components (Coughlin, 2010; Noel & Colopy, 2006; Patrick et al., 2013). However, formal educators seldom may see the need for during- and post-visit activities even when the institution provides the activities (Anderson & Zhang, 2003; Patrick et al., 2013; Karnezou et al. 2013; Kisiel, 2014). Understanding these foci, their criticalness, and their use is important for both formal and informal educators. The negotiations occurring between formal and informal educators are an important aspect of capitalizing on during field trip activities and science learning (Kisiel, 2014). To ensure field trips are scholastic, formal and informal educators must work together to create a comprehensive learning experience.

As early as 1979, Koran and Baker identified informal educators as an important resource for formal educators. They suggested informal educators provide formal educators with learning objectives, a visit sequence, and student learning evaluations. The evaluation should reflect the objectives. Even though these ideas appeared in the 1970s, research shows formal and informal educators may not collaborate to align their field trip expectations and prepare students (e.g. Karnezou et al. 2013; Kisiel, 2014; Morag & Tal, 2012). In addition to sharing with educators how the field trip will develop learning, informal educators should consider the resources available to formal educators. A lack of resources is the number one reason educators cite for not taking field trips (Dolan, 2016). These findings and others substantiate the need for communication about the field trip (Davidson et al., 2010; Jarvis & Pell, 2002, 2005; Kisiel, 2013, 2014; Patrick et al., 2013; Tal et al., 2005; Jose et al., 2017). For example, Gateway National Recreation Area invited educators to participate in professional development programs. During the programs, the cultivation of communication between the formal and informal educators led to the realization that the park educators should take a more active role in teaching. Park educators better understood the need to change from a walk-and-talk program to an inquiry-based learning approach (Adams & Branco, 2017). However, the interactions between students, informal educators, and the institution are not enough. Formal educators should design a well-planned field trip consisting of pre-visit, during-visit, and post-visit activities (Davidson et al., 2010; Patrick et al., 2013). In fact, optimization of learning that takes place during field trips is best when formal educators integrate the content of the field trip into the classroom curriculum and include the informal educator (Adams & Branco, 2017; Coughlin, 2010; Davidson et al., 2010; Moormann, 2017).

17.1.1 Formal and Informal Educator Relationships

Students may learn during field trips; however, roadblocks can hinder learning. First, students may find long talks by informal educators boring and uninteresting (Davidson et al., 2010). This transmission mode of instruction is the result of informal educators modeling their experiences in classrooms and observing peers (Sanford & Sokol, 2017). Second, learning is unlikely to occur if the goals of the informal educator and formal educator do not align. For example, Davidson et al. (2010) found when the formal educator did not prepare students for the informal educator's conservation learning goal, the students did not have knowledge about conservation. Third, the educators may be unaware of the learning goals set forth by each other and how the trip fits the pre-visit and post-visit activities (Davidson et al., 2010; Patrick et al., 2013; Patrick, 2017). Fourth, informal educators may be resistant to new content and new pedagogical practices for field trips (Allen & Crowley, 2017). Fifth, informal educators in the same institution may have differing opinions about successful pedagogical practices (Yeh, 2017). Sixth, formal educators may view informal educators as motivational speakers instead of "critical contributor[s] to science literacy" (Sanford & Sokol, 2017, p. 297). We may avoid these barriers if formal educators and informal educators forge meaningful relationships related to field trip design (Bevan & Dillon, 2010; Davidson et al., 2010; Kisiel, 2014; Patrick & Tunnicliffe, 2013; Patrick et al., 2013). The relationships should include defining learning goals and expectations at the formal and informal institutions (Faria & Chagas, 2013; Moormann, 2017; Morag & Tal, 2012). When informal educators who are part of the zoo education system plan and implement lessons through an iterative process (Allen & Crowley, 2017) and with the formal educator, they develop activities focused on student learning (Delen & Krajcik, 2017; Kisiel, 2014; Weiland & Akerson, 2013). We applied general systems theory (GST) to determine the interactions between formal and informal educators.

17.1.2 General Systems Theory

Researchers founded GST in the 1950s to identify the interdependent parts of a biological, physical, and/or social system (Boulding, 1956; von Bertalanffy, 1950, 1962, 1968; Forrester, 1991). GST provides an orderly frame on which to structure a system (Boulding, 1956) and considers the environmental and social demands placed on the system (Parsons, 1951). GST relies on understanding how the actions of the system cause changes in the environment and vice versa. GST identifies a population as distinctive and possessing attributes, experiences, and knowledge related to its intended purposes. When differing populations interact they develop interdependent relationships that are dynamic in nature (Lai & Lin, 2017). A balanced system seeks equilibrium and effectively responds to external stimuli (Barile & Polese, 2010a, 2010b; Christopher, 2007). To reach system goals, the system must consider available resources and interactions with other systems in the environment (Poole, 2014).

Researchers apply GST across formal education research to describe and understand education systems (DePetris & Eames, 2017; Gilbert, 2016; Jacobson & Wilensky, 2006) and science education (Chen & Stroup, 1993; Lee, 2002). In 2008, Lemke and Sabelli suggested using a systems-approach framework to frame studies regarding the planning and design of educational interventions. They argued that to coordinate affective change in a system, interventions must interconnect learners, practices, and events across multiple levels. Some extant research mentions systems theory as part of an interconnected science education system (Falk et al., 2014). Specifically, some proclaim ecosystems theory as a way to understand science learning across formal and informal science education resources (classrooms and out-of-classroom settings) (Chen & Stroup, 1993; Falk & Dierking, 2018; Falk et al., 2014; Hecht & Crowley, 2020; Traphagen & Traill, 2014). While some research spotlights the relationships between formal and informal educators and formal and informal learning settings, we could not locate research applying GST to defining the interactions between zoo educators and elementary (students ages 4–11) classroom educators. When we describe the details of the study we use the terms zoo educator (informal educator) and elementary educator (formal educator). We use the terms formal educator and informal educator in the discussion of the broader implications of GST as a theory in informal science education.

GST provided us a foundation to identify the complexity of the interactions between elementary educators and informal educators in a zoo education system. Defining how, where, and why the exchanges occur is important to preserving system functionality (Barile & Polese, 2010a). We were interested most in how zoo educators and elementary educators interacted at the system boundary, which included in what manner elementary educators utilized zoo educator provided pre-visit and post-visit field trip activities. Below, we describe the fundamental concepts related to systems theory and explain how we defined the concepts within a zoo education system.

17.1.3 System Concepts

17.1.3.1 Components

Complex interacting components compose systems. A system is a collection of enmeshed components that operate "as one in relation to its environment and to other systems" (Poole, 2014, p. 50). GST explains the interactive relationships among system components and how the system responds to inputs from external sources. The system components are interdependent and simultaneously interact with each other and the environment and react through feedback, meaning one cannot function successfully without the other (Lai & Lin, 2017). The component interactions spur adaptations or behavior change (von Bertalanffy, 1968). To define the system, organizations should delineate the interacting components and evaluate how the integration of external elements influence the system (Mele et al., 2010). For this study, the interacting system components were elementary educators, zoo educators, pre-visit and post-visit zoo activities, and zoo programs provided during field trips.

17.1.3.2 Goals

The goal is the target outcome of the system. Goals ensure the system will endure and must be well defined (Morasky, 1977; Poole, 2014). When planning goals, developers must consider the system and develop strategies to achieve the goals (Lai & Lin, 2017). Developed goals provide control of the system and we may evaluate the success (or not) of goals (Morasky, 1977). The goal of the zoo education system was to provide elementary educators with pre-visit and post-visit activities to use in the classroom.

17.1.3.3 Interdependence

Components tie to each other because they are interdependent. A component may be dependent on another component, or the dependence may be reciprocal (Poole, 2014). No matter the dependence, components influence each other and support the achievement of "something that would otherwise be extremely difficult or impossible to achieve" (Wei-Skillern & Silver, 2013), (DePetris & Eames, 2017, p. 174). In this study, the interdependence is the interactions occurring between the elementary educators, zoo educators, pre-visit and post-visit zoo activities, and zoo programs.

17.1.3.4 Feedback

Feedback is information about the relationship between the current level of the system and the level the system would like to establish (Poole, 2014; Ramaprasad, 1983). Communication occurs within a social context and provides balance within the system (DePetris & Eames, 2017; Hands, 2005). Systems include positive and negative feedback. Positive feedback reinforces the system's movement, while negative feedback counteracts the system. Negative feedback causes the system to become unstable and seek stability (Poole, 2014). We focused on the gap between zoo educators' perceptions of how elementary educators used pre-visit and post-visit zoo activities and how elementary educators used pre-visit and post-visit zoo activities. We sought feedback to determine if and how elementary educators used activities provided by zoo educators.

17.1.3.5 Boundary

The system boundary exists between what is in the system and the external environment. However, the recognized system components can interact with peripheral dimensions of the system. At the boundaries of the system, participants share in organized and causal interactions with participants outside the system. To study the system, the research must define the boundary and it participants (Poole, 2014; Price-Mitchell, 2009). Kisiel (2014) names the regular interactions between formal and informal educators' boundary activities and their long-term support of each other a boundary community. Internally, our system was bound by the zoo education department and zoo educators. Just external to the boundary were the elementary educators, pre-visit and post-visit zoo activities, and zoo programs provided during field trips.

17.1.3.6 Environment

The boundary separates the system from everything else, which is the system environment (Poole, 2014). Systems connect to and embed in the environment in which they exist (Davison & Martinsons, 2016). Participants in the system interact with people outside the system and exchange resources and ideas (Faik et al., 2019). The environment may provide feedback to the system. As described above the feedback can be positive or negative and sustain or correct the system (Kast & Rosenzweig, 1972). When the system develops an "open exchange with the environment" (Lai & Lin, 2017, p. 4), the system may "grow and survive without deteriorating" (Lai & Lin, 2017, p. 4). Elementary educators were the environment for this study and their open exchange with zoo educators.

17.1.3.7 Input and Output

Anything entering the system from the environment is an input. Anything exiting or produced by the system is an output (Lai & Lin, 2017; Poole, 2014). Inputs are responsible for causing outputs. Inputs produce outputs through feedback (Aksulu & Wade, 2010). The input for this study was feedback from elementary educators about their use of zoo pre-visit and post-visit activities. The output was zoo programs and their related pre-visit and post-visit activities.

17.1.3.8 Process

Processes occur when systems change (Poole, 2014). The system processes information provided by inputs and acts to implement change. The system receives inputs, the system manages the inputs, releases the inputs as outputs, and monitors how the outputs are received. Feedback from the external environment regulates how the system processes the inputs into outputs (Ludwig, 2015). "*Negative feedback* is to correct errors in order to maintain the current state of the system whereas *positive feedback* is to change the system through improvement or growth" (Lai & Lin, 2017, p. 4). We were interested in the zoo educators processing positive and negative feedback from the elementary educators.

In addition to the GST concepts we mentioned above, pedagogical knowledge is part of the zoo education system and its environment. Pedagogical knowledge is the knowledge of how to craft learning in a way all can understand. For formal educators, pedagogical knowledge includes "knowledge of learning theory, classroom management, and student motivation" (Auerbach & Andrews, 2018, p. 1). Formal educators' pedagogical knowledge is part of the system environment and exists on the boundary of the system. The definition of pedagogical knowledge is the same for informal educators; however, their knowledge differs from formal educators. Tran and King (2007, 2011) describe six unique elements of informal educators' pedagogical knowledge—choice and motivation, content, context, learning, objects, and talk. Therefore, formal and informal educators may characterize pedagogical knowledge in different ways—defining how to teach students or the importance of pre-visit, during-visit, and post-visit activities may differ. These differences could prove to limit how well the formal and informal educators interact at the system boundary. Formal and informal educators may dismiss each other because they do not possess an understanding of the other's teaching practices. While research identifies professional development of informal science educators (Bevan & Xanthoudaki, 2008; DeGregoria Kelly, 2009; Piqueras & Achiam, 2019; Tran & King, 2007, 2011; Dwolatzky et al. 2021) and the implications of field trips, there are few reports demonstrating the integration of elementary educators' and zoo educators' beliefs about zoo-provided activities. Zoo educators should recognize the role of elementary educators in the zoo system environment. By identifying the input of elementary educators, zoo educators may ascertain how elementary educators use pre-visit and post-visit activities. Recognition of input from formal educators can lead to system processes that promote improved outputs. GST is advantageous because it identifies the zoo education system and the formal education system as parallel systems (Christopher, 2007). As parallel systems, they may interact next to each other and allow for a reflection on the dynamic nature of the interactions between formal and informal educators and how those interactions influence the system.

17.2 Example Study—Zoo

17.2.1 Literature Review

Some evidence supports learning can take place during zoo field trips (DeWitt & Storksdieck, 2008; Marth & Bogner, 2017; Sattler & Bogner, 2017; Tunnicliffe, 1995). However, there is still uncertainty as to the ways elementary educators utilize zoo field trips to promote science knowledge. Moreover, little research identifies the relationships between zoo educators and elementary educators and how these relationships lead to student learning. Rennie and McClafferty (1995) found zoo educators believed classroom educators who completed zoo-led professional develop workshops more successfully led field trips. When I asked teacher candidates to prepare zoo field trips before and after listening to student conversations during a zoo field trip, their field trip designs improved post-visit (Patrick et al., 2013). However, there is still uncertainty about how to facilitate learning-maximized programs or program best practices. For example, little is known about the interpersonal relationships between zoo educators and elementary educators, which may influence the design and success of field trip programs.

Based on the importance of pre-visit, during-visit, and post-visit zoo activities and the relationships between elementary and zoo educators, we were interested in their perceptions of each other and their perceived roles in field trip preparation and during field trip experiences. The relationships that develop between the elementary educators and the zoo educators are part of the interconnectivity of the zoo system.

17.2.2 Methodology

We completed a qualitative explanatory case study to define the boundary encounters between zoo educators and elementary educators (Saldaña & Omasta, 2017). We chose an explanatory case study because we sought to explain if an intervention could influence elementary educators use of pre-visit and post-visit field trip activities. We bound the study by definition and context (Huberman & Miles, 2019). We defined the zoo education system and context in the introduction. The zoo educators worked at Conservation Center Zoo (CCZ, pseudonym) and the elementary educators brought their students to CCZ for a field trip and zoo program. We employed interviews and questionnaires (Hung et al., 2012) to examine the interactions between CCZ educators and elementary educators occurring at the zoo education boundary.

We administered our original questionnaire to a convenience sample of 100 elementary educators from 40 urban schools near the CCZ, who brought students to the zoo for a field trip and attended a CCZ program. Of the 40 schools that participated in the original questionnaire, 26 were public schools, four were public charter schools, 10 were private schools, and two of the 40 schools had low socioeconomic status (SES). The low SES schools were part of a city grant-funded program, which paid for the extra CCZ-developed field-trip programming. Elementary educator responses to the initial questionnaire determined they did not use zoo-provided activities, which directly were related to the during zoo visit programs and activities. Once we discovered the elementary educators were not using the activities, we sought to explain why. Additionally, we focused on how changing the processes or the engagement between CCZ and elementary educators at the boundary would influence in what ways elementary educators used the activities. This led us to ask the following questions:

1. Why were elementary educators not using the activities?
2. What did zoo educators believe about elementary educators use of the activities?
3. How could we increase elementary educators use of the pre-visit and post-visit activities?

17.2.2.1 CCZ and Education Programs (System Output)

The CCZ is a small zoological facility located on the east coast of the U.S. Annual visitorship is approximately 300,000 with 60,000 of these visitors participating in education programs. The CCZ educators developed three 40-min educational field trip programs based on topics from grade-level state science standards and accompanying pre-visit and post-visit activities. A program focused on one of the following topics for each grade level: animal adaptations, animal habitats, or mammals. CCZ provided the programs during field trips for an additional fee and the elementary educators chose the topic. When an elementary educator signed up for a program, they received a confirmation email including pre-visit and post-visit activities related to the program topic.

17.2.2.2 Participants

Formal Elementary Educators

Of the 100 elementary educators who participated in the original questionnaire, 16 participated in the final study. These 16 participants completed the original questionnaire, a follow up questionnaire, and we observed their students during the CCZ visit. The 16 participants brought students to the zoo for a field trip and a CCZ program before and after the first questionnaire. Using a simple random sample, we chose six of the elementary educators to participate in an interview. The teaching experience of the interviewees ranged from one year to 25 years of experience and one taught in a Title I school, two taught in public schools, two taught in private schools, and one taught at a charter school. Additionally, five identified as female and one identified as male, including three African Americans, one Asian American, and two Caucasians.

Informal Zoo Educators

A convenience sample of six CCZ educators participated in interviews. Their experience in informal education was one year to 23 years. Participants were four females and two males, including one Latino/Hispanic, four Caucasians, and one African American. The second author was an educator at CCZ but did not participate.

17.2.2.3 Stage 1 Data Collection (Boundary Interactions)

We meant the boundary interactions to occur when (a) the zoo educators provided pre-visit and post-visit activities and met with the elementary educators and (b) elementary educators used the pre-visit and post-visit activities and brought their students to the zoo. To determine the output interactions at the boundary, we interviewed six CCZ educators prior to collecting data from the elementary educators (Falk et al., 2006). The interviews lasted 45 min to one hour and took place privately in the CCZ education office. We asked the zoo educators to talk about field trip content and layout, development of pre-visit, program, and post-visit activity content, opinions regarding their communication with elementary educators before and after a field trip, and their experiences with elementary educators.

We defined boundary interaction inputs by collecting data from 16 elementary educators over two school years. In Stage I, the 16 elementary educators who brought their students to the zoo in the spring and participated in a CCZ education program, completed a questionnaire (Merriam, 2009). When an educator arrived in the CCZ classroom, we asked if they would like to participate in the study. After agreeing to participate and signing consent forms, the educator completed the questionnaire while students were taking part in the CCZ program. (NOTE: Prior to the zoo field trip, we emailed to the educators the pre-visit and post-visit activities we designed for the zoo education program students would attend.) Participants completed the questionnaire in approximately 10 min. In addition to demographic data, the questionnaire included the following questions: (1) Why did you bring your class to the zoo today? (2) Did the zoo educator contact you before the school-program field trip? If so, what did you discuss? (3) (If the answer is yes). Did you find the communication helpful? Why or why not? (4) Did you implement the suggested pre-visit activity? Why or why not? (5) (If the answer is yes.) Do you think it was beneficial to your students? Why or why not? (6) Will you implement the suggested post-visit activities? Why or why not? As stated above, this data indicated educators did not prepare students for the visit by using the pre-visit activities and did not intend to engage students with post-visit activities.

After the zoo visit, we interviewed six of the 16 elementary educators (Vanover et al., 2021). The interviews took place over the phone, lasted 30–45 min, and we recorded using a digital recorder. In addition to demographic questions, we asked participants: (1) What did you think about the overall experience? (2) Did you receive pre-visit and post-visit activities as part of the field trip? (3) (If the answer is yes.) Did you use them? (If the answer is no.) Would you use them if you received them? (4) Did a CCZ educator communicate with you about the program prior to the field trip? (5) (If the answer is yes.) Can you recall any specific examples? (6) (If the answer is yes.) Was the communication helpful? (7) Do you have time in your classroom for added activities that are not part of the curriculum? Why or why not?

17.2.2.4 Stage 1 Data Analysis

Even though this was a case study, we analyzed the data across the questionnaires (N = 16) and transcribed interviews (N = 6 zoo educators and N = 6 elementary educators) using a phenomenological approach. We employed a phenomenological approach because we wanted to know what happened at the boundary and how the elementary educators experienced the output of the zoo educators (pre-visit and post-visit activities) (Creswell & Poth, 2018). We read the data while suspending our ideas about the conclusions. For each question, we grouped similar answers to determine the what and the why for the boundary experience. We labeled the answers with a code so we could compare the answers in Stage 1 to answers in Stage 2. For example, we coded as FQ1 the first elementary educator to complete the questionnaire. Additionally, we matched the questionnaire with the interviewee and coded the interview FI1.

Stage 1 Results

Zoo Educators

The six zoo educators thought school programs were unsuccessful for three reasons: (a) student preparation, (b) student behavior, and (c) lack of communication. The educators described students as ill-prepared for engagement and learning during the program. "Students come in unprepared… You have to spend 20 min on an intro because they are totally unfamiliar with the concept" (II2). Zoo educators believed a lack of preparation by the elementary educator led to student behavior problems, such as being, "wild. They show up all scattered and the kids are wild because they are feeding off of their educator" (II3). A main concern of the zoo educators was communication with the elementary educators. They described successful field trips as including increased communication. II4 explained, "It's nearly impossible to conduct a great or even good class without some sort of communication beforehand. You need to know to some extent who is walking through that door and how you can teach them best" (Elementary Educator A4). Even though zoo educators felt communication for planning the field trip was important, they believed the planning should be a team effort. However, when they tried to reach out to elementary educators, they felt expected to plan the trip. II6 described their feelings about communication in the following way:

> When there was a lack of communication, the planning fell all on the teachers' shoulders. When we call though, and email, sometimes we never get a response, or we do, and we are expected to plan out every single detail. It is disheartening and I know a lot of us sometimes don't bother to reach out.

Elementary Educators

Results indicated elementary educators visiting the facility were not using the 40 min pre-visit and post-visit activities. Of the 16 elementary educators, 14 stated they did not implement the pre-visit activities in their classroom prior to the zoo visit and 15 did not plan on implementing the post-visit activities upon return. The elementary educators provided five reasons why they did not use the activities: (a) time, (b) knowledge, (c) materials, (d) unaware, and (e) communication. Elementary educators who thought time was an issue stated, “I don’t have time because I have to follow standards. These don’t fit. I cannot take time away from my lessons” (FQ2). Educators who stated they received the email containing activities explained they did not know what they were or how to use them, “Yeah, I got them, but I don’t know what they were. I didn’t have time to look at them” (FI3). The availability of the materials needed to complete the activities was a concern. Educators described a lack of funding and resources. FQ16 said, “I don’t have enough materials to do the activities. I don’t get extra funds to buy this stuff”. Educators were unaware of the activities. They stated, “I just didn’t see [the] email. So didn’t know about it” (FQ4). Moreover, FI6 described a lack of knowledge as not being told about the activities, “Well I really don’t know what they are. I’ve never used them. I don’t even think I’ve ever had an informal educator suggest anything like that. Actually, maybe they have. I don’t know, really.”. The most mentioned reason was a lack of communication. Elementary educators felt the zoo educators did not provide suitable communication about the field trip and the program. FI4 thought, “…if I had some sort of guidance or even just someone reaching out and explaining more what we’d be doing the day of the trip, it would be a better experience for everyone”. FI14 and FI7, respectively, reiterated this feeling, “I’ve never had an experience planning a trip where I had any sort of communication besides booking the actual field trip or class.” and “I would love to have more communication with the zoo educator. Sometimes I think about reaching out, but I don’t know where I would even start, who I would call at the place”. FI13 suggested they would use the pre-visit and post-visit activities, “…if the zoo educator suggested it beforehand. Like, several weeks beforehand and explained to me what we were supposed to do and why”. FI9 elaborated further about the importance of communication from the zoo educator:

> In the past, when planning a field trip that involves a class at the facility, I never really had any communication until the day of. That’s why we try to avoid field trips in general. It’s always confusing and crazy. I honestly would be so excited to have some guidance, I would do anything they said.

17.2.2.5 Stage 2 Intervention

Based on the system feedback—outputs from zoo educators and inputs from the elementary educators—we determined three issues with the pre-visit and post-visit activities. Problem 1: Educators were not using the activities. Problem 2: Educators felt the activities were too long and took too much classroom time. Problem 3: Zoo educators and elementary educators did not communicate. Problem 4: Zoo educators believed elementary educators’ lack of planning for the program caused problems during the zoo programs. The problems represent the outputs and inputs taking place at the system boundary.

We shared the feedback with CCZ educators and asked them to generate ideas about how they could change the system—use of pre-visit and post-visit activities.

Table 17.1 Zoo educator output

Initial output	Updated output
• 30–40 min pre- and post-visit activity • No phone call from zoo educator to elementary educator before school program • No email from zoo educator to elementary educator before school program • Registrar booked the program and sent email with pre- and post- visit activity attached	• 10–15 min pre- and post-visit activity • Zoo educator sent email to elementary educator 3–4 weeks before the school program • Zoo educator made phone call if the email was unanswered • Zoo educator made a follow-up phone call to the elementary educator 1 week after the school program took place • Registrar booked the field trip and school program, sent the elementary educator contact information to the zoo educator to contact the elementary educator and establish a line of communication before the school program

Based on the feedback, the CCZ educators designed and implemented two interventions. Intervention 1: Zoo educators redesigned the pre-visit and post-visit activities. They designed the new activities to take 10 min and to occur on the school bus during travel to and from the zoo. Intervention 2: Zoo educators agreed to contact the formal educators. When the 16 elementary educators signed up for a zoo field trip program in the fall of the next school year with new students, a zoo educator called the elementary educator. Additionally, the zoo educator emailed the elementary educator three weeks before the field trip. The zoo educator asked if the educator received the pre-visit and post-visit activities sent via email. Additionally, the zoo educator explained the activities would take approximately 10 min of class time and stated they would be available if any questions arose. The system outputs before and after zoo educators were aware of teacher use of pre-visit and post-visit activities are shown in Table 17.1.

17.2.2.6 Stage 3 Data Collection and Analysis (Boundary Interactions)

After implementing the changes to the pre-visit and post-visit activities, we completed the same data collection with the 16 elementary educators. During the fall program, the 16 educators completed the same questionnaire, and we interviewed the six elementary educators and zoo educators a second time. Additionally, we employed the identical phenomenological data analysis we described above.

Stage 3 Results

We found implementation of the redesigned 10 min pre-visit and post-visit activities and contact from the zoo educators inspired some educators to implement the pre-visit and post-visit activities. Of the 16 elementary educators, eight stated they used the pre-visit activities, and 6 identified post-visit activities would be useful. Educators indicated they saw a change in student behavior, engagement, and knowledge. FI13 described her class's response to the pre-visit activity in the following way, "I used the pre-visit activity with my class just a few days before the trip. They all seemed really interested and excited for the class [zoo program]. They knew more than I thought they would about mammals; they surprised me." Even though some educators did not use the pre-visit activities, they recognized the importance of the activity after the program and stated they intended to use the post-visit activities. FI6 admitted,

> I didn't use the pre-visit activity so the instructor had to use a lot of time introducing words the students probably should have known. I'll use the post. I want my students to remember what they learned today, especially for when we go over this unit again in the spring.

While the two interventions did not persuade all educators to employ the pre-visit and post-visit activities, the educators agreed communicating about the activities and the zoo field trip was important. They agreed school programs were more successful in terms of student engagement and learning when they communicated with zoo educators. FQ11 stated the previous field trip, "wasn't organized well at all". In response to the zoo educator email and phone call, FQ11 said they, "took the lead this time and reached out to the facility". Similarly, FQ3 felt, "The last field trip we went on was way too hectic. It was a mess. I decided to answer the emails from the instructor and call them back to try to plan better."

All zoo educators agreed the increased communication and use of pre-visit activities strengthened the zoo programs for the educators who participated. IQ6 described reaching out to the elementary educators as "a little more work", but believed the extra communication "leads to a better program and a higher level of learning for the kids. If the formal educator is a little more aware of what is going to happen, that should mean the kids will be also." IQ3 thought when they explained the importance of the pre-visit and post-visit activities "teachers they use them! I've had several phone call conversations with teachers who have been so happy I called and said they would try their best to fit in the pre activity and the post after". Zoo educators felt if they took the time to increase communication with elementary educators, the educators would positively respond. IQ2 explained "If we go through the extra leg work to contact the formal educator, they should, and I think they usually do, put in that same effort". Furthermore, they recognized when a zoo educator did not contact elementary educators. IQ1 explained during a program, "You can always tell when someone didn't do their job and reach out to the formal educator".

17.3 Discussion

We used a systems theory lens and an explanatory case study to describe what happened at the zoo education system boundary. The questionnaire and interviews offered insight into how (a) informal educators believe formal educators use pre-visit and post-visit activities, (b) formal educators view pre-visit and post-visit activities, and (c) formal educators use the activities. Furthermore, the systems theory lens supported identifying how the activities became a *boundary crossing* (Akkerman & Bruining, 2016; Bakx et al., 2016) for zoo educators and elementary educators. Kisiel (2014) described boundary activities and a boundary community.

We define the *boundary crossing* as a bidirectional interaction at the system boundary where the zoo educators and elementary educators interacted culturally and professionally (Engeström et al., 1995; Penuel et al., 2015). The bidirectional interaction occurred where the zoo education system overlapped with the elementary educators' system. Direction 1: The zoo educator reached out to the elementary educators and asked how they would use the activities. Based on the feedback from the elementary educators, the zoo educators changed the activities and provided practical activities and contacted the educators prior to the zoo visit. Direction 2: Elementary educators explained time and lack of knowledge about how to use the activities were constraints. Additionally, elementary educators spoke with zoo educators to understand better how to use the activities and prepare students for the field trip.

All educators described a need for communication. However, each saw the other as responsible for successful communication. Even though we overcame this pitfall and communication increased in both directions, the elementary educators did not view increased communication as supporting successful school programs that promoted student learning. Instead, they described a successful program based on better student behavior management (see Karnezou et al., 2013) and a more organized field trip.

The chapter contributes to the small body of literature on applying learning theory in informal science learning environments in three respects:

1. We determined the consequences of applying GST in a zoo education system through the lens of formal and informal educators. GST should be a continuous assessment of the interactions between formal and informal educators.
2. We show GST can identify the interdependent elements between formal and informal educators. The recognition of the elements and their mutual dependence can lead to successful changes.
3. We offer GST as a participatory theoretical framework for informal researchers and practitioners to share in the process of understanding the bridge between formal and informal educators. Framing GST as a participatory theoretical framework allows for its implementation in participatory research, which embraces the perspectives of stakeholders (Cornwall & Jewkes, 1995). Even though our study included one of the zoo educators as a researcher and included informal educators as participants, future studies should consider including a formal educator as a researcher.

17.4 Applying Systems Theory

Our overarching goal in this chapter is to present how to apply GST to depict the voices of participants on both sides of a system boundary. Within this goal, we viewed how zoo educators and elementary educators crossed the boundary to communicate.

In this section, we provide an overview of systems theory to assess program success and engagement between formal and informal educators at the boundary of their systems. Additionally, we describe how to apply systems theory in other areas of informal science education research.

GST is a valuable tool for identifying and investigating system challenges and interventions. Complex problems, such as the interactions between formal and informal educators, are fertile areas for using GST to discern what is happening, who is involved, and how the issue evolved, and to establish solutions. GST considers the interdependence of the actors, the system, and the factor contributing to their interactions. The agentic actors who are making decisions and reacting to imposed resolutions in the system continuously are adjusting to the environment. In this study, the zoo educators unfortunately made the decision to develop classroom activities based on their beliefs about what was needed, and expectations of knowledge students would bring to the zoo program. Unfortunately, the educators reacted by not using the proposed activities. Even though the success of the program related to the activities, the two groups of educators did not discuss their design or usability prior to the zoo visit. The expectations of each group may have been a successful field trip and zoo program. However, the pre-defined activities not necessarily were used for the same end goal.

GST allowed us to expound on the reality of the system and its issues. We need to bridge the gap between formal and informal educators by defining the needs of both systems through appropriate measurement tools and theoretical frameworks and mapping the overlap and disparities between them. Our study may seem a cursory view of the impedances occurring at the *boundary crossing*. However, we revealed the multi-dimensional margins of the boundary, the multi-level positions constructed at the boundary crossing, and the complexity caused by the interacting components—formal educators, pre-visit and post-visit zoo activities, and zoo programs provided during field trips. The intersection of the components at the *boundary crossing* can shape the learning taking place during the zoo programs.

We defined the *boundary crossing* with four key components—formal educators, informal educators, pre-visit and post-visit zoo activities, and zoo programs provided during field trips. Our study shows if the components occur in a positive way through communication and development with formal educators, there is potential for formal and informal educators to develop a positive relationship. Formal educators are more likely to develop a sense that pre-visit and post-visit activities are important. Informal educators are more likely to design activities based on the needs of formal educators. Therefore, we add communication as a component upon which to establish a successful and positive relationship.

GST as a framework offers researchers a view of the interactions constructed between members of systems and the ways stakeholders influence each other. Additionally, GST highlights the added complexity that even if the stakeholders are sharing a boundary, they may not develop respectful relationships conducive to the success of the system. Consequently, system stakeholders may struggle to overcome obstacles in the system and at the boundary and legitimately participate. The hindrances befalling the system's success simply may need identification and explanation. GST focuses on identifying the components and overlaying them with the system concepts to explain why the system is or is not productive.

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Part VI
Expeditionary, Place-Based, Variation Theory

Chapter 18
Connecting the History of Science to the Holocaust Through Expeditionary Learning

Gary M. Holliday

18.1 Expeditionary Learning

It was a beautiful summer morning in Lublin, Poland, and our study-abroad group just stepped out of the van at the Majdanek concentration camp. The Mausoleum, erected in 1969, loomed in the distance (see Fig. 18.1) and we walked slowly towards it. Once we climbed the stairs of the monument and stood at the edge of a large circular pit, we were able to see the ashes and remains of cremated victims who lived and died at the camp between 1942 and 1944. When viewing the human remains that still lie in this massive pile of ash, it boggles the mind to think how 360,000 people perished at this site. The group of students were largely silent and the sounds of cawing crows echoing through the landscape were striking. I wondered, "How could something like this happen?".

The Holocaust was a horrific event in human history, and it is important to the remember what happened and remember the many people impacted. During the Holocaust, over 6 million Jews were killed with half of these murders being Polish Jews. Unfortunately, it often seems that these larger events are outside of ourselves, and we have no connection to them because it happened long ago. In American schools, and in certain curricula, this history is taught in social studies classrooms, but there is an often-overlooked opportunity to make connections between what happened in history, the scientific process, as well as the development of scientific knowledge. As McComas (1998) stated, "science is at its heart a human activity" (p. 17).

This chapter describes a study-abroad course with a focus of expeditionary learning in which 10 students traveled to Germany and Poland during a 12 day excursion during summer 2019. The main goal of the trip was to incorporate the Holocaust into science and social studies lessons, but the focus here will be teaching

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Fig. 18.1 Mausoleum at Majdanek, Lublin, Poland (Image: Gary Holliday)

about the Holocaust in science curricula. Expeditionary learning (EL) takes place outside the classroom, allowing teachers and students to act as co-learners through the process of creating knowledge. Participants interact in a collaborative learning environment while simultaneously residing in another culture. Facilitating these intercultural exchange projects is an organization that originated in Poland, Expedition Inside Culture, that focuses on tolerance building and democratic education through onsite study of a local region or area (Mazurkiewicz et al., 2007). Kurt Hahn, founder of Outward Bound, originally developed EL education, and the Expedition Inside Culture Association has taken the tenets to a global level. As such, during each step of a trip abroad, critical activities focus on:

- Discovering and sharing individual, local, and national history.
- Studying and exploring local culture (including ethnic, social, and religious traditions) by gathering, analyzing, comparing, and discussing information.
- Studying and analyzing perceptions of cultural groups and nations in the society.
- Analyzing, discussing, and reflecting on the group work dynamic and experiences (Mazurkiewicz et al., 2007, p. 9).

Ten principles of expeditionary learning are: self-discovery, curiosity, responsibility for learning, empathy, success and failure, collaboration and competition, diversity and inclusion, the natural world, solitude and reflection, and service and compassion (Mazurkiewicz et al., 2007, see also Fischer et al., 2007). In the course I describe here, students visited cities in Germany and Poland and experienced the cultural and historical sites while learning about the nature of scientific knowledge and the use of pseudoscience to legitimize atrocities. This included visiting concentration camps, ghettos, and other places of importance.

Although this study-abroad course was short term, previous studies show such programs to have a positive impact upon students' development of cross-cultural sensitivity (Anderson et al., 2006; Gaia, 2015) and to help with personal development facilitation (Cheng, 2014). Castelão-Lawless (2002) argued for the need for science studies courses that would help to "destroy students' stereotypical certainties about science and help them become 'historical real-ists' in regard to scientific practices" (p. 251) and to address students' misunderstandings of science. Further, distorted history (pseudohistory) and false ideas about science (pseudoscience) are important to address, especially when considering how the scientific process works and science as a human endeavor (Allchin, 2004). The inclusion of nature of scientific knowledge in science education curricula aims to promote scientific literacy and is a desired outcome of science teaching (Lederman, 1992; Tairab, 2001).

While an untested assumption, science literacy is noted as requiring an understanding of nature of science (NOS), historically known as nature of scientific knowledge (Lederman, 2008). The phrase *nature of science* typically refers to the values and assumptions inherent to scientific knowledge and the development of scientific knowledge. Although disagreements occur about specific aspects of NOS, the focus here is on generally agreed aspects, accessible to K–12 students, and important for all citizens to know. Lederman (2008) provides the following, agreed upon, aspects that define the characteristics of scientific knowledge and its development: scientific knowledge is based on observations and inferences; scientific laws and theories are distinct types of scientific knowledge (one does not turn into the other); the development of scientific knowledge involves human imagination and creativity; scientific knowledge is subjective and/or theory laden; "Science as a human enterprise is practiced in the context of a larger culture, and its practitioners (scientists) are the product of that culture" (p. 834); and all scientific knowledge is subject to change.

18.2 Description of the Course

The study-abroad group mainly consisted of undergraduate students (n = 7) in a teacher-preparation program at a mid-sized university in the Midwest USA. Two in-service teachers and one retired teacher participated on the trip as well. The learning outcomes for the course were as follows:

- Explore the historical and cultural development of science and the evolution of scientific knowledge.
- Become familiar with philosophical tenets, assumptions, goals, and values that distinguish science from technology and from other ways of knowing the natural world.
- Engage in critical analysis of false or doubtful assertions made in the name of science.
- Articulate insights into one's own cultural rules and biases.

- Interpret intercultural experience from the perspectives of one's own and more than one worldview; demonstrate ability to act in a supportive manner that recognizes feelings of another cultural group.

The students' views of science and the development of scientific knowledge, within the context of the Holocaust in this case, and how those views might have changed over the course of this study-abroad experience was of particular interest. In terms of NOS as described above, the focus of the course was on the concepts 'scientific knowledge is subjective', 'scientific knowledge is subject to change', and 'science is a human enterprise within a larger culture'.

This course also focused on preparing educators, namely middle school (11–13 years) and secondary (14–18 years) teachers, as civic leaders and to better understand and confront hate in all its forms. The course situated the Holocaust as a case study where students applied principles and foundations in economic and science education (as discussed in this chapter). To address economic education, learners studied how political choices influence economic outcomes, with a focus towards identity, expropriation, and extermination in Nazi Germany during the Holocaust. To address science education, learners engaged in a critical analysis of false and doubtful assertions made by Nazi leaders in the name of science before and during WWII. In particular, students investigated America's and Nazi Germany's use of pseudoscience and eugenics as a means to 'improve' the genetic quality of the human population (through sterilization and other means).

Students participated in interactive sessions before, during, and after the trip, in order to discuss and reflect on what they experienced, while connecting to the involvement of science in the events they were witnessing. Pre-trip sessions included an overview of the trip (including destinations and sites to visit), an introduction to the Holocaust, assigned history and science education readings (with media response reflections), a visit to a museum of Jewish heritage, and exploration of original documents at an archive of psychology records and materials. Students explored these primary source documents and discussed articles found in journals from the early 1900s. *The Journal of Heredity: A monthly publication devoted to Plant Breeding, Animal Breeding and Eugenics* (American Genetic Association) is an example of one of the original documents. Articles in the December 1916 issue discussed the propagation of strawberries (for example) along with discussions about immigration policies and eugenics.

Eugenics, the study of how to increase the occurrence of "desirable" heritable traits in the human population and to "self-direct" human evolution (Laughlin, 1923), was an important aspect of the conversations. In the early 1900s, eugenics held a position as a legitimate science that drew its support from many other fields of science. This is shown in an illustration by Laughlin (1923), created for the second international congress of eugenics at the American Museum of Natural History, where eugenics is depicted as a massive tree along with the statement about how it "draws its materials from many sources and organizes them into an harmonious entity". The roots of the eugenic tree include the scientific fields of biology, genetics, medicine, anatomy, as well as psychology, history, and politics. This viewpoint certainly changed as history marched forward.

During the twelve-day tour of Germany and Poland, students engaged in expeditionary learning activities centered on field research skills and service learning. This expedition started by bringing students to Berlin, the political nerve center of Nazi Germany in WWII, where they visited Holocaust Memorials, the Jewish Museum, restored Reichstag, the Berlin Wall, and the House of the Wannsee Conference. In Poland, students visited a number of cities and historical sites: Warsaw (including visits to the Warsaw Ghetto, POLIN Museum, and Old Town), Lodz (the Marek Edelman Center of Dialogue, Kazimierz: Old Jewish Cemetery), Lublin (Dabrowa Tarnowska, Old Jewish Quarter, and Majdanek extermination camp), and Krakow (Oscar Schindler Factory Museum, Galicia Museum, Jewish Quarter, Wawel Castle, and Auschwitz I and II (Birkenau)). Throughout the course, students met with Holocaust survivors, scholars in Holocaust and genocide studies, representatives from Jewish community centers, local universities and schools, and local peace-building activists. Students also had free time to explore the various cities and sites on their own.

A typical day during the trip involved group sessions, such as sharing circles, through which students could process and de-brief what they had been seeing, discussion of readings, blog entries, and other activities. An example of an activity during the trip (and conducted in a hotel lobby) is the E-mail Lab (Lederman et al., 2015). Working in small groups, students received a packet of 16 e-mails with instructions to retrieve four out of the packet without looking at the others. After reading the selected e-mails, they were to construct a story based on the information found. After that, they could draw another four (when instructed), continue building upon the story, and then select a final two e-mails. The remaining e-mails were unviewed. After the groups read through all the selected e-mails and finalized their stories, we gathered together again, and each group shared their e-mails and stories. While every group had the same e-mails, the stories varied from group to group depending on the sequence of the retrieved e-mails and the information in the body of the text (along with dates, the sender, the receiver, etc.) the group found pertinent. This activity and subsequent discussions helped illustrate a number of NOS aspects:

- Scientific investigations use a variety of methods;
- Scientific knowledge is based on empirical evidence;
- Scientific knowledge is open to revision in light of new evidence;
- Science is a way of knowing; and
- Science is a human endeavor (Lederman et al., 2015, p. 61).

18.3 Course Materials and Analyses

The course materials were reviewed and analyzed to see how the expeditionary learning process impacted students. During the course (and study-abroad trip), students were to create a blog describing their experiences. Every student kept a digital story-telling blog (DST) of learning and reflections from the study-abroad activities or discussions and built it over the length of the course. Suggested topics were discussed for the blog, such as pre-trip goals and guiding questions, as the group visited various sites in Germany and Poland. Examples included:

- What are your pre-trip goals? Are there 1–2 questions you're seeking to answer? Any sites or locations you most are looking forward to seeing?
- Based on your experiences and field research in Warsaw (for example, visiting the POLIN Museum, Warsaw History Museum, tours with the guide, etc.), in what ways does bias influence the nature of science? In particular, how is scientific bias evident in the study of the Holocaust?
- What contemporary issue did you find most interesting during your visit to Poland or Germany? Describe this issue, why you selected it, and how it related to your experiences overseas.

The participants were encouraged to use their assignments as a means to describe how information from the course were impacting their learning and perspectives and to use linked media (video, images, weblinks).

In addition to the DST blogs, there were assigned readings that addressed eugenics, science, and/or NOS, including the following:

- Hitler's Eugenic Reich (Black, 2012, pp. 279–287).
- Chronology of the Biological Concept of Unfit People (Carlson, 2001, pp. xi–xiv).
- Flow Diagrams and the History of Ideas (Carlson, 2001, pp. 397–404).
- The Principal Elements of the Nature of Science: Dispelling the Myths (McComas, 1998).

The students were also asked to complete a 'media response' template in which they would identify quotes in the readings and write reactions to those quotes. Relevant quotes from these media response assignments were included in the analysis. Finally, the post-trip assignment [Choosing to Act Project] was reviewed and analyzed. This project asked students to create action plans based on what they learned during the trip and challenged them to consider how they could make an impact as an 'upstander' (a person who speaks or acts in support of an individual or cause).

At the beginning and end of the course, students were given the Views on Science-Technology Society (VOSTS) inventory (Aikenhead et al., 1989), with 16 items selected from the larger instrument of 114 multiple-choice items that addresses a broad range of science, technology, and science (STS) topics (see the appendix for the abbreviated VOSTS). Each item of the inventory starts with a prompt about STS, and participants were asked to select a position that comes closest to their own personal view or belief when considering that prompt. An example is as follows: *Some cultures have a particular viewpoint on nature and man. Scientists and scientific research are affected by the religious or ethical views of the culture where the work is done.* After each prompt, five position statements were provided that support the influence of religious or ethical views on scientific research. In addition, two statements were provided which support the viewpoint that scientists are uninfluenced. There were also three options if the participant does not understand the prompt or does not feel the statements support their basic viewpoint. There is no scoring key to VOSTS, but the survey can "monitor students' views on Science-Technology-Society topics", and the legitimacy or validity of the instruments rests on being able to "reflect the perspective of the student" (Aikenhead & Ryan, 1992, p. 488).

The data were analyzed, which included the VOSTS responses, blogs, course readings, and assignments, using a constant comparative approach along with an inductive analysis. This data analysis allowed for identification of changes in views and perceptions. Initially, all participant responses were reviewed at the same time and in random order, so to find statements that stood out from the rest. Examples follow in the next section, participants were given a pseudonym for confidentiality.

18.4 Results

When looking at the DST blogs, posts written at various points before the trip and while abroad were analyzed. This helped reveal the experience of students during this intensive trip. For example, Sara's comments written at two moments, before and during the trip, illustrate a profound thought process…

> **[Pre-Trip]** So, what do I want to get out of this trip? What are my goals? Beyond the perogies.
>
> I don't think I exactly have that answer, but I know I'll find it when I'm there. I can't wait to see all of Germany & Poland. The darkness and the light.
>
> **[Majdanek—During the Trip]** was a very personal experience to me. It was very surreal and freeing to walk into the fenced yard, and out of it ... as [a] Jewish woman. I don't really know how to process something so big as that, because at times it's too much.
>
> In this class we discuss heavily the economic and science factors that went into making the Holocaust possible. As humans we analyze. We analyze and try to make sense of the senseless. Or, at least that's what I think anyways.
>
> So at times, I think we need to step back from trying to analyze, and make sense of something so bad such as the Holocaust. And instead, just sit with the feelings we have about it. How these thoughts mold us into the people we want to be. That ... is what I will take with me as a future educator.

When considering bias, students directly connected this concept to the places and sites they were visiting. While in Warsaw, Elizabet wrote the following:

> But it was through these guided walks of the city and the museums that I began to understand the bias. The scientific bias that the Nazi's had to confirm their horrific muderus [sic] desires. From the self-same nation which was the most advanced in science (coupling the United States) came the ultimate acts of inhumanity—to the point that no one was able to believe that human beings were capable of such behavior. I thought on this act—why? Because their intellect was not based on foundations. Their intellect came in a form of anti-Semitic views coupled with a pseud-science [sic], Eugenics.

Rachel goes a little further when discussing bias in her blog post…

> Bias influences the nature of science because scientists are human and carry pre-conceived notions with them into their work. In the case of eugenics, the scientists of the time truly

> believed that eugenics was a legitimate science and saw no moral or ethical issues with sterilizing and murdering certain groups of people in the name of science. I think that bias influencing science is most evident in the nazi [sic] creation of 'the final solution to the Jewish question'…. The idea of the gas chamber was to make it easier not only for the soldiers but also to increase efficiency. I think this is a good example of bias because the Nazi leaders used their bias and contempt to innovate new scientific methods. Although this may be an extreme example of bias influencing science, I think it exemplifies the ways in which a bias can radically alter science.

The readings, and associated media response templates, supported the ideas found in the blog posts. Sara wrote, "Science is highly biased, and influenced by the environment the science is being tested in". Elena noted, "people usually take the word of scientists as absolute truths and don't realize that all of them have biases that could alter their findings". Matilda recognized her own misconceptions, "…experiments are always presenting the truth because it is data. I did not realize the human element".

Student views about science seem clarified as a result of the expeditionary learning experience. Overall, there seemed to be no great change in students' positions, but the trip (and associated activities) did seem to help make Sara more knowledgeable and/or confident about addressing Science-Technology-Society issues, as shown in her VOSTS responses (see Tables 18.1 and 18.2). She initially indicated she did not know enough about the subject and was unable to make a choice. On the post-VOSTS inventory, she was able to indicate her position.

Table 18.1 Comparison of Sara's pre- and post-responses for item 20,141 on the VOSTS inventory (Aikenhead et al., 1989)

20,141 A country's politics affect that country's scientists. This happens because scientists are very much a part of a country's society (that is, scientists are not isolated from their society). Your position, basically	
Pre (response L)	Post (response H)
I don't know enough about this subject to make a choice	Scientists ARE affected by their country's politics: It depends on the country, and the stability or type of government it has

Table 18.2 Comparison of Sara's pre- and post-responses for item 40,221 on the VOSTS inventory (Aikenhead et al., 1989)

40,221 Science and technology can help people make some moral decisions (that is, one group of people deciding how to act towards another group of people). Your position, basically	
Pre (response H)	Post (response E)
I don't know enough about this subject to make a choice	Science and technology cannot help you make a moral decision: because moral decisions are made solely on the basis of an individual's values and beliefs

Table 18.3 Comparison of Matilda's pre- and post-responses for item 40,221 on the VOSTS inventory (Aikenhead et al., 1989)

40,221 Science and technology can help people make some moral decisions (that is, one group of people deciding how to act towards another group of people). Your position, basically	
Pre (response A)	Post (response B)
Science and technology can help you make some moral decisions: by making you more informed about people and the world around you. This background information can help you cope with the moral aspects of life (Pre/A)	Science and technology can help you make some moral decisions: by providing background information; but moral decisions must be made by individuals (Post/B)

Table 18.4 Comparison of Matilda's pre- and post-responses for item 20,611 on the VOSTS inventory (Aikenhead et al., 1989)

20,611 There are groups of people who feel strongly in favor of or strongly against some research field. Science and technology projects are influenced by these special interest groups (such as environmentalists, religious organizations, and animal rights people). Your position, basically	
Pre (response E)	Post (response D)
Special interest groups do have an influence: because some special interest groups give money for certain research projects. Some other special interest groups give money to prevent certain research projects (Pre/E)	Special interest groups do have an influence: because they influence government policy and governments decide whether to fund a research project or not (Post/D)

For Matilda, she initially indicated that religious or ethical views do not influence scientific research and this view changed to their having an influence, because certain powerful groups can support certain research projects (VOSTS Item 20,411). Otherwise, the shifts were smaller on her VOSTS inventory responses, but they were still of interest (see Tables 18.3 and 18.4).

The post-trip assignment, the Choosing to Act Project, asked students to discuss action plans through which they might apply what they learned during the trip. The action plans included the following and illustrate students' clarified perspectives:

- A news app with a focus on immigration and activity at the southern border of the United States (US).
- A blog with a focus on family history and collection of the older generation's memories. Family members were from Poland and Germany.
- Acquiring a law degree to be involved directly with US deportation processes and policies.
- Create a seminar series for the community.
- Create curriculum for high school students pertaining to the Holocaust.
- Create curriculum that focuses on bringing awareness to loaded words (such as concentration camp) and a historical context (during the Holocaust vs. US immigration issues during the early twenty-first century).

18.5 Conclusions

Intensive study-abroad experiences that emphasize expeditionary learning provide an opportunity to connect science to history and greatly impact students in many ways. No doubt this course was a life-changing experience for students, and it helped these educators in training become more cognizant of the relationship between history and science. That said, it was important to have intentional instruction of NOS (Akerson et al., 2007) while students engaged in this expeditionary learning experience.

Davis and Appelbaum (2002) write about the importance of including the Holocaust, in particular, into science and science education curricula…

> Holocaust and genocide studies are usually thought of as falling under the rubric of social studies and literature. This is why science education itself must take the responsibility for the heritage that science has willed to our society. This is a "lesson" learned from the Nazi state itself: that science and science education are constituted by and also constitutive of the ideological commitments and the development of political structures in a given society. If we are to promote a democratic, post-Holocaust society, then science must be part of that societal commitment. (p. 183)

This includes emphasizing the relationship between science and society, the representation of science, and "scientists' positions relative to social dynamics" (Davis & Appelbaum, 2002, p. 183). As a reminder, NOS emphasizes the idea of 'Science as a human enterprise is practiced in the context of a larger culture, and its practitioners (scientists) are the product of that culture' (Lederman, 2008, p. 834). Very often, this is a difficult aspect to address when teaching about NOS to teacher candidates. However, while engaged in expeditionary learning when traveling through Germany and Poland and when participating in the various course activities, one could not avoid seeing how science (and the misrepresentation of it) played a significant role in history. This chapter demonstrates how science educators can further the understanding of science and scientists, while making connections to history and culture. By providing such study abroad opportunities, especially when students were presented with explicit (sometimes, challenging) connections to real experiences, science can be clearly shown as an ongoing human activity throughout the world.

Appendix

VIEWS ON SCIENCE-TECHNOLOGY SOCIETY © (*Abbreviated*)

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College of Education

NAME: ______________ DATE: __________.

INSTRUCTIONS TO STUDENTS:

Each question of the VOSTS inventory begins with a statement about science technology-society topic. Most of these statements express an extreme view on the topic. You may happen to agree strongly with this view; you may happen to disagree vigorously; or your own position may be in between the two.

Next, there is a list of positions (or viewpoints) on the issue. These usually go from one extreme to the other. You are asked to choose one of these positions, BUT ONLY ONE that comes closest to your personal view or belief.

To summarize:

Read the statement carefully.

Think to yourself whether you agree or disagree with the statement, or can't make up your mind. Then read the list of different positions on the topic.

Pick the one that comes closest to your own position.

Every page ends with the same three positions. Here is how you can use them if you wish:

X. "I don't understand." This choice is included in case there is a key word or phrase that you just don't understand.
Y. "I don't know enough about this subject to make a choice.
Z. "None of these choices fit my basic viewpoint." This choice can be used when none of the other positions comes close to your own belief, or when you want to combine two or more choices into one position.

There are no "right" answers; this is not a test. We simply want to understand what your position is on a number of issues about science and about how it relates to technology and society.

Example: **10,111 Defining science is difficult because science is complex and does many things.**

But MAINLY science is:

Your position, basically: (Please read from A to K, and then choose one.)

A. a study of fields such as biology, chemistry and physics.
B. a body of knowledge, such as principles, laws and theories, which explain the world around us (matter, energy and life).
C. exploring the unknown and discovering new things about our world and universe and how they work.
D. carrying out experiments to solve problems of interest about the world around us.
E. inventing or designing things (for example, artificial hearts, computers, space vehicles).

F. finding and using knowledge to make this world a better place to live in (for example, curing diseases, solving pollution and improving agriculture).
G. an organization of people (called scientists) who have ideas and techniques for discovering new knowledge.
H. No one can define science.
I. I don't understand.
J. I don't know enough about this subject to make a choice.
K. None of these choices fits my basic viewpoint.

The following are the prompts used in the revised survey. The full survey described in this chapter, and position statement options for each prompt, can be seen when scanning the QR code:

10,411 Science and technology are closely related to each other:

20,121 Community or government agencies should tell scientists what to investigate; otherwise scientists will investigate what is of interest only to them.

20,141 A country's politics affect that country's scientists. This happens because scientists are very much a part of a country's society (that is, scientists are not isolated from their society).

20,321 Few scientists and technologists would choose to work on military research and development.

20,411 Some cultures have a particular viewpoint on nature and man. Scientists and scientific research are affected by the religious or ethical views of the culture where the work is done.

20,611 There are groups of people who feel strongly in favor of or strongly against some research field. Science and technology projects are influenced by these special interest groups (such as environmentalists, religious organizations, and animal rights people).

40,111 Most scientists are concerned with the potential effects (both helpful and harmful) that might result from their discoveries.

40,121 Scientists should be held responsible for the harm that might result from their discoveries.

40,216 Scientists should be the ones to decide what techniques will be used with unborn babies (for example, amniocentesis for analyzing chromosomes of the fetus, altering embryo development, test-tube babies, etc.) because scientists are the people who know the facts best.

40,221 Science and technology can help people make some moral decisions (that is, one group of people deciding how to act towards another group of people).

60,211 The best scientists are always very open-minded, logical, unbiased and objective in their work. These personal characteristics are needed for doing the best science.

60,221 Certain personal characteristics can be important in science (for example, being open-minded, logical, unbiased, objective). Scientists display these characteristics, not only in their research work, but in their home life as well.

70,111 Loyalties affect how scientists do their work. When scientists work together as a team, their *loyalty to the ideals* of science (open-mindedness, sharing results with others, etc.) is replaced by a *loyalty to the team* (for example, putting the team's interests ahead of the interests of science, or conforming to the team's views).

70,212 When scientists disagree on an issue (for example, whether or not low-level radiation is harmful), they disagree mostly because they do not have all the facts. Such scientific opinion has NOTHING to do with moral values (right or wrong conduct) or with personal motives (personal recognition, pleasing employers, or pleasing funding agencies).

70,711 Scientists trained in different countries have different ways of looking at a scientific problem. This means that a country's education system or culture can influence the conclusions which scientists reach.

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Chapter 19
Fostering Bedouin Students' Sense of Place in the Light of Place-Based Education and Third-Space Theory

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19.1 Introduction

Sense of place—a concept that describes the fundamental relationship between people and places—has been noted by environmental researchers as a key component in understanding and encouraging environmental behaviour (Ardoin, 2006). It is based on the idea that people's relationship with a place affects their attachment to it and desire to reside in it, encouraging them to care about the place's environmental health and strengthening their commitment to protect it (Avriel-Avni et al., 2010). A primary assumption in environmental education research is that to develop a strong sense of place, students should deepen their understanding of their surroundings through hands-on, outdoor learning. Place-based education takes place outside school walls, in the students' local environment, and therefore strongly is based in a paradigm of outdoor learning. The place-based learning experience is designed to develop a sense of responsibility and encourage students to become involved in the goal of achieving local ecological and cultural sustainability (Woodhouse & Knapp, 2000).

Our study followed a group of young Bedouin students (initially fifth graders, aged 10) throughout a three-year, place-based education program conducted in their local environment, examining that program's influence upon the students' sense of place. These students live in small, rural villages along the banks of the Hebron Stream in Israel's Negev Desert. This stream is an environmental hazard, with contamination

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Fig. 19.1 Unrecognized Bedouin village on the banks of Hebron Stream

by sewage runoff and mounds of dumped waste along its banks (see Fig. 19.1). We conducted this program in tandem with an extensive project we designed to rehabilitate the contaminated environment in which these students live.

Creating an authentic place-based program that would be relevant to the environmental, social, and cultural issues that concern these particular students required a detailed characterisation of the place in which they live and the students' relationship with it. We therefore drew upon Homi Bhabha's (1994) notion of the third space to create data collection tools that accurately would reflect the students' understanding and experience of their environment. We enlisted students from our target population as participants in our research tool development process, which incorporated multiple cycles of interviews with small groups of students, who orally completed and provided feedback on different iterations of a gradually developing questionnaire. These interviews served as a third space in which to conduct a 'negotiation' between the concepts and categories Western tools employ for measuring nature connectedness and the experiences and worldview of the Bedouin students. The 'negotiation' then continued throughout the program's implementation, defining the program's content as well as our analysis of its influence. In this chapter, we describe the process of developing and implementing our place-based education program, highlighting the critical role third-space theory played in creating it and in gaining an accurate and comprehensive understanding of its results.

19.2 What is 'Sense of Place' and Why Is It Important?

'Sense of place' can be defined broadly as the meaning and importance individuals or groups ascribe to a given setting, based on their experience within it (Stedman, 2003). In this context, the term 'place' refers not just to a place's natural, environmental, and physical elements, but also to its cultural and social characteristics (Ardoin, 2006; Stedman, 2003). As a result, sense of place reflects the complex web of lifestyles, meanings, and relations associated with a particular place at a particular time by an individual or group of individuals (Garavito-Bermúdez & Lundholm, 2017).

Despite the concept's complexity, scholars have agreed on a combination of two complementary principal aspects of sense of place: place attachment and place meaning (Haywood, 2014). Fundamentally, *place attachment* refers to the bond between people and places and reflects how strongly people feel attracted to places, while *place meaning* deals with the symbolic value people ascribe to places (Kudryavtsev et al., 2012). Place meaning serves as the reason for place attachment and depends on the value characteristics people ascribe to places (Stedman, 2003). As Manzo (2005) notes, "it is not simply the places themselves that are significant, but rather what can be called experience-in-place that creates meaning" (p. 74).

Most studies on 'sense of place' focus primarily on people's positive experiences in a healthy natural environment (Manzo, 2005). However, to expand the meaning of the concept beyond this context, we must learn more about people's relationships with natural spaces that are contaminated or unsafe (Kudryavstev et al., 2012). The setting of our study sets it apart from most sense-of-place research because it offers an opportunity to examine the sense of place of individuals who live in an unsafe, contaminated environment. This is especially important in light of the fact that experiences in unsafe environments are no less powerful and significant than positive experiences in healthy environments and no less influential in shaping individuals' relationships with their environments.

19.3 The Relationship Between Sense of Place and Place-Based Education

Sense of place begins developing at a young age. Indeed, Briggs et al. (2014), and Morgan (2010) identified childhood as a critical period in its development, during which place meanings and attachment begin to form and subsequently influence development of an individual's identity. One issue concerning researchers is that this bond is being disturbed as children's access to positive experiences that encourage a personal bond with their local environment has declined (Castonguay & Jutras, 2009). The situation is worse in poorer areas, where there are more problems and fewer resources and where opportunities for positive encounters with places are less frequent. There is therefore a worry that individuals and communities that lack a sense of place will not care much about that health of their local environment nor have concern about maintaining it.

In light of these concerns, environmental researchers and educators increasingly emphasize sense of place and connectedness to nature, based on their potential role in curbing the environmental crisis and promoting a more sustainable future (Lankenau, 2018). The last decade in environmental education has focused on creating programs designed to strengthen children's connection with natural places, emphasizing the importance of spending time in natural environments to the forging (or reforging) of nature connectedness and sense of place (for example, Cheng & Monroe, 2012; Liefländer et al., 2013). Strengthening this connection between people and places is one of place-based education's primary goals (Gruenewald, 2003; Kudryavtsev et al., 2012; Wooltorton et al., 2020).

Place-based education is an educational approach that emerged from a perceived need to bring students closer to their local environments and the particular problems that affect them (Smith, 2002; Sobel, 2004; Wooltorton et al., 2020). As such, we can view it as a countermovement, responding to dominant educational cultures that focus on global or abstract issues that bear no tangible relation to place (Eijck, 2010). Though place-based education is a relatively recent term, it draws upon and shares qualities with other educational approaches, including community-oriented schooling, ecological education, bioregional education. This approach considers indigenous ways of knowing, and the role of power historically contextualized within a space (Dean, 2021; Wooltorton et al., 2020).

Place-based learning must take place in an environment that is authentic (Braund & Reiss, 2006) and provide opportunities for hands-on learning (Lavie-Alon & Tal, 2015). Place-based approaches to environmental education focus on the problems and the benefits of a particular place, using these to teach students to be sensitive to the needs of the environment, to understand environmental problems, and to promote sustainable solutions. Place-based education is therefore critical to the field of environmental education—not only to encourage an environmental conservation ethic among learners, but also to make learners aware of the deeper social, ecological, and political forces embedded in places (Smith & Sobel, 2010).

19.4 The Bedouins and Their Relationship with Place

The Bedouins of the Negev Desert are an indigenous people, a sub-group within the Arab minority in the State of Israel. While the Negev Bedouins are Muslims, they are a distinct sub-culture owing to their close ties to the desert landscape and the lifestyle that evolved there before 1948. The Bedouin economy has, for most of their history, been semi-nomadic, structured around seasonal migration with herds, with women, children, and elders left behind to tend a specific familial territory, and men returning to their designated homes periodically in accordance with the seasons (Al-Krenawi, 2004). This means that, though nomadic, individual tribes historically associated over time with a single, continuously populated place.

For much of their history, the Bedouins, like other indigenous communities around the world (Abu-Saad, 2008; Holt, 2006), relying directly on local natural resources for survival and using these resources in a sustainable manner. The Bedouins' traditional agricultural activities and lifestyle adapted to the natural cycles and seasons of the desert, overcoming water scarcity by capturing and storing water flows in seasonal creeks and streams during winter through a system of stow dams and terraces (Abu-Rabia et al., 2008). Abu-Rabia (2002) describes the Bedouins' ecosystem knowledge, which resulted in traditional land management practices for sustainable grazing. He claims the Bedouins roamed in specific environments in the Negev ecosystem because of the abundance of a combination of green vegetation and stubble (*hasida*) that provided a rich and balanced diet for flocks. The wild herbs they gathered were both food and medicine and generally had higher nutritional values than cultivated vegetables (Abu-Rabia, 1999). Overall, this was a community of people whose lifestyle moulded to suit the specific requirements and characteristics of their environment and who were fully aware of the importance of their place in providing pasture and drinking water for both people and their livestock (Abu-Rabia et al., 2008).

Like other indigenous populations, however, Bedouin society has, over the past several decades, undergone a relatively rapid process of urbanization and modernization. In the Bedouins' case, this came by their close proximity to other, sedentary populations with vastly different lifestyles and further expedited by the sharp decrease in land left available for the Bedouins' use, as areas they had been accustomed to living on were reallocated by the state for other uses. As a result, approximately 50% of the Negev Bedouins now live in state-recognized townships, while 34% live in unrecognized villages, and the remaining 17% live in recently recognized villages. Unrecognized villages do not receive municipal funding and suffer from a lack of infrastructure. Moreover, any domestic structures formally classified as 'illegal' are under perpetual risk of being torn down, so they tend to be temporary, composed of light substances such as fabric, tin, or wood. Whatever their legal status, all of the Bedouin localities rank lowest in socio-economic indices in Israel at large and remain the most underdeveloped in all areas, including education, infrastructure, industry, and commerce (Rudnitzky & Ras, 2012; Sedawi et al., 2019).

One basic municipal service these settlements lack is the organized collection and disposal of household and other rubbish. As a result, the residents must dispose of this themselves. Studies of settlements with similar waste-disposal issues show that the lack of the means and knowledge for proper disposal, together with the combined inaction of the government and the community in addressing this lack, can lead to environmental and health problems like foul smells, the agglomeration and reproduction of harmful insects and bacteria, and the outbreak of infectious diseases (Ismail et al., 2017). The disposal method currently employed in the unrecognized and recently recognized Bedouin villages involves backyard burning of household waste, dumping household and agricultural wastes in unregulated dumps in and around the settlements. Storing bulky waste such as asbestos in backyards and dumping waste in streams and streambeds (Sedawi et al., 2014). It is worth noting that practices like incineration or leaving waste to biodegrade worked reasonably well when Bedouin communities were smaller, nomadic, and generated waste that was almost entirely organic. However, the waste generated by the Bedouin villages whose children participated in our study is an amalgam of miscellaneous packaging materials, diapers, aerosol containers, cardboard, glass, etc., all of which also constitute part of the children's environment (Meallem et al., 2010; Sedawi et al., 2020).

Despite the recent fundamental shift away from the traditional Bedouin lifestyle, various elements of it still remain. For example, raising sheep, though often no longer financially beneficial, is still common practice in unrecognized Bedouin settlements, both as a domestic source of meat and milk and as a means of preserving a traditional lifestyle (Degen & El-Meccawi, 2009; Meir, 2018). Caring for and herding sheep is generally a task reserved for women and children. From an early age, Bedouin children are expected to make an active contribution to their household, gradually taking on various age-appropriate tasks designed to help support their family. This means that, even today, Bedouin children have much more direct, daily contact with their natural environment than urban children do (Ben-Zvi Assaraf et al., 2012; Sedawi et al., 2020). In addition to helping with the livestock on their family farms, they spend a great deal of time outdoors, herding sheep and playing in nearby fields.

Bedouin children in the Negev also far more directly are impacted by adverse environmental conditions than urban children tend to be. Many of them walk several kilometres to get to school, crossing streams that can become impassably blocked by flooding on rainy days. Since much of their home environment is unpaved, rain can turn their immediate surroundings into an inconvenient, muddy quagmire. At the other extreme, life in the desert exposes these children to the dangers associated with extreme heat and dry weather, such as heat stroke and dehydration, as well as water-born infections due to the lack of proper plumbing and local hazards like scorpions and toxic plants (Elsana et al., 2014).

19.5 How Do Bedouin Children Understand and Experience Their Environment? Developing Research Tools in the 'Third Space'

To design a place-based education program accessible and relevant to this particular group of children, we first needed to learn more about these children's lives, particularly about their relationship with their immediate environment. Most of the tools developed for describing and assessing children's relationship with nature were designed for relatively affluent European or American children (see, for example, Cheng & Monroe, 2012; Liefländer et al., 2013; Thompson et al., 2008), but, as we noted above, the lives of Bedouin children are markedly different from those of children growing up in urbanized, Western environments. As various critics, including Duhn (2017), pointed out, researchers of children's relationship with nature must beware of a "tendency for universalizing childhood," since "how a child engages with spaces … differs enormously" according to the "environments where one's childhood is located" (p. 1365). These potentially extreme differences in the experiences of children from different cultures in different places raise the very real possibility that tools, and studies developed for children in one place will be based on assumptions about these children's everyday lives that are wholly inapplicable to the lives of other children. Our first task was therefore to create an information-gathering tool that accurately would reflect the lives of our target population.

Despite their potential limitations, we concluded that standard tools for measuring relationships with nature could be a useful starting point from which to begin to construct our research tool. To use such tools productively, however, we needed to ask ourselves: How can we make the students' experience 'communicate' productively with the theoretical concepts defined in the literature? To facilitate this 'communication,' we drew upon Homi Bhabha's (1994) notion of the third space, which serves as a theoretical framework for researchers interested in understanding and (re)negotiating the relationships between Western perceptions and the culture of individual, non-Western communities. The theory seeks to explain and address the tensions and conflicts that can arise when several different cultural identities come into contact. It has been applied in a wide variety of disciplines, including architecture, ethnology, cultural studies, linguistics, and education (Cook, 2005), including specific applications in research into science and environmental education (for example, Lowan, 2012; Wallace, 2004). As Glosson et al. explain:

> The local indigenous culture provides meaning and identity to community members in the first space, while Western ideas (e.g., Eurocentric science) provide a second space for learning in schools, often in European languages. However, students and community members must function in a third space to negotiate meanings and understandings for the intersections of knowledge, practices, and languages from merging cultures. (2010, p. 128)

This process of negotiation generates change, creating hybrid interpretations of science and the environment. The third space generates a shared foundation between indigenous and Western perspectives, a place in which to engage in dialog, where "multiple discourses may be woven together without sacrificing or dismissing the importance of their speakers' experiences and ways of knowing the world" (Wallace, 2004, p. 908).

In what follows, we present the seven-stage process through which we developed our questionnaire, adapting it to the culture of the Bedouin students who live in the Negev's unrecognized settlements (see also Sedawi et al., 2021). We suggest that this development process can itself be perceived as a third space—a site for continuous dialog between the framework of the Western assessment tools and the specific experience of the Bedouins. In that space, we literally *negotiated* with a group of students from our target population over the form and content of the questionnaire until we produced a version comprehensible to the students and reflective of their experience.

19.5.1 Stage 1—Creating a Bank of Statements

We gathered the statements from the first version of the questionnaire from two sources. We drew most from a variety of existing tools for measuring ‘connectedness to nature’, most prominently Cheng and Monroe’s (2012) CNI (connection to nature index), adapted specifically for children. However, we also conducted semi-structured interviews with ten Bedouin students in order to gather information about their experiences and perceptions of the nearby natural environment. The interviews included questions like, “Tell me, what natural places near you do you like?”, “What places do you not like and why?”, “What animals do you raise/like?”, “How do you feel when you are in the natural environment near you?”, and “What bothers you when you are in the natural environment?” Based on the students’ responses, we created new statements that used simple, local language and drew upon the students’ own experiences. Stage 1 produced a preliminary bank of 46 statements, written in Modern Standard Arabic and divided according to the four categories of nature connectedness suggested by Cheng and Monroe (2012), namely, enjoyment of nature, empathy for living creatures, sense of oneness, and sense of responsibility. To these, we added an additional category, ‘experience of nature in my immediate environment,’ with statements drawn from the Bedouin students’ interviews.

19.5.2 Stage 2—Preliminary Testing of the Students’ Understanding of the Statements

To test the statements gathered in Stage 1, we conducted interviews with 12 groups of students from two separate villages. Each group consisted of four randomly chosen students who participated in two consecutive group interviews, each of which covered 23 of the 46 statements. During these interviews, we read aloud the statements in the questionnaire, one by one. For each statement, we asked the students to note if it was clear, what, if anything, they did not understand about it, whether they agreed or disagreed with it, and why.

These group interviews revealed several obstacles. For example, many students had difficulty understanding some of the more abstract or general statements like, “My actions will change the natural world”, or, “I like to hear the different sounds in nature.” They asked, “What are sounds in nature?”, and “What sounds do you mean?” Other statements, such as, “I enjoy gathering rocks and shells,” were either irrelevant to the students’ lives, or incompatible with their experiences. Though we removed the reference to shells from the statement (there are no shells in the desert), the students viewed gathering rocks as a dangerous activity that could be harmful to others (“the rock might hit someone and hurt him”). Another example of a statement that our students found irrelevant was, “I would always prefer spending time with my friends to spending time alone in nature.” This is a reverse statement we designed to test respondents’ sense of identification with nature. However, the students' responses indicated they play with their friends outdoors, *in nature*, that their nearby natural environment is where they play, and that spending time with their friends is therefore inseparable from spending time in nature. Thirdly, the preliminary test revealed a linguistic obstacle, since the everyday Arabic spoken by the students is very different from written Arabic, and this made it difficult for the students to read and understand the translated statements. Finally, we designed the original questionnaire to be marked on a Likert scale, with answers rated between 1 and 5. The students never had used such a scale; they had difficulty rating the extent of their agreement between "not at all" and "very much," and particularly were confused and frustrated by the "not sure" option.

19.5.3 Stage 3—Consultation with Experts

Following the preliminary testing of the original questionnaire, we consulted a variety of experts, asking for their feedback on the questionnaire and on the students' responses to the initial testing. These experts were of two types: (a) experts in environmental education and science education, (b) educational and environmental professionals who work in daily contact with the Negev Bedouins. The experts in the latter group were particularly helpful in improving our understanding of the social and cultural characteristics that may have shaped the Bedouin students' perceptions of the questionnaire. We met with each expert separately, describing our preliminary testing experience and the challenges we had encountered. The experts commented on our findings and expressed their opinions regarding the reasons underlying the students' response to the various statements. We also asked specific questions, such as, "Tell me about the lives of children in the Bedouin community; how does a day in the life of these children look at school, in the village, and at home?", "How are beliefs, values, and norms reflected in these children's education, especially their environmental education?", and "What sort of difficulties or challenges have you come across in your work with children from the Bedouin community?".

The interviewees raised a variety of issues in response to our data and our questions. The environmental education supervisor, for example, raised the issue of the Bedouin students' relationship with nature. For example, she noted the statement "My actions will change the natural world" is problematic, because Bedouin children see themselves as part of nature and are therefore unclear about what it means to "change nature." She also addressed the practical impact of the environmental conflicts the Bedouin community faces and their lack of resources. She explained that "environmental education in the Bedouin community is peripheral … the students live in a polluted environment … that lacks waste disposal and infrastructure, which makes it difficult for them to apply the things they learn in the educational activities in their homes." The circumstances in which they live, she pointed out, make it difficult for these children to be agents of change and engage in environmental activism. She therefore recommended that all statements referencing environmental behaviour be rephrased as 'willingness' to act and protect the environment, rather than as a statement of the act itself. Thus, for instance, a statement like, "I protect the nature around me", would be replaced by, "I am willing to protect the nature around me."

The two Bedouin teachers addressed the students' experiences in their immediate environment, as well as their relationship with that environment and their language. For example, they emphasized the importance of the local Bedouin dialect and the concepts the students used in their daily lives, which differ significantly from concepts in the literary Arabic of the questionnaire. This gap, they pointed out, made it difficult for the students to understand the statements. They therefore suggested adding words from the local spoken language to the questionnaire (for example, using the local word for "pasture" instead of the literary one, and incorporating a local term that refers specifically to "hills surrounding the olive trees").

19.5.4 Stage 4—Revision of Statements Based on the Results of Stages 2 and 3

The student interviews and the expert feedback led to significant amendments to the questionnaire. Many statements we substantially altered or removed completely and replaced with new statements. Furthermore, in light of the students' frustration with the Likert scale, we reduced the number of options to two (agree/disagree). After we finalized the statements, we also gave each a visual illustration that reflects its content. We designed this to help overcome language barriers and increase the students' interest and motivation.

19.5.5 Stage 5—Testing the Revised Questionnaire

When we completed the revised questionnaire, we tested the new version using the same method we had employed in Stage 2, with the same groups of students. This round of testing revealed that some of the illustrations did not fit the statements to which we assigned them, or were not representative of the children's culture, so the questionnaire underwent another round of development.

19.5.6 Stage 6—Readjustment of Illustrations and Statements

After testing the original illustrations, we made adjustments to make sure each illustration represented the content of the statement. We also made sure to provide illustrations of both boys and girls, wearing colours and clothing appropriate to the students' culture. We designed the illustrations to be relevant to the students' everyday lives (representing only activities and objects the students would recognize and identify with).

19.5.7 Stage 7—Adding a Formal 'Explanations' Section to the Questionnaire

The experts had suggested the questionnaire should provide flexibility for each respondent to express their own personal perceptions and experience. The students already had been doing this informally during the first two testing stages, and this input had provided a great deal of additional information. We therefore decided to add a new section to the questionnaire, in which we invited the students to provide open-ended explanations for their responses to specific statements (to say, in their own words, *why* they agreed or disagreed with them). The students' explanations ultimately provided a great deal of qualitative data about their relationship with nature, revealing critical nuances that would have been undetectable by their answers to the closed questions alone.

The final form of the questionnaire allowed us to conduct an in-depth exploration of how the particular cultural, social, and environmental factors that shape the lives of children in the unrecognized Bedouin villages of the Negev impact their relationship with their natural environment (see also Sedawi et al., 2020). Our findings showed the Bedouin students have ambivalent and complicated feelings about their connection to nature. Their responses suggested their awareness of their environment's contamination leads them to avoid contact with natural spaces and fosters a sense of helplessness based on the idea that they lack the ability to take responsibility for their environment. The results also revealed a wide range of specific factors that influence students' relationship with their environment. Some rooted in their experience of living in a highly rural home environment, which influenced their perspective on things like playing in nature ("… it's fun to slide down the dunes, I bring a piece of plastic, sit on it and slide,"), safety concerns ("… the water in the stream is dirty and causes sickness."), weather conditions ("… in the winter there's mud, I can't go to school with mud…."), and instrumental views of nature ("I hunt pigeons and raise them. When the eggs hatch, chicks come out and I sell them."). Others were rooted in socio-cultural factors, like religious beliefs ("I like to see nature clean, because the prophet said, cleanliness comes from faith."), traditionally distinctive gender roles ("I don't like herding goats because that's boys' work."), and tribal territory and affiliation ("I'm willing to clean only in our people's space; everyone should clean in their own people's area."). All of this extensive data ultimately informed the choices that went into the design of a place-based education program specifically tailored for the Bedouin students living in this area – the Hebron Stream Study Unit.

19.6 The Hebron Stream Study Unit: An Authentic Place-Based Program Relevant to the Environmental, Social, and Cultural Issues That Concern These Students' Relationship With Their Place

The Hebron Stream Study Unit spanned 36 h of teaching per year, over three years. Its purpose was to help the students develop an in-depth understanding of authentic environmental phenomena in their surroundings, while encouraging a deeper sense of place. Importantly, the education program was part of a larger regional project that also included the rehabilitation of the heavily polluted Hebron Stream on the banks of which this Bedouin community lives, and the introduction of a new waste disposal program, including the establishment of waste treatment systems in the Bedouin community. We incorporated into the program explicit observations of and discussions about these changes to the students' environment, engaging the students in reflection about how such developments were—or were not—changing their relationship with their environment.

The program took place during school hours and consisted of a combination of indoor and outdoor learning. We built it around four field trips per year—some in the students' village environment, some around Hebron Stream, and some at other streams located on nature reserves with healthy ecological systems. Each trip was preceded by two hours of preparation, in which students discussed their experiences and emotions regarding the village and the stream, received introduction to basic concepts (stream, tributary, creek, etc.), played card games such as 'gifts from the stream,' watched film clips about the impact of waste on water pollution and on animal life, and more. We followed each preparation with two hours of in-class knowledge integration activities. In these, the students reported the results of their observations from the field trip, defined socio-environmental problems they observed while on the field trip, conducted comparisons between a 'healthy stream' and a 'sick stream,' examined photos they took on the field trip, and arranged these photos according to the interaction between the stream and the vegetation, animals, people, etc. At the end of each school year, the students participated in a series of additional 'summarizing and looking ahead' activities. These included constructing a model that described the students' vision of a future stream, learning about various solutions for managing and preserving water resources, and multiple activities we designed to encourage the students to take responsibility and develop their sense of competence as agents of change.

This 'negotiation' that had begun in the questionnaire development process continued throughout the program's implementation, defining the program's contents as well as our analysis of its influence. Table 19.1 presents a sample of the program's activities. It shows how each topic drew upon components from the 'first space' (eliciting knowledge from the students' own experiences in their local environment) and upon components from the 'second space' (familiarizing the students with elements drawn from Western science and culture). Finally, it shows how the program created a third, transformative space, in which the students could harness, examine, and combine ideas and experiences from multiple sources of knowledge.

In its third year, the program expanded to include intergenerational encounters, in which adults from the students' community shared stories about their community's rapidly vanishing traditional past, including traditional Bedouin strategies for sustainable living. Through discussions with their elders, the students learned about the socio-environmental history of their place, gathering information about local plants and animals, and learning stories from members of their community that emphasize their traditional lifestyle and Bedouin society's historical reliance on nature.

Students also learned about traditional Bedouin practices during a tour of the Wadi Attir Project (http://www.sustainabilitylabs.org/wadiattir/), which demonstrated an approach to sustainable desert agriculture that combines traditional Bedouin values, know-how, and experience with modern-day science and cutting-edge technologies. Following the tour were in-class knowledge integration activities, in which the students reported the results of their observations from the field trip and compared the ecological footprint of traditional Bedouin society to that of Bedouin society today. At the program's conclusion, the students, accompanied by their mothers, prepared a presentation, and conducted an information tour in the students' school, introducing students in other grades to the importance of their village's social and natural environment through an intergenerational perspective. This activity is multigenerational, and the mothers' involvement contributed to increasing the students' engagement in the process.

19.6.1 Before and After—Assessing the Program's Influence

Our analysis of data from multiple sources throughout the three-year implementation of the place-based education program showed it influenced the students' sense of place in a variety of important ways (see also Sedawi et al., 2019). Like the development of the initial research tool and the implementation of the program itself, our analysis of its impact also emphasized the importance of allowing the students to express their perceptions, experiences, and opinions in their own voices. To this end, in addition to observing the students throughout the program, we also employed two additional research tools: drawings and semi-structured, in-depth interviews.

Drawings are a well-established methodology for examining how students make sense of a given space and identifying meanings in students' lifeworlds, not least because they allow students the freedom to express their knowledge without limitations of language (Alerby, 2000; Avriel-Avni et al., 2010). In this study, we deployed the drawings in two stages—before and after the completion of the intervention program. We asked the students to make two drawings at each stage, describing (a) *my village* and (b) *the stream in my environment.*

After the students completed their drawings (both before and after the study unit), we conducted semi-structured interviews with them to gather additional information the drawings did not provide. The pre-interview described how the students

Table 19.1 First-, second-. and third-space activities in the intervention program

Experience of indigenous knowledge and my local environment	Experience of Western knowledge and perspectives	Third space: ways of knowing are negotiated and shared
The stream as an ecosystem		
• Developing sense of place by identifying and expressing personal feelings toward the village and stream environment (via drawings, games) • Observations to get to know the immediate environment and develop an understanding of human–environment interactions • Introduction to local animal species, going to the stream with guides to identify the animals in relation to their desert environment	• Introduction to traits of stream in general, how created, its parts, and the qualities of desert streams specifically • Introduction to natural water sources and their characteristics; what is a healthy stream within a functioning ecosystem • Observations to characterize the stream in a nature reserve, as a resource and a habitat: gathering data and observation of its hydrological components and its function as a habitat. Affective experiences during visits to healthy streams on a nature reserve	• Creating an 'ID card' for Hebron Stream using information drawn from both personal familiarity with their home environment and new knowledge about the stream as part of the ecosystem • Reflective comparison between Hebron Stream and a healthy stream • Reporting results of inquiry, with emphasis on defining socio-environmental problems present in the field. Discussing local socio-environmental dilemmas in the context of the stream as a water resource and habitat
Waste treatment in my village		
• Introduction to components present in our waste, connection between our consumption practices and the waste we produce • Inquiry activity: the waste situation at home, at school, our consumption habits and the waste we generate • Local methods of waste treatment in my unrecognized village (burning and throwing into stream) and their negative effects	• Introduction to types of waste sources and generators. Information re quantities • Learning the route taken by waste, from collection bins to the landfill • Introduction to the environmental impact of waste, with emphasis on harm to open spaces • Introduction to the concept of combined waste management, and to solutions like 'reduce, reuse, recycle'	• Environmental social dilemmas in the context of waste treatment in my village and compared to other places • The implications of introducing Western waste management practices into my environment. How have the open spaces in my environment been impacted by waste?
Connection between waste, the stream and challenges related to biodiversity		
• Describing the relationships they have seen between local plants and animals and the waste in my environment • Identifying and characterizing animals (especially birds) drawn to the waste around the stream • Working in groups, telling stories of animals harmed in the village environment, particularly by waste	• Introduction to problems caused by waste, with emphasis on water pollution and its impact on humans and animals (emphasis on birds and butterflies) • Meeting with experts on monitoring birds and butterflies, experiencing research practices like ringing and observation through telescopes, and reporting the results • The importance of birds and butterflies to the ecosystem	• Reflecting on environmental social dilemmas in the context of animals harmed by exposure to waste and pollutants, drawing upon personal experience and new knowledge about the importance of biodiversity
• On-site observation of die stream reclamation process • Drawing pictures representing their vision for the future of the stream and its integration into the fabric of the village	• Introduction to combined solutions for edamation of water habitats; introduction to water treatment • Observing and describing the rehabilitated portion of the stream, noting changes to the stream, as well as nearby animals, plants and human activity	• A critical perspective on the rehabilitation process: practical limitations of the rehabilitation so far • Raising and discussing dilemmas regarding the future of the stream as a natural place versus an artificial environment

experience the Hebron Stream area, how they perceive the stream itself, the practices involved in their experiences of the area, and the perceptions and intentions that underlie these practices (for example, "What places in your village do you like/dislike? What changes would you make to it?", "Describe the stream to me. What do you feel towards it?"). The post-interview conducted two years later, we designed as a reflective activity in which the students addressed any changes their perceptions had undergone following the study unit, focusing on how they now perceived the stream and the importance of changing its condition. We presented each student with the pre- and post-pictures they had drawn and we asked: "What are the differences between the two pictures you drew?", "What changes have occurred in the village/stream?", "What do you think about these changes?", and "How do you feel about the stream/village?".

We conducted additional semi-structured interviews with students and their mothers following the intergenerational activities in the third year. The students' interviews included questions as, "What do you think of your meeting with people from the tribe?, What things were new/interesting to you?, and "What did you feel during the presentation in the classroom?, Was it important for you to present?, Why?". The mothers' interviews consisted of questions like, "How did you feel when you saw your son present?", "What do you think about the program in which your son participated?", and "Do you feel there have been changes in your son's attitudes and behaviour?".

A comparison of the pre- and post-results showed that after the intervention, Hebron Stream became a much more positive part of the students' sense of place than it had been before. In their pre-interviews, 92% of the students described the stream as an ugly place filled with waste that spoils the landscape, noting details like, "there's garbage in the streambed, an old mattress, cans, old diapers, dead animals, bottles, bags." Far from seeing it as part of their home, some students expressed the wish that it would disappear altogether, saying, "I want them to cover up this stream. It's not important at all. I say they can block it up and it would be better." Furthermore, 67% of the students dismissed the stream's importance as a natural resource and even described it as harmful to the environment, making statements like, "the stream has no value. It's just garbage," or noting more specific problems like, "animals drinking from [the stream], eating bags … and dying, and then [people] throwing them in the stream."

After the program, many of the students drew a cleaner, more aesthetically pleasing stream, and about a third drew a stream as a 'healthy' ecological system. The students' explanations of their drawings showed a rise in their awareness of the stream's importance as a natural resource. For example, one student explained:

> The stream is very important. It collects rainwater and runs it to a different stream or the sea. Without the stream there would be floods. Animals drink out of it and there are plants to which it gives water. And there are plants in the water that the turtle and the ducks eat. Around the stream there are plants that I didn't know before, like saltbush, cattail, soft rush, thorn tree. I also got to know the eagle and the hyrax and the ibex … All these animals near the stream … it is very important.

Descriptions like this one reflect the impact of the program's incorporation of field trips to other, healthier streams. These field trips included exercises in scientific observation, in which the students identified different types of plants on the banks of the stream and conducted observations to identify animals and note signs of their presence (for example, tracks, droppings). The plants and animals students encountered in these observations not only featured in descriptions like the one cited above, but also in about a third of the students' post-drawings (see Fig. 19.2). The drawings and interviews describe the stream as a nice, clean, aesthetically pleasing place, full of the plants and animals they observed on their field trips to the nature reserves. One student explained, "the stream is prettier when it's clean … we'll look at the birds and the flowers around it." This student's remark reflects those of others in that it does not strictly describe the stream as it *is*, but rather looks ahead to how it *could* be.

Another element of the program that opened the students' eyes to the possibility that their own environment could be different was the intergenerational activities with

The student explained:

"I drew Habesor steam, where there are ducks and turtles. In our wadi (stream) there are no turtles. We went to the Habesor Wadi and I had a great trip. Before the project I thought all the streams were dirty, every time I think of a stream I am reminded of waste. Today I think there are dirty streams and there are clean streams. I feel that our wadi will be clean, and will not be dirty and will not cause disease. I imagine that it is clean and the people do not throw rubbish in it away or burn. If it was clean I would love it, because animals would come and eat from it and drink from it..."

Fig. 19.2 A student's post-intervention drawing and explanation adults from their own village. Like the visits to the healthy streams, the intergenerational discourse provided the students with a *comparative view* of their physical environment. In this case, however, the comparison was of their own environment at two different points in time—past versus present.

The adults pointed out that in the past the place was clean and healthy, while now it is damaged and polluted. As a result, the students' interviews emphasized the changes to the local environment, describing the stream and the wealth of flora and fauna that used to live around it but no longer do. For example, "When the stream wasn't dirty like today, it was clean and you could drink from it. Animals came there, like the desert fox, wolves, turtles, starlings. All these animals disappeared because people polluted the stream and they stopped coming." The discussions with their elders also introduced the students to indigenous knowledge from their own culture. Their knowledge included a range of scientifically valuable environmental practices Bedouin society developed as traditions, based on an in-depth everyday experience with the natural environment in which the Bedouins live. One student described, for instance, "… they would put a piece of fabric to strain the [rain]water, and the clean water went down into the well, they dug the well in a low place and directed the water through a ditch like a track so the water would go into the well." Like the visits to the nature reserves, these experiences encouraged the students to imagine the possibility that Hebron Stream could be a positive part of their sense of place:

> I imagined the stream in the past, imagined that it was clean and there were tents near it, and no-one dumped trash there at all … there were also plants near the stream like germander and mayweed … I hope these plants come back because they are medicines for people. They took everything from nature, there was no market or factories, and that's good for the environment and doesn't harm it.

One important component that arose from both the pre- and post-sets of student interviews is their awareness of the relationship between the stream, the community, and the political-economic situation. Because the village had no access to organized waste disposal, for example, residents habitually resorted either to burning their garbage or to throwing it in the stream, actions that became accepted norms in the village. A substantial number of the students' pre-interviews (45%) reflect their awareness of this, in statements like, "Where would they put the garbage, near the house?! Where can they go with the garbage, that's why they dump it in the stream." We also noted this practical constraint in the post-interviews, with some students noting, "We still burn; we don't have a bin. We asked but they didn't bring one. It's not good to burn, it pollutes the air, but where should we put the garbage?".

As this quotation illustrates, the students' post-interviews included explicit reflection on flaws in the progress of the regularization process (for example, delays in providing families with bins, or in emptying those provided, disappointment that, though the banks were cleaner, the water in the stream was still not fit to drink). However, the interviews also expressed a newfound optimism regarding the improvement in the stream's conditions that contrasted sharply with their earlier fatalistic attitudes. In the pre-program interviews, many of the students (59%) expressed feelings of anger and hopelessness towards the stream, making negative predictions about its future. For example, "The stream won't change. If now no-one does anything … in the future, they will?! It will be even more dirty… people multiply, and they'll dump more garbage." In contrast, nearly all of their post-program interviews (96%) expressed greater optimism and the hope the situation will improve. For example:

> In the past I thought the stream was dirty because people threw garbage in it. And today there isn't a lot of garbage in the stream. I thought the stream would not change and would get worse. Today I think it will improve and people won't dump garbage in it.

Importantly, the program also encouraged the students to think reflectively about their own behaviour and that of their community. Learning about the significance of the stream as an ecosystem and about the environmental impact of their current waste management practices prompted the students to look more critically at behaviours they previously took for granted. One student said, for instance, "It was normal for me that we dump garbage in the stream… From the project I understood that the stream is important and if it's dirty that harms us… we have to protect the stream." Another said, "I didn't think of it before, we need to look after the stream, and not burn. They will bring us trash bins. I didn't think that we were polluting the environment." The intergenerational conversations also encouraged such reflective thinking by emphasizing the relationship between the community's behaviour and the changes that have occurred in their environment. As one student explained:

> Today they open the pipe for the whole day and waste a lot of water. They used to take one bucket, not waste the water. From the animal droppings, they lit the fire, took advantage of the droppings and did not leave them. It's good that they used the droppings, they didn't cut down trees to light the fire.

As another student noted, "The stream helped us, we drank from it, and we need to protect it because we need it… It does us good, and if we keep polluting it, we won't be able to drink from it."

One goal of the intervention was to develop the students' sense that they were capable of creating change in their own community, and the program incorporated several activities that addressed ways of expanding the circle of people involved in the protection of the stream. However, while 35% of the students' interviews after the first two years reflected their *desire* to take action, references to taking *actual* action to change the behaviour of others were notably absent. The interviews did, however, include several references to the difficulty of taking such action. One student said, "I learned that if my friend litters I should tell her not to. We were in the field and I told her not to litter and she laughed at me and said, 'there's lots of garbage here'." Another told us she anticipated a similar reaction if she tried to talk to others about their behaviour, claiming that, "when we tell our cousins and our neighbours [not to litter] they will laugh at us."

In response to these results, the third year of the program introduced structured activities designed to help the students take action to promote environmental behaviour in their community. The interviews we conducted after the intergenerational information tour at the students' school reflected its contribution to the students' sense of empowerment and self-efficacy. The students reported feeling their fellow students respected them and feeling proud of their participation in the project—not just as learners, but as *active participants*. The students felt more confident about taking part in social interactions that promote environmental issues, and influential in passing on messages and encouraging other children to engage in environmental activity. As one student said, "I felt that they really understood me and did what I asked. I felt happy, because I was explaining to them and that could bring an end to the pollution that's in the stream, because I'm influencing them, and they'll tell their parents." The mothers also raised this change in their interviews about the program's influence. One mother expressed the opinion that the program "builds character," adding that "regular learning doesn't teach and build character." Another mother said, "my son is more social after the project. I didn't expect it. I was surprised… The project increased the child's self-confidence."

19.7 Discussion

All over the world, indigenous societies are living in close contact with Western society, and often in a state of 'transition' due to its influence. Our study highlights the importance of developing tools that examine these communities' relationships with the places where they live, and of designing programs that take the complexities of these relationships into account, thereby addressing each community's particular social, cultural, and environmental needs. In this chapter, we demonstrated how to leverage productively the combination of place-based education and third-space theory in various ways to manage the problems—and take advantage of the opportunities—inherent in working with students from indigenous backgrounds.

The diversity and specificity of the students' experiences of their 'place' required us to gather a great deal of specific information to design an appropriate place-based education program. The third space thus became a critical site in which to 'negotiate' the form and content of the tool with which we learned about these students' particular ways of life. Based on this detailed information, we created a program we specifically tailored to the lives of these students and to the particular environmental challenges they face. We found after the program the students were more likely to view their local stream as part of their village. They were also more aware of the stream's importance as a natural resource and of the relationship between the stream, the community, and the political-economic situation.

Place-based education is built upon the idea of forging connections between learners and the places in which they live by giving learners opportunities to have experiences in their local environments (Herman et al., 2020; Sobel, 2004). However, the environment in which these students live is highly contaminated, which severely limited the types of positive learning experiences it could provide. We therefore incorporated additional experiences through visits to healthy natural environments, which served as 'surrogates' for Hebron Stream—alternative places where students could experience environments similar to what their own environment could be.

According to Avriel-Avni et al. (2010), learning about a place means changing a learner's point of view of that place or offering them a new way of experiencing it by, for instance, separating an object from its habitual context and relating it to other contexts. Thus, in this study, we recontextualised Hebron Stream for the students through personal experiences with other, healthy streams. Another, similar form of recontextualisation for the students was their intergenerational encounters with older members of their tribe. Engagement with the community is an important concern of place-based environmental education, since it can help students achieve "understanding through multidisciplinary, experiential, and intergenerational learning that is not only relevant but potentially contributes to the well-being of community life" (Gruenewald, 2008, p. 7). Their dialogue with adults taught the students about the history of their place and elicited comparisons between the state of the stream (and the behavior of its inhabitants) in the past versus the present. This newfound familiarity with the history of their environment and with parallel natural environments seems to have changed the ways the students experienced their current environment, opening their eyes to possibilities they had not entertained before.

The incorporation of both ecological observation field trips to nature reserves *and* intergenerational conversations with local elders indicates the general strategy that defined the program. As we showed in Fig. 19.2, we designed the program to draw upon both Western and indigenous 'funds of knowledge', and then provide a third, 'hybrid space' where "everyday resources are integrated with disciplinary learning to construct new texts and new [scientific] literacy practices that merge the different aspects of knowledge and ways of knowing offered in a variety of spaces" (Moje et al., 2004, p. 44). This meant incorporating (a) activities that elicit knowledge based on the students' own experiences and those of their community, (b) activities that provide access to Western knowledge and experiences, and (c) activities that employ both sources as a foundation for reflection and dialog.

In our program, this dialog focused on three principal goals. First, processing and filtering all the information, experiences, and insights we collected throughout the program. One such processing activity was creating an 'ID card' for Hebron Stream using information drawn from personal familiarity with the students' home environment, knowledge gained from intergenerational encounters about their community's use of the stream in the past, and scientific concepts about the stream as part of the ecosystem based on conducting scientific observations. During this processing, the students employed a combination of scientific terms for the stream as a healthy system and their own community's terminology for local phenomena using their own local dialect.

The second goal was to engage in dialog about dilemmas or areas of discomfort illuminated by the combination of students' personal experience and the knowledge they were gaining in the program. For example, the students discussed environmental social dilemmas in the context of animals they had seen harmed by exposure to waste and pollutants, informed by new knowledge about the importance of biodiversity. In discussing possibilities for the future of the stream, the students engaged in a prolonged discussion of the relative benefits of maintaining it as a natural place versus a more 'artificial' environment.

The third goal was to engage the students in critical reflection, encouraging them to re-examine their underlying assumptions regarding various aspects of their current relationship with their place. This means, for example, recognizing the connection between consumption practices and waste management practices, and the implications of the waste management methods their village currently employed. The students also engaged in critical reflection on the rehabilitation process, addressing the practical limitations of the rehabilitation so far.

In conclusion, our study reveals the conceptual benefits of employing both place-based education and third-space theory as ways of understanding how people, in this case young Bedouin students, relate to their local environments. It also shows how using an approach that drew on place-based education and third-space theory led both to the development of a culturally sensitive research instrument and to an educational program that helped these young Bedouin students gain a greater sense of ownership over their environment and a more optimistic vision of its future.

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Chapter 20
Application of Variation Theory to Zoo Education: Case Study of Immersive Habitat Classrooms

Christine Preston

20.1 Introduction

In this chapter, I describe the potential of variation theory to inform the science teaching practices in locations other than schools. Out-of-school is a collective term for a research agenda describing various activities engaging learners in experiences that occur outside of formal educational environments (Rennie, 2014; Rennie et al., 2003). Just as the professional knowledge and work of schoolteachers is vital to the quality of student learning in schools, so is that of educators in out-of-school settings (Tran & King, 2011). They play an important role in providing holistic and motivating experiences for learning science (Braund & Reiss, 2006). Zoos, for example, actively involve hundreds of millions of visitors annually in education, combining direct science instruction with active engagement and self-motivated learning (Dwolatzky et al., 2021; Wagoner & Jensen, 2010). What is missing is research that provides evidence of quality educational practice and impact on learning (Jensen, 2014). Compared with school-focused research, the out-of-school sector lacks rigorous research into professional teaching practice, in part due to the "limited research and theory on learning and teaching in informal science environments" (Tran & King, 2011, p. 283). A research framework is needed to support out-of-school educators to evaluate the impact of their teaching on science learning and provide them with a tool for self-improvement of lesson design.

The informal education sector is broad and supports science education in a variety of ways. To demonstrate application of variation theory, I focus on the provision of science lessons in out-of-school settings that support students' learning of mandated state school science curriculum. I use the example of teaching in a Zoo where educators deliver formal, one-off lessons during school excursions. In Australia,

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Environmental and Zoo Education Centres distributed across NSW (and Queensland) provide education programs for school groups. The educators are qualified teachers either in direct employ or on loan from school jurisdictions. The zoo context presents a different situation to many out-of-school settings where the teaching is docent-directed and less learner-centred and where the educators follow a knowledge-transmission model (Tran & King, 2011). The example illustrates the potential of variation theory for use in Zoo education specifically, and out-of-school contexts, generally. I restrict the study description to focus on how variation theory was used to view the learning experience from different perspectives. The chapter provides a synopsis of the central tenets of variation theory, the elements of which have been described in a variety of ways by different authors (for example, Akerlind, 2015; Bjorkholm, 2014; Carlgren et al., 2015; Fredholm et al., 2020; Marton & Pang, 2013; Runesson, 2006; Voon et al., 2020).

For educators delivering one-off lessons for schools, the challenge is supporting students' meaning making when they neither know them nor are privy to their prior learning experiences. Examining educators' knowledge and practice provides a means of understanding and improving student learning in out-of-school settings. We need a robust theory to guide such examination and case studies in different out-of-school settings. This chapter argues that variation theory has the potential to bring the educators' intentions and chosen teaching methods closer together whilst strengthening their thinking (Voon et al., 2020) about the efficacy of their practice. Variation theory holds that discriminating the critical aspects of a phenomenon dictates learning. Applying this theory in a classroom "makes it possible to understand how different experiences can be converted into a common understanding of a learning object" (Holmquist & Mattison, 2008, p. 31). As students come to lessons with unique learning paths, that which draws their attention in the teaching situation, impacts what they can learn.

20.1.1 Variation Theory

Variation Theory of Learning (Marton, 2014; Marton & Tsui, 2004) is a pedagogical perspective on learning made popular in Sweden and Hong Kong for its value in school curriculum design. The theory focuses on the relationship between learning and the circumstances that make learning possible (Pang & Marton, 2013). Learning is "a process of discerning new aspects of learning objects in new ways" (Carlgren et al., 2015, p. 148). The variation theory of learning comes from Ference Marton (see Marton, 2014; Marton & Booth, 1997) and pinpoints variation as a crucial teaching element for learners to notice that which is to be learnt. The theory is not touted as a 'fool-proof' recipe for learning, as success is dependent on the relationship between what the teacher makes *possible* to learn and what *use* of the possibilities is made by the student (Xu, 2019). A perfect lesson could make all ideas available to learn, but students still fail to learn because they do not focus attention on the critical aspects. According to variation theory learning depends on:

- what students *attend* to in a lesson,
- their *ideas*, interests, and state of being,
- how the former *interacts* with the latter.

If the learner does not detect the vital elements, they cannot discern what is to be learned. In terms of conceptual understanding, the learner must direct attention to the key ideas needed to comprehend the concept. The learner must make sense of these elements which also need reconciliation with previous ideas. It is insufficient for teachers to simply convey ideas to students. The teacher must present the fundamental notion(s) in a way that emboldens the learner to act on the new information and make personal sense of it. Ideally, the meaning made by the learner should align with what the teacher intended.

Kullberg et al. (2017) elucidate, "the analysis of *what is made possible to learn* also sheds light on what is *not made possible* to learn" (p. 566). Identification of what is lacking in a lesson can provide the impetus for improvement. This chapter concerns the potential of variation theory as a tool for teachers to scrutinise, reflect on, and develop ways to improve the *potential* effectiveness of out-of-school lessons of curriculum-specific content. The next section describes variation theory including a short history of its development from its roots in phenomenography (see Marton & Booth, 1997).

20.1.2 History and Development of Variation Theory

Variation theory developed from empirical studies in phenomenography from Göetborg in Sweden during the 1970s. The phenomenographic research tradition involves how we perceive, understand, or experience an object, phenomenon, or interaction in our world. Phenomenographic research is about descriptions of *something*, a phenomenon. Two perspectives can be taken: the first-order concerns understanding the something itself, for example, sound; and the second order focuses on someone's sense making of that something, for example, children's experience of sound. Marton and Booth (1997) developed a phenomenographic theory of learning and awareness. Phenomenography is a research approach that aims to describe the different ways a group of people come to understand a phenomenon (Marton, 1981). This is distinct from phenomenology which seeks to clarify the form and meaning of the phenomenon itself (Giorgi, 1999). Phenomenographic studies lead to a categorisation of different ways of experiencing a particular phenomenon. Marton (2000) defines experience as, "a relationship between object and subject" (p. 105). Interest in the different ways of experiencing a particular phenomenon developed into variation theory which relates to understanding the *difference* between ways of experiencing the same phenomenon (Pang, 2003). Variation theory extends phenomenography to encase learning as experiencing something in more complex ways.

The development of variation theory relates to an understanding of awareness (Xu, 2019). Experience relies on differentiating something and relating it to a current

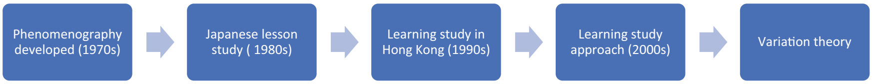


Fig. 20.1 History of variation theory

context along with noticing the part-whole relationships. This involves the interplay of features at the front or edges of our consciousness, which determines an individual's awareness. The features to which a student gives notice and attention at the same time (discernment and simultaneity) define how the student experiences the phenomenon (Xu, 2019). Experience of a phenomenon brings about a change in awareness, which stimulates a change in discernment that results in learning (Runesson, 2006). Learning results in a qualitative change in the person's way of seeing that object. If a teacher expects students to adopt a view like their own, for example, a scientific view, they must focus on the same critical elements required for learning.

Figure 20.1 provides a graphical overview of the history of Variation theory, traces back to phenomenographic studies in the 1970s. These studies informed Japanese lesson study involving a triad of teachers following a professional learning model. From 1999, Learning Study developed into a strategy used to assist classroom teachers in focusing on the object of learning and the necessary conditions for learning (Lo, 2012). Research lessons tested the application of variation theory in classrooms and data collection aided its further development into the learning study approach. Following from the work of Martin and colleagues, variation theory has since stood on its own, as a theoretical framework for analysing lessons. The theory can establish a relationship between teaching intent and resultant learning wherever an instructional situation occurs. Hence, variation theory can now be a pedagogical tool to analyse lessons and consider possible improvements to teaching. In this chapter, I apply variation theory to the out-of-school context of zoos with this purpose.

20.2 Variation Theory of Learning

20.2.1 Object of Learning

At the core of variation theory is a focus on something, *the object of learning*. Variation theory involves understanding *something*, which Marton (2014) denotes as the *object of learning*. Essentially *the* object of learning is the prime goal of learning, which may be a concept(s), phenomenon, experience (Bussey et al., 2013), skill, or technique (Bjorkholm, 2014). Lo (2012) describes the object of learning as, "what the students need to learn to achieve the desired learning objectives" (p. 43). Importantly, the object of learning is both dynamic (evolves throughout a learning

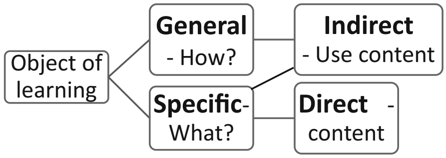


Fig. 20.2 Aspects of object of learning

experience) and context specific. Where a lesson occurs, i.e., in a school classroom or out-of-school context, is one factor that can impact strongly on the meaning of the object of learning. The teacher or educator makes decisions about the specifics of what students are to learn. Effective teachers choose the most valuable object of learning to exploit according to time and situation. Learning involves a change in how we view something. To achieve a certain view requires awareness of and simultaneous discernment of its aspects (Lo & Marton, 2012).

At the basic level are two aspects of the object of learning (Fig. 20.2). The specific aspect is *what* we are to learn (the subject knowledge) (Marton & Tsui, 2004; Lo, 2012), and is a short-term goal. The general aspect concerns *how* we can use that learning (capability or attitude) and is a long-term goal. The specific aspect is the most common focus of studies involving variation theory (Xu, 2019). Simultaneously, the object of learning can be direct or indirect. A direct object of learning is normally the same as the specific object of learning. To give an example in relation to the current study, a direct object of learning could be *animal adaptations*. Whilst the indirect object of learning, how the learner uses or what they can do with this information, can relate to the general or specific object of learning. For example, *recalls* that animals can have adaptations that aid their survival in specific environments, relates directly to specific content. Whereas being able to *distinguish* between features that are or are not adaptations, *using* the definition of adaptations, are indirect objects of learning involving general aspects.

20.2.2 Critical Aspects and Critical Features

Central to variation theory is the act of discernment as shown in Fig. 20.3. Essential elements that learners must notice before they can grasp the object of learning are *critical aspects*. The learner must discern these aspects in specific ways to make sense of them. Voon et al. (2020) define discernment as, "the ability to hold an aspect of a phenomenon in focal awareness and contrast it with its environment in order to construct meaning for that aspect and, subsequently the phenomenon (p. 3)". Attached to critical aspects are more nuanced elements termed *critical features*. These terms sometimes are interchangeable in the literature, which can be confusing. To understand the difference, requires delving into the notion of variation from which the theory gets its name.

For a learner to discern the defining features of a mammal, for example, requires difference or variation. To make this clear, a teacher can show examples of animals

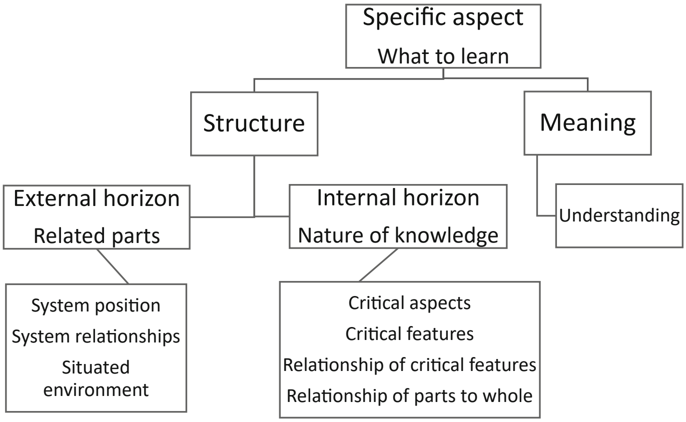


Fig. 20.3 The attributes of the object of learning and relationships (modified from Lo, 2012, p. 63)

that are *not* mammals. Not only is it important to show examples and non-examples, but the order is also important. Variation theory maintains that discernment is impossible from sameness, and for greater effect difference should precede likeness (Marton, 2014). Adding a *dimension of variation* (critical aspect) is needed to elucidate mammals as vertebrates that have fur and mammary glands that produce milk for babies. Bringing into focus other animals that *do not* have these features, such as birds, reptiles and some that do, Bilby and Echidna (Australian animals), *opens-up* this dimension of variation, bringing it to the learner's attention. The critical features of the Bilby and Echidna are special *values on the dimension of variation.*

Voon et al. (2020) conclude, "variation theory does not specify what the critical aspects are or how specific content should be handled. It is the teachers who decide what needs to be the focus of the learning, what the critical aspects might be, and how to make these become visible to the learner", (p. 21). In applying variation theory for the purpose of lesson design, teachers usually first consider the critical aspects and set up the learning experience to enable students to discern them (Carlgren et al., 2015). In lessons where the object of learning is concept-based, the critical aspects are discrete ideas that underpin the concept. A sound understanding of discipline-specific concepts is required for teachers to delineate the critical aspects and critical features.

In science, a good starting point may be the *Big ideas of Science* which Harlen and colleagues (2015) developed. Underlying big idea 10, "The diversity of organisms, living and extinct, is the result of evolution" is the concept, "Animals and plants are classified into groups and subgroups according to their similarities" (p. 29). Animal diversity could be a critical aspect with the critical features being vertebrates and invertebrates. Once this concept has been discerned, vertebrates could become the critical aspect and groups of vertebrates—fish, amphibians, reptile, birds, and mammals—would be critical features. In turn, one of these groups, becomes the critical aspect illustrating the dynamic nature of the object of learning in a learning situation. Concepts that are more complex will take more effort by the teacher to elucidate the critical aspects. For example, the concept of adaptations of living things to their environment starting from the idea, "Living things are found in certain environments because they have features that enable them to survive there" (p. 29), is not as straightforward. Depending on their level of biological science knowledge, the educator may need to expend considerable effort to unpack the underlying ideas before fulfilling their role to, "foster individual student's discernment of a critical aspect that comprises of variant and invariant aspects" (Voon et al., 2020, p. 20).

20.2.3 Perspectives of Objects of Learning

One way of applying variation theory to analyse a lesson is to identify and compare the objects of learning from three perspectives:

- what the students experience, the *lived object of learning*,
- what the teacher aimed to do, the *intended object of learning*
- what took place in the classroom, *the enacted object of learning*.

The first is the learner's perspective, the second is from the teacher's standpoint, and the third from the angle of the observer (in this case the researcher). Between the intended and lived objects of learning are the examples, actions, and verbal exchanges, making the object of learning available for pupils. A visual illustration of a theoretical interpretation of the possibilities for student learning in the context of a zoo lesson given on a school excursion by a Zoo Educator, is shown in Fig. 20.4 (adapted from Xu, 2019).

From the teacher's perspective, the intended object of learning is what the teacher *wants* students to learn, for example, the concepts derived from the school curriculum about which the students needed to learn. From the observer's perspective, the enacted object of learning is what the students *possibly* could learn (intended or not) from the situation. This is what the observer captures, for example, through participant observation, to provide a descriptive account of *how* the teacher made the objects of learning available to students and *what* conditions of learning prevailed. On a cautionary note, Fig. 20.5 shows the intended object of learning does not automatically equal the enacted object of learning. From the learner's perspective, the lived object of learning is what the students *do* learn (Marton et al. 2004; Xu, 2019). Evidence of this comes may be through a post-test. Likewise, Fig. 20.5 shows the lived object of learning may not equal the enacted object of learning.

Each circle represents an aspect of learning during a lesson (see Haggstrom, 2008). As shown in Fig. 20.4, partial overlapping of the circles shows that some, not all, aspects the teacher desires may eventuate and what students do take away from the learning experience may vary from that expected. The star in the middle is the 'bullseye' where aspects of all three objects of learning coalesce; this is the 'sweet spot' or the ultimate target of teaching. This overlap encapsulates the teacher-student interaction where learning manifests and is the *space of learning* (Bussey

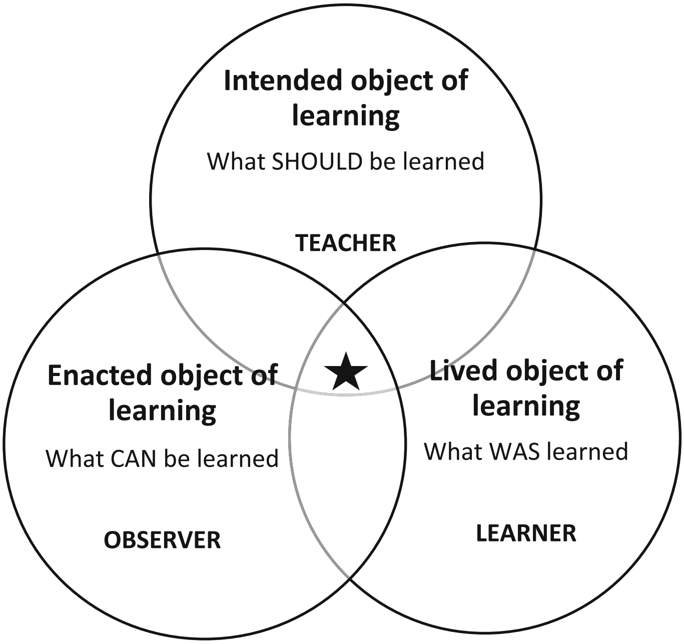


Fig. 20.4 The objects of learning adapted from Xu (2019)

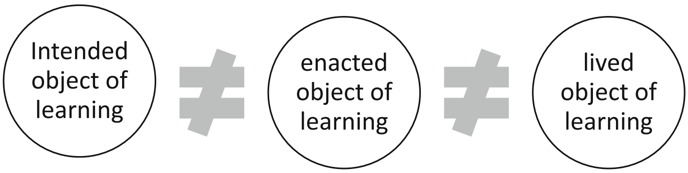


Fig. 20.5 Relationship between objects of learning

et al., 2013). Improved learning experiences should result in expansion of this core area. It is important to note, this is a generalized model. Individual students have prior conceptions and unique life experiences, which will affect how they perceive the provision of the intended object of learning (Xu, 2019).

The bottom two spheres in Fig. 20.4 will receive the most attention in this chapter. How can we tell what students *do* learn in a one-off lesson? The answer to this question provides important feedback to teachers in out-of-school settings. What inferences can we make about specifics of the *actual* learning experience that had the potential to influence (or not) students' thinking and understanding of the targeted science concepts? The answer to this question allows teachers in out-of-school contexts to reflect on and further develop their teaching practice. It is the latter that has potential to incentivize continuous improvement and contribute to the professional status of teaching outside of schools.

20.2.3.1 Space of Learning

The space of learning is a term Marton and Tsui (2004) use to describe the conditions of learning a specific situation provides. A researcher can observe patterns of variation incorporating dimensions and aspects of specific phenomena. Xu (2019) explains the space of learning, "depicts what is made possible to learn in relation to the intended object of learning—the possibility of seeing something in a particular way" (p. 149).

20.2.4 Differentiation and Discernment

The notions of difference and discernment are at the centre of variation theory and explain how learners assimilate novel meanings into their understanding (Fredholm et al., 2020). Teachers aid this by the strategies they use to help learners discern ideas, first by teasing out (separating) the critical aspects (component ideas / skills) and then bringing them back together (fusion). To discern a critical aspect requires experience of variation in that aspect to separate it from the other details (Marton & Pang, 2013). Colloquially, this is like helping students see the 'trees' amongst the 'forest'.

In terms of conceptual understanding, variation in understanding is difference in awareness of the critical aspects comprising the concept (Akerlind, 2015). Hence, ways of understanding delve from aspects of the concept of which a person is (or is not) conscious. Poor understanding thus is incomplete (as opposed to wrong). Helping students learn a concept requires focusing their attention on the critical aspects, which wisely devised patterns of variation can achieve. Though a complex task (Tan et al. 2020), designing the patterns of variation is fundamental to lesson design. The critical aspects discernible in a lesson determine what students can learn; different dimensions of variation make the learning of different concepts possible (Kullberg et al., 2017).

As learning is a difference discovering ability (Fredholm, 2020), the teacher's role becomes one of creating situations that will facilitate changes in awareness about a phenomenon. To reiterate, learning requires discerning. Individuals must personally experience the discernment of critical features through difference (variation) and sameness (invariance). Next, I discuss patterns of variation, "a necessary condition of learning" (Lo, 2012, p. 83).

20.2.5 Patterns of Variation

Teachers can structure their lessons to use patterns of variation to enhance students' learning and facilitate their impact through choice of appropriate teaching methods. According to variation theory, experiencing difference, not just similarity, is vital for learning. Lo (2012) states, "without experiencing difference, it is impossible

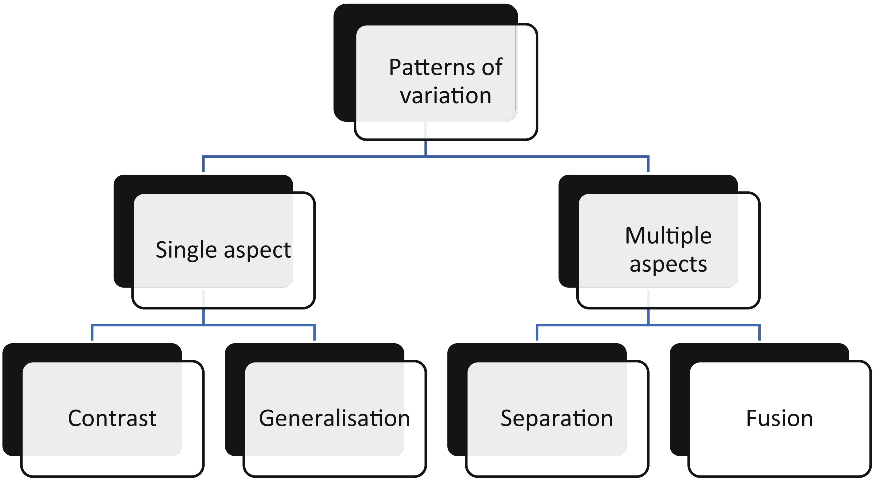


Fig. 20.6 Patterns of variation

to discern similarities. Thus, in addition to showing examples, teachers must also show non-examples" (p. 85). Awareness is raised in four ways through patterns of variation: contrast, separation, generalisation, and fusion. As depicted in Fig. 20.6. the patterns of variation differ for single or multiple aspects. For a single critical aspect contrast and generalisation apply for more than one aspect separation and fusion apply (Marton et al., 2004; Xu, 2019). Below, I explain each of the four patterns.

- **Contrast** allows the learner to compare the object of learning with something else, giving them a reference point. This aids discernment of the idea, bringing it forward in a student's mind, separating it from the context and other ideas. For example, showing students a non-living thing and a living thing enables focus on the differences, making it easier to discern the critical features. This is a common strategy of experienced teachers. A conflict with students' prior knowledge also can create contrast. To be effective, teachers should make opportune the simultaneous focus of the old and new ways of seeing (Lo, 2012). Such simultaneous awareness can be effective in enabling a learner to discern alternative conceptions.
- **Generalization** allows the learner to experience different forms to focus on the defining (relevant) features and distinguish them from irrelevant features. For example, viewing several different living things and identifying common features.
- **Separation** allows the learner to distinguish the value (critical feature) from the dimension of variation (critical aspect). The first step is to create relevance by divorcing the object of learning from its context. Students must experience each aspect of a concept changing whilst keeping others the same. This raises awareness of that feature, after which one may view it independently. A pattern of variation can bring about separation or generalisation. It is important to make the object of

learning clear. To help students discern ideas vary the critical features and keep non-critical features the same.

- **Fusion** allows the learner to become aware of multiple critical aspects at the same time. Fusion can occur when aspects are first discerned independently before they are considered together.

Learning is the ability to see and experience by detecting patterns of variation in critical aspects of a concept (for example) in a learning situation. Voon et al. (2020) note, "the learners' perception of variation within and between *critical aspects* allow them to construct a mental model of a given concept that is unique to them" (p. 3). As such, the theory provides a way of accounting for differences in learning (Fredholm et al., 2020). This helps to answer the question why students who experience the same lesson exit without an equivalent learning achievement. In other words, teaching does not guarantee learning. Variation in conceptual understanding arises from differences in awareness of the aspects comprising the concept (Akerlind, 2015). Variation theory looks at the possibilities for learning and the extent to which the learner makes use of them. Therefore, what students experience and take away from a lesson is not always congruent with what the teacher intended.

The 'teacher thinking' outlined above is vital because the key elements in focus govern the understanding of a concept. Teachers should carefully select the critical aspects and features of each object of learning in a lesson. For any given learning situation, the teacher must determine what the critical aspects and the associated critical features are, and which strategies will be most effective for handling the specific content. Hence, the teachers' role is pivotal; they decide the learning focus, identify the critical aspects, and orchestrate ways to make these accessible for learners (Voon et al., 2020). Critically, the learner's experience of the variation makes learning about the object possible (Marton, 2014).

Realisation comes through the intersection of a triad of overlapping perspectives. The 'stuff' to learn (techniques, knowledge, appreciation), the object of learning, comes through noticing differences (variations) in its critical aspects and features. Carlgren et al. (2015) explain this as, "understanding learning as a process of discerning new aspects of learning objects in new ways" (p. 148). The theory operates on the basis that the critical aspects a learner must discern to grasp the object of learning are identifiable. It is then the job of the teacher to bring these vital constituents into a learners' realm of consciousness. In addition to noticing (discerning), the learner also must discriminate and discern differences (variation) in each aspect. Discernment relies on variation and discerning in specific ways the different aspects of the subject knowledge.

The teacher's role becomes one of diverting students' attention to critical aspects through carefully implemented patterns of variation to build up understanding of the concept. What students could learn is determined through judiciously planned variation of the critical aspects of learning (Lo, 2012). Variation theory is about content (i.e., what to teach) not methods (how to teach). This is because there are many different methods to draw students' attention to the critical aspects underlying the object of learning. Individual teachers may effectively use a range of teaching strategies so long as the teacher clearly delineates the essential elements of what is to be taught and makes them available for student action. "Conceptualisation, therefore, depends on discerning common and differing features among examples and experiences, *generalising* from these according to the scope of examples that are presented, and *fusing* these features into a concept" (Kullberg et al., 2017, p. 8 emphasis added). Variation theory offers a useful framework for understanding more about direct relationships between teaching and learning and is suitable for application in a range of instructional contexts. The next part looks briefly at the usefulness for teachers both in general and in the context of out-of-school settings.

20.3 Why is Variation Theory Useful?

20.3.1 Use for Teachers in General

Variation theory provides different functions for teachers in general. For example, a way of scrutinising learning opportunities in classrooms, a specific view on what it means for an individual to learn (discriminate and discern critical aspects), and a theoretical lens to develop a teaching instruction instrument. Pang and Lo (2012) showed variation theory to be a potent tool for teachers to analyse the learning object and plan lessons. It also provides a theoretical framework for, "understanding the relationship between teaching activities and learning" (Bjorkholm, 2014, 196). Variation theory has been used to: "identify the critical differences in experiencing and understanding certain phenomena", "investigate the significance of variation in opening up possibilities for student learning", and "guide the design and implementation of learning studies" (Xu, 2019, p. 147). Variation theory can help teachers use the science-specific instructional strategies of problem solving, inquiry learning, and experimental methods and determine their effectiveness.

Using this versatile theory, teachers can analyse existing learning sequences and learning processes in action, and design or redesign learning experiences. Pragmatically, variation theory provides an approach for teachers to consider the dynamic relationships between the intended, experienced, and actual learning of science concepts in lessons. Lo (2012) discusses two reasons why identifying critical features of the object of learning is important. (1) To help teachers better understand the object of learning. An educator may have a strong understanding of a concept but overlook the need to focus on its component critical features during teaching. It is normal for teachers and students to see the object of learning in different ways because they have different life experiences. Teacher reflection of their understanding of the object of learning can help identify the critical features students need to discern to construct meaning. (2) To cater for individual differences of students being taught. Students with differing learning needs and prior experiences require varying ways to notice the critical aspects.

Variation theory also provides a basis for understanding the conditions that support learning at a deep rather than superficial level (Runesson, 2006). From the perspective of variation theory, poor understanding results when the learner does not notice all the important aspects. Taking this view, teachers can enhance learning by enabling greater awareness and discernment of more aspects of the object of learning. Xu (2019) describes variation theory as a "powerful explanatory tool for relating the teaching and learning of science" and enhancing instruction through looking for "conditions that might enable (or hinder) the desired ways of seeing" (p. 160). As a pedagogical perspective on learning, variation theory focuses on helping teachers gain evidence of what "students have learnt rather than leave it for chance" (Lo, 2012, p. 192).

20.3.2 Use for Teachers in Out-of-School Settings

Variation theory can be used as a framework to describe and analyse discrete occurrences of teaching episodes in specific contexts distinctly different from normal school classrooms. The framework is multi-faceted, based on three perspectives: teacher (what should be learned), researcher (what possibly can be learned), learner (what was learned). These 3 viewpoints could be construed broadly as the.

- why (school/curriculum purpose),
- what (content/examples), and
- how (impact/outcome which is learning students realise) of learning.

Significant amongst the three basic principles of learning Lo (2012) highlights content, arguing that "content and how to deal with it" ought to be "deliberately designed with the aim of achieving worthwhile educational objectives" (p. 15). Educators would benefit from an empirical, theoretical base to endorse their choice of specific content and ways to support students' learning of it.

In out-of-school lessons, the teacher does not have the advantage of knowing the students, nor do they usually have the luxury of time or pre-exposure to determine students' prior knowledge. They usually must make use of what they know generally about learner's views of the objects of learning and topics. In contrast, without the confines of school, these other contexts provide a space for educators to experiment with innovative educational techniques. Innovations require targeted evaluation and variation theory provides a reliable framework.

The benefit of using variation theory in research with inbuilt professional learning for out-of-school educators is that it can direct their awareness to dynamic relationships between the intended learning, teacher instruction, and actual student learning. Braund and Reiss (2006) note "a well-versed criticism of learning science in less formal contexts such as science centres is that science learning is rarely substantial, that misconceptions are initiated or fostered, and that engagement through enjoyment of the interactions that take place is far more important than educational gains" (p. 1377). A huge variety of settings offer opportunities for Learning Outside the

Classroom (LOtC) and learning quality can vary comparably with science learning in different classrooms (Kapelari, 2015). Grounding pedagogical practice in theory that helps educators understand conditions needed for learning (Lo and Marton, 2012) has the potential to elevate the professional status of educators in out-of-school settings.

20.4 Application in the Literature

The purpose of this section is to review applications of variation theory to out-of-school learning. Literature searches turned up only one study that came close to matching this brief. This could mean that this field of education lacks a theoretical basis or alternatively that no one yet has applied this theory to out-of-school learning. Kullberg et al. (2017) extensively applied variation theory to the analysis of teaching and students' learning in classrooms and in testing instructional sets. Reviewing the application of variation theory to school classroom situations is outside the scope of this work. A brief review of research into the use of variation theory in science and mathematics learning, though, offers worthwhile background to this chapter.

20.4.1 Preschool Forest Outings

Gustavsson and Pramling (2014) used variation theory to analyse preschool children's learning about nature during outside lessons on immersive excursions to a forest in Sweden. Over a nine-day period, they captured on video the interactions between 4 and 5-year-old children (n = 15) and their teachers as they explored the forest environment. Results focus on opportunities for science-related objects of learning. Analysis of teacher-student conversations revealed ways teachers supported children to discern the critical aspects of arachnids and discriminate a spider from an ant. An example of a failed opportunity of understanding about a shrimp was relayed and explained in terms of presumption of shared experiences and thus prior knowledge. The example illustrates that the type of teacher–child talk is a vital determinant of different opportunities for learning. Through probing, "what is and is not a spider", they achieved key characteristics of conversation that, "opened up dimensions of variation" to guide children to discern and conceptualise the characteristics of an animal (ibid, p. 70).

20.4.2 Variation Theory in Teaching Science and Mathematics

Variation theory use in the development of learning study in Hong Kong includes some examples of its application to science concepts. Lo (2012) provides useful examples of specific lessons with science content that discusses the three types of variation in: "students' ways of understanding the object of learning; teachers' understanding and ways of dealing with the object of learning; and ways of designing learning experience" (p. 31–2). Analysis of example lessons illustrate the ways the teacher managed the object of learning, whether the lesson achieved the desired learning, and how patterns of variation could be used strategically to improve the lesson and enhance teaching and learning.

Xu (2019) used variation theory to analyse the relationship between teaching and learning in a two-lesson sequence on density in a science class for thirteen-year-old students in Australia. The variation theory perspective provided insights into why students may perceive density in certain ways. Findings highlighted student's confusion between the density of objects and the substances of which they are made. My study builds on the use of variation theory in analysis of pre-planned lessons, taking it one step further to involve the teachers in reflecting and acting on the findings.

Additional research combined variation theory and the constructivist framework with the aim of elevating science learning for nine-year-old students. The study highlighted the role of teaching practices such as using incorrect answers, starting with differences, and dealing with one idea at a time to bring about contrast (Voon et al., 2020). The results indicated success of a seamless learning process for helping students understand heat transfer through active engagement in hands-on experiments.

Kullberg et al. (2017) discuss variation theory as an instructional design principle drawing on data from professional development with mathematics and science teachers. The finding that teachers change what aspects of content they make noticeable for their students resulting from learning about variation theory also has relevance for teaching outside the classroom. Analysis of what is and *is not* made possible to learn in a specific lesson design and presenting evidence to teachers is a powerful way to raise awareness of teacher practice. I illustrate this point in the example that follows.

20.5 Example—Science Learning at Nambaroo Zoo

In this section I discuss how variation theory was used to analyse science lessons conducted at Nambaroo Zoo (pseudonym) in eastern Australia. Whilst this is a specific case, the analysis approach is relevant to other out-of-school locations.

Fig. 20.7 Rainforest, Woodland, and Desert Immersive Habitat Classrooms

The stimulus for this study was the opening of three specially designed classrooms that model the natural habitats of a rainforest, a woodland, and a desert. Figure 20.7 shows the three habitat classrooms in action.

Students are seated on the floor facing the habitat section, that is separated by a low glass wall. You can see some elements of each habitat, (rock, log, termite mound, rope vines) extend into the class section. Educators can open a door in the glass wall to allow some animals to enter the sitting area for closer observation or interaction with students. The rich stimulus of live plants and animals in these classrooms provide an immersive learning experience for students. Zoo educators use the classrooms to provide one-off lessons for school excursions. The lessons align with government-mandated curriculum, most commonly in Science and Geography.

20.5.1 Overview of Case Study

The research aimed to explore the impact of a lesson in one of the habitat classrooms on students' understanding of science concepts. The study was conducted by two researchers (author and research assistant). Participants were class groups of first-year high school students from 4 different schools. Students completed a drawing task (similar to Jensen, 2011) before and after participating in a 50-min lesson on the topic of classification and adaptations. Verbal and written instructions were provided: '*Draw the environment and the living things in a rainforest (or desert or woodland), include groups of animals and ways animals survive in this place. Add 4 words to describe the environment and label the things you draw*'. Drawings were collected and scanned to provide pre- and post-data for each student.

I was a participant observer in each of the lessons and used unobtrusive, hand-written field notes to record observations. This method collected data on zoo educator actions, information, learning activities, types of animals displayed, student engagement, use of habitat, and animal behaviours that drew students' attention. We used this data to verify direct influence of the lesson experience on students' drawings. Data analysis was completed in two phases.

20.5.2 Preliminary Analysis

First, student drawings and lesson observation data were analysed separately to provide preliminary results. We identified specific elements in student drawings and used those elements to develop a scoring rubric for comparison of pre-post drawings. From lesson observations and field notes we identified topic themes, specific concepts, teaching strategies, student–teacher interactions, and animals or aspects of the environment.

Evidence of a strong positive impact of the immersive experience on students' understanding of science ideas was obtained through drawing analysis. Lesson observation revealed extremely high levels of sustained student engagement. Teaching strategies of guided observation (animals and environment), interactive questioning, animal antics and interactions contributed to student engagement.

A focus group with zoo educators was held to communicate these initial findings and gain their perspectives of teaching in the immersive habitat classrooms. The education team was highly motivated to develop quality teaching, very receptive of feedback, and eager to continuously improve their practice.

Second, variation theory was then used to provide a framework for deeper analysis of the data. The next section shows how variation theory provided greater insights into the learning experience by considering the impact of the immersive habitat classrooms on students learning of science ideas from different perspectives.

20.5.3 Variation Theory Analysis

As an analytical lens, variation theory enabled us to probe more deeply *how* the lesson experiences impacted student learning of science ideas. The analysis was structured around examining the three objects of learning: intended, enacted, and lived, which Fig. 20.4 shows encompasses the perspectives of the teacher, observer, and student. Additionally, Fig. 20.4 highlights different elements of the teaching–learning experience. Figure 20.8 reflects the objects of learning with annotations relating to this example.

I gained a general idea of the intended object of learning derived from content analysis of advertised information describing the excursion program. The lessons in the study were designed to teach the lesson topic *classification and adaptations* and content was planned by the zoo education team with no input from the researchers. This differs from the traditional use of variation theory in lesson study research which commences with collaborative planning, involving ascertaining the critical aspects and how to teach them. As this was an evaluative study, I focused on the enacted and lived objects of learning first.

The students' drawings comprised demonstrated outcomes and provided evidence of understanding of science ideas. The participant observation data enabled me to document the information or content provided and the delivery process of the lesson.

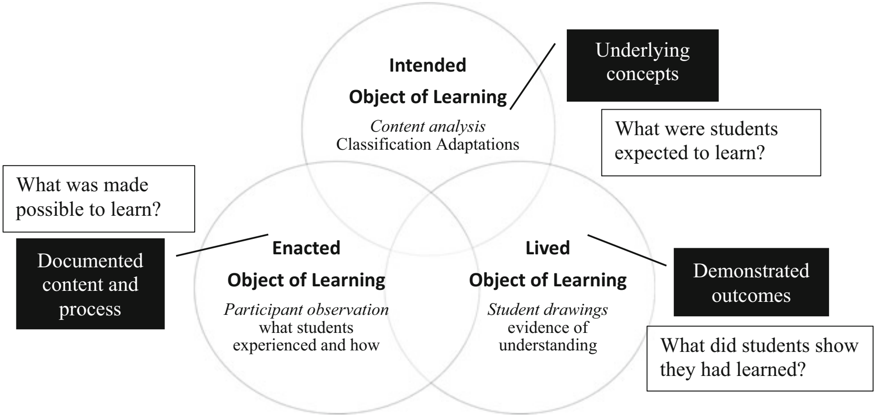


Fig. 20.8 Objects of learning in the study (adapted from Xu, 2019)

Using observation notes, I developed a summary record of a typical lesson in each of the habitat classrooms. This enabled scrutiny of the nature of the educational experience and use of the unique classroom environment and animals (both within and brought in for demonstration) without undue attention to individual teachers. The approach differs from previous studies which, for example, compared ways different teachers taught the same lesson to determine peculiarities that could open-up different degrees of variation. I made this distinction as evaluation of individual teacher practice was not my goal. Whilst careful not to single out zoo educators, I still could note specific strategies pivotal to my research aims.

In analysing the data, I started with what the drawings showed the students had learnt, as evidence for the lived object of learning. Figure 20.9 visually represents the method I used to apply variation theory to analyse the lesson through focus on the three objects of learning. To correlate evidence of student learning with the lesson from the researchers' perspective, I then referred to the field notes and recollections from participant observation as the enacted object of learning. This enabled me to pinpoint zoo educator strategies, actions, and words, including conversations and questions, and use of animals and the environment, to describe how students gained help to discern the main ideas for understanding. From analysis of the observed lesson, I could determine what opportunities the zoo educators provided for the students to discern critical aspects of the intended object of learning. Compared to lesson study research, I worked backwards, analysing the lived object of learning first. I then verified whether (and if so, how) the enacted and intended objects of learning aligned.

The last step identified the specific features of the intended object of learning. This required backward mapping to the syllabus and consideration of the ideas underlying the topic of classification and adaptation. It is beyond the scope of the book to provide detailed results. The next section presents some insights gained from my application of variation theory.

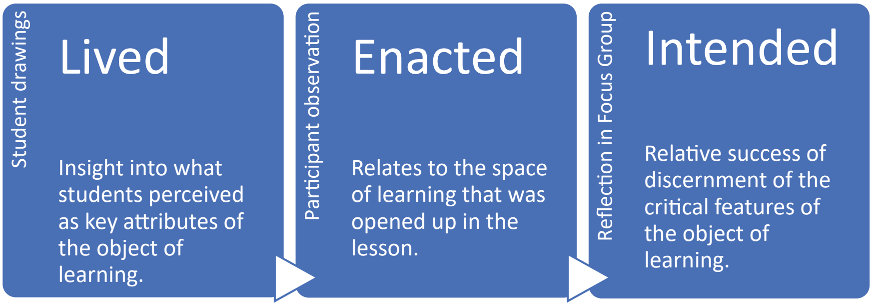


Fig. 20.9 Order of analysis of objects of learning

20.5.3.1 Lived Object of Learning—What Students Learned

As stated, the starting point of application of variation theory in this study was the students' perspectives. Finding out what the different students focused on from experiencing the same learning situation addressing comparable content gives an indication of lesson impact.

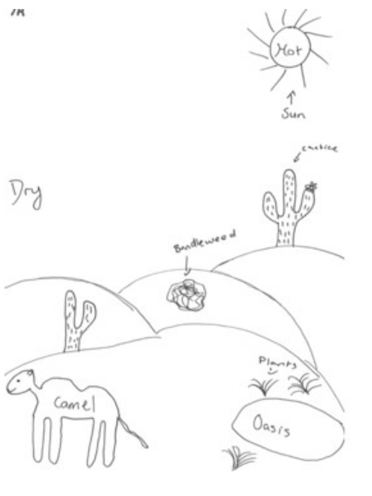
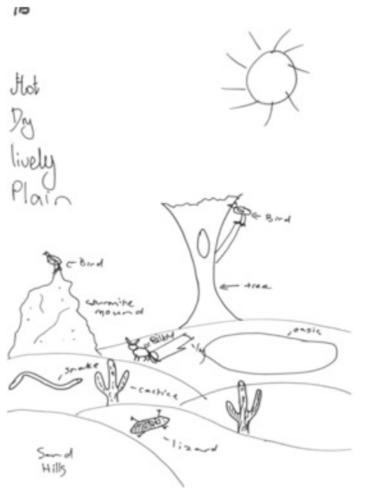
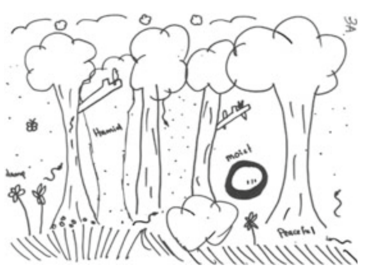
Examination of student drawings from before and after the lesson showed growth in learning through changes in what they chose to represent. The pre-drawings revealed a variety of preconceptions that demonstrated differences in students' prior experiences for all classrooms. Their initial representations of the environments lacked detail. On average two to three animals and fewer plants that were shown. Labels were mostly generic, for example, bird, lizard, with mammals more likely named. Structural adaptations shown in pre-drawings were unlabelled and unannotated.

Student post drawings contained a greater number and more types of organisms as well as additional habitat features. Overall, a greater diversity of plants and animals appeared in the post drawings. Drawings showed a blend of living and non-living elements and relationships between them, such as birds in tree hollows. Students included more plants and animals, expanded the animal groups they included (not always named), and showed and frequently named specific types of animals. Specific adaptations appeared more commonly in the drawings of animals after the lesson. Few students made annotations to explain how specific adaptations aided survival.

Comparison in pre-post drawings for each habitat classroom revealed the following trends shown in Table 20.1. For the desert habitat the pre drawings had one or less animals and cactus or dead tree for plants. The post drawing shows greater animal diversity, representing three animal groups—reptiles, birds, and mammals.

In the post drawing, names such as Cotton Top Tamarin, Bleeding Heart pigeon, crocodile, and snake appear. This indicates attention to the types of animals present in the rainforest. Additionally, adaptations discussed in the lesson are depicted but not labelled. Students less commonly included explicit detail about classification in pre- or post-drawings. The exception was the woodland drawing in Table 20.1 where the student listed types of animals.

Table 20.1 Pre and post drawings from the 3 habitats

Habitat	Pre drawing	Post drawing
Desert		
Woodland		
Rainforest		

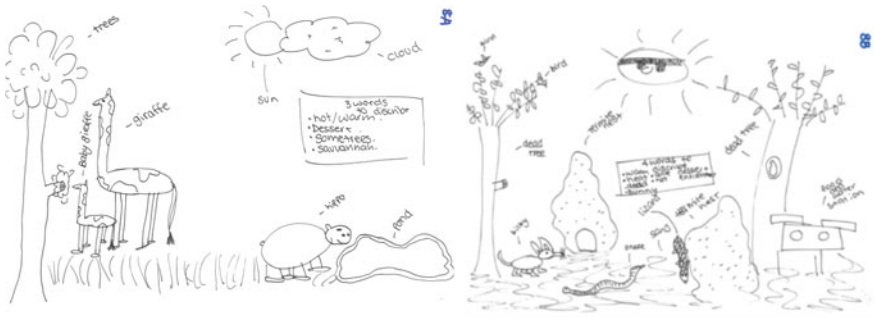


Fig. 20.10 Post drawing showing detail

Notable differences in habitat features appeared in student drawings. In general, post drawings included more detailed features of the habitat. Figure 20.10 shows this was particularly obvious in the desert habitat. After their lesson, most students added environmental characteristics. Alternative conceptions/stereotypes in pre-drawings usually disappeared in post-drawings, the most common being pyramids (desert), but cactus often remained (even though there are none in the habitat classroom). Camels were also more common in pre-drawings than post-drawings. Figure 20.10 is typical in that it shows African animals, mainly mammals, commonly appeared in the desert habitat before the lesson. After the lesson, a greater variety of animal groups, such as mammals, reptiles, and birds, were drawn and included Australian examples.

A clear impact of the learning experience on many students was the inclusion of some detail concerning adaptations (structural or behavioral). Few students included details about adaptations in pre-drawings. In the post-drawing, students labelled more environmental features, while adaptations are obvious but unlabeled. For example, the Bilby has big ears, long nose, and long tail. We assumed students showed these features deliberately and indicated understanding of adaptations discussed not simply because that is what the animal looks like (We must interview students about their drawings to confirm the assumption.) Many students included specific details of adaptations in their post-drawings, directly attributable to participation in the learning experience. In post-drawings, students more frequently drew reptiles with their tongue out, something discussed as an adaptation for smelling. Not all students included specific information about adaptations in post drawings. According to variation theory, if students are to discern what an animal adaptation is, they first must understand what an adaptation is not. We observed the strategy of pointing out non-adaptations rarely during the lessons. Changes in drawings indicate most students developed greater scientific understanding of some of the intended learning.

Impact on student learning ultimately determines quality of any lesson. Evidence from students' pre- and post-lesson drawings yielded rich insights into their prior knowledge and growth in conceptual understanding and provided a sense of the *lived* object of learning. The observation data verified influences on students' understanding of science concepts resulting from what they experience during the lesson.

This data and its analysis captured the enacted object of learning. The impact of any lesson on students conceptual understanding depends on the enacted learning achieving fusion (object of space) of the critical features. Whilst most students achieved an increase in conceptual understanding overall, this demonstrated only some, not all, of the critical aspects of classification and adaptations.

20.5.3.2 Enacted Object of Learning—How Students Experienced Learning

From analysis of the lessons we observed, I determined what opportunities the zoo educators provided for the students to learn. This made it possible to verify whether, and (if so) how, the enacted object of learning aligned with the lived object of learning. I first describe how a typical lesson looked from the observer's perspective, before providing examples of the impact of teaching on student learning.

Lesson description.

I observed a highly interactive teaching style from the beginning to end of the lesson. Students entered the room, sat on the floor, and had a short time to observe the habitat. Typically, the zoo educator started by asking questions: "Can you see any animals?", "What is in the corner there?", "With these animals that you see, what do they have in common?". The zoo educators encouraged students to notice animals in the habitat and answer questions from their prior knowledge. Students observed examples of different vertebrate groups along with one or two invertebrates. Attention went to one animal at a time and the lesson proceeded as an interactive discussion. Zoo educators regularly asked students for their input and students spontaneously asked questions to which the zoo educators responded. Educator questions such as, "What are the vertebrate groups?", elicited prior knowledge. Student questions usually focused on the animal features.

I observed immersive teaching when the zoo teacher capitalized on spontaneous occurrences in the habitat. Resident animals in the habitat frequently did something to captivate students' attention. For example, in the rainforest room, Cotton-Top Tamarin monkeys climbed about on the vines, ate food provided, fought, and made noises. In the woodland or desert, when birds moved on the ground or in the air, their presence became obvious to students who previously had not noticed them. When this happened, the zoo educator would pause, allow students to observe the animal(s), then ask questions, "What just happened?", "Why do they do that?", before using the discussion to segue into the next teaching point. The zoo educator rarely spoke without specific reference to an animal or part of the habitat.

In addition to observing the animals that lived in the habitat, the zoo educator introduced other animals from a side room. After showing different vertebrate animals, the zoo educator introduced an invertebrate with a question, "Is there a feature these animals do not share?". The frequency of introducing a new animal, every five to eight minutes, maintained high levels of student engagement. Figure 20.11 shows a zoo educator handling and displaying one of these animals for close-up observation

Fig. 20.11 Zoo educator handing White-lip Tree Frog

by students. The zoo educator talked about the adaptations of the animals, pointing out and discussing structural or behavioural features.

Sometimes the zoo educator placed an animal on the ground for students to observe the animal's movement. However, animals within the habitat arrived when prompted. In the desert room, the Bilby appeared from their burrow under the tree enticed by the sound food being offered. While students observed the animals, the zoo educators talked about them. For example, "Bilbies collect food in their cheek pouches then take the food back to the burrow. Why is this a good adaptation that will allow them to survive?" In addition to adaptations, discussion also included structural features used for classification. In the following conversation during the lesson, the zoo educator(s) challenged alternate conceptions elicited from students.

Educator: What separates birds from other groups?

Student: Feathers.

Educator: Yes, only birds have feathers.

Student: Eggs.

Educator: Other groups have eggs.

Student: Wings.

Educator: Wings are like limbs that other groups have. Equivalent to flippers inside they are like our fingers, so we do not use wings to classify. If you've got feathers, warm-blooded, and lay eggs, you are a bird.

Educator: What is the snake body covering?

Student: Scales.

Educator: Fish have scales. Why isn't this guy a fish?

Student: It has lungs.

Educator: Yes. Unlike fish scales, these scales are dry.

Specific examples of teaching

This section demonstrates the techniques zoo educators employed to teach about the adaptations of specific animals and how this impacted student learning. Table 20.2 illustrates examples extracted from students' post-lesson drawings which focus on specific animal adaptations. These examples align specifically with zoo educator quotes and illustrates that zoo educators bringing structural and/or behavioural features to students' attention did influence the students' thoughts about the habitat.

The first row in Table 20.2 shows the Cotton Top Tamarin using its tail for balance. This contrasts pre-drawings that showed possums or monkeys hanging from trees with their tails. The echidna in row two details adaptations made explicit in the lesson. Students noticed rear feet facing backwards, spines, ears (shapes above the 'eyebrows'), and a long snout and tongue for eating ants. Whilst students did not see the echidna eating ants, discussion occurred about this action, and it may have received emphasis by the termite mounds being obvious in the habitat. Row three shows a Shingleback Lizard with details including the body covering of scales, the tongue out for smelling, and the fat tail, with text describing the fat store and the effect of appearing as if it has two heads. Row four, the cartoon-style drawing shows the "story" of how the false head can aid survival. This adaptation seemingly appealed to students, as they more commonly included this adaptation in post-lesson drawings.

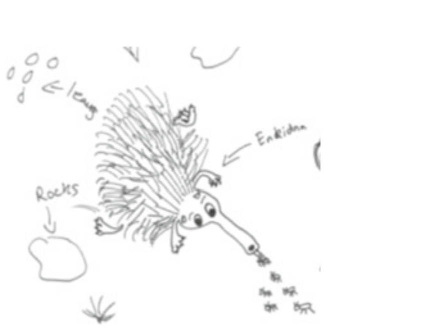
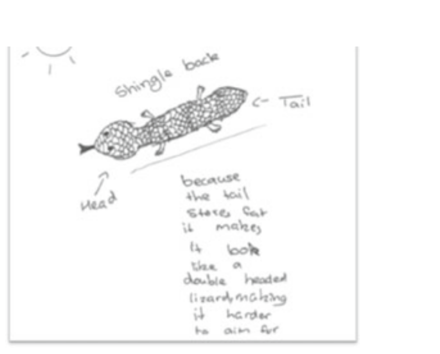
The examples shown above evidence impact of the zoo lessons. The data indicates that students noticed ideas about several adaptations which were explained by the educator and experienced by the students. The inclusion of the new ideas in students' representations may determine the overall success of the learning experiences. However, the sensitivity of the research instrument should be considered. Students may have learned ideas they did not draw, either by choice or because the idea was difficult to represent. Annotations detailing animal adaptations were included more often than different animal groups. Student drawings often included animals that represented vertebrates from different groups, without explicit labels.

20.5.3.3 Intended Object of Learning—What Students Should Learn

I determined the learning aims for the lessons by reading the zoo education program advertising sent to schools and talking with the zoo educators. The lesson topic was linked to *Classification and Adaptations* from the state school curriculum. The state school authority syllabus encompasses the first two years of high school for students 13–15 years old. The main learning outcome the lessons addressed was, "relates the structure and function of living things to their classification, survival and reproduction" (NESA 2019). This entailed making connections between features of different animal groups and linking their classification to the adaptations needed for survival in their specific habitat.

The state curriculum content dictated the direct object of learning, whilst the indirect object of learning (what students were expected to do with the content) was identified by the educator. The curriculum does not specify the critical aspects/features.

Table 20.2 Examples of students post-lesson drawings

Drawing inclusions	Zoo educator directions/explanations
 	"Have a look at how they use their tails" "Notice they use tails for balance, it is not prehensile, they can't hang with it" "See how agile they are, there is no hair on hands and feet, this helps them grip on vines"
	"The long nose called a beak is very sensitive" "Their long tongue is good for catching ants in termite mounds or logs" "Spines, for protection. Short limbs, close to ground where food is Placed on the ground—"See its backward-facing hind legs? They can burrow really fast" Echidna held up—"See the one long claw, it can scratch its back between the spines"
	Educator: "This is Gordon, a Shingle-Back Lizard, feel his skin, what is it covered with?" Student: "Scales" Educator: "They are made of keratin, a good insulator. Why do you think they are thick and raised? What is the most important resource in the desert?" Student: "Water" "Scales keep water from evaporating" "Notice its tail looks like its head? This is an adaptation. It is mimicking another head. The tail contains fat; acts as an energy store"
	"Look at the legs, they can do something other reptiles can't do, walk backwards!" "Confuses predators, walk backwards to make fat tail look like a head." "A bird looking down from a tree will go for its head. They will likely survive a bite to the tail, can live better without a tail than a head!"

Lessons intended to teach two main objects of learning. Presumed learning objectives, underlying critical features and indirect learning objectives are listed below.

Object of learning 1—Animal species have special features that are adaptations to their environment. Possible critical features are:

- animals have particular features (structures) and/or do certain actions instinctively (behaviours)
- these adaptive features determine if an animal can survive in certain habitats
- not all structural or behavioural features are adaptations; must aid survival and reproduction
- animals cannot choose or change themselves to gain adaptations

The indirect object of learning—demonstrate the ability to:

- infer features of animals that may be adaptations that aid survival in the habitat
- explain how the adaptations of some animals assist them to survive and reproduce.

Object of learning 2—classification helps organise the diversity of living things. Possible critical features are:

- Classification groups animals using similarities and differences in structure and function.
- Animals in the same group share structural features.
- Distinguish between vertebrates and invertebrates.
- Outline the structural features that distinguish animals into vertebrate groups.

The indirect object of learning—be able to:

- Recognise similarities in structural features of animals in the same group
- Identify differences in structural features of animals in different groups.

In Fig. 20.12, the example post drawing from the woodland habitat provides evidence of the indirect object of learning 1. After the lesson students were more likely to link lesson animal features with adaptations needed for survival in a specific habitat. However, no evidence of the indirect object of learning 2, classification, was found. The drawing in Fig. 20.12 shows what was *possible* to learn during the lesson. However, the lack of communicating an understanding of object of learning 2, may reflect a knowledge deficiency. The lack of knowledge or understanding after the lesson begs the question: Why do some students and not others construct knowledge or learn when being taught? This is an intriguing aspect of teaching that variation theory may help zoo educators better understand.

The next step was to determine if the objects of learning (1 and 2) were worthwhile and ascertain whether they were simple or complex notions for students to understand. A direct relationship to school curriculum content should mean objects of learning are worthy. However, the objects of learning are complex due to the number of underlying critical features. While the intent was for students to learn about classification and habitat related adaptations, the data showed students identified classification or adaptations with adaptations being drawn more often. This finding suggests it was difficult for students to split attention between two objects of

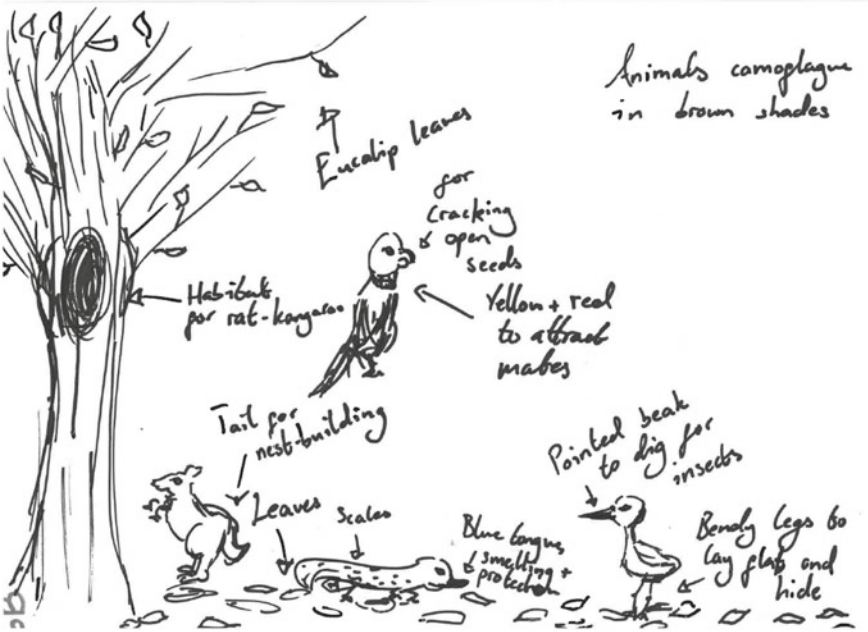


Fig. 20.12 Woodland adaptations—post drawing

learning (1 and 2) in the one lesson. Therefore, activities and lessons should focus on one object of learning instead of two objects of learning.

20.5.4 Outcome of the Analysis

The final step in the current study involved the zoo educators reflecting on the findings and engaging in professional learning about variation theory. Critical reflection on the objects of learning and identification of any gaps between zoo educator intensions and student learning, can facilitate deeper understanding of professional practice (Rolandsson et al., 2017; Voon et al., 2020). As Holmqvist and Mattisson (2008) found "it is only when the lesson content is specified and the pupil's knowledge before and after a lesson is both ascertained and related to how the specific learning object has been presented in class, that one can determine what the pupils have learned, and why they have learned it" (p. 37). Professional development can usefully guide teachers to embed patterns of variation in critical aspects (Pang, 2006; Akerlind, 2015) to aid student learning of concepts.

What the theoretical perspective reveals about ways to enhance learning potential can then be considered by the zoo education team. This may involve consciously defining a specific object of learning and devising new ways to help students discern the critical features. Neither variation theory nor the state curriculum specifies what the critical aspects are or how teachers should manage the content. A recommendation was made to reduce the conceptual expectations of a single lesson and use variation theory to guide modifications to enactment. This change will help zoo educators use the theory to decide, "what aspects to focus on, what aspects to vary simultaneously and what aspects to keep invariant or constant and to consciously design patterns of variation that can help to bring about desired learning outcomes" (Lo, 2012, p. 32). One suggestion is to discuss organism features that are *not* adaptations before introducing adaptive features. The impact of specific changes in teaching practice on student learning will be the aim of a follow up study.

20.6 Importance to Research

Variation theory reminds us that what a teacher has in mind for students to learn from a discreet lesson, is not guaranteed. A range of factors can impact student learning because of complex and dynamic interactions during the lesson (Lo & Marton, 2012). In general, this explains why some students learn 'better' than others in any lesson. The aim of teaching enhancement is to maximise the number of students that *do* learn well. Achieving learning consistently cannot be left to chance; to change requires concerted actions by teachers. As represented in Fig. 20.13, variation theory helps teachers focus on the *what* of learning, that is what *is* made possible and what possibilities students *use*. Such a focus enabled teachers to work on ways of increasing impact of their lessons. Variation theory allows teachers to gain greater understanding of their teaching and student learning by focusing on learner perceptions. Professional learning about variation theory can guide teachers to find ways to embed variation into their lessons.

Even though these were experienced zoo educators and based on variation theory, the context in which they taught was beneficial, only one educator (albeit unknowingly) employed the occasional use of pedagogical variation. The zoo educators were very aware of curriculum requirements and deliberately attempted to engage students in active observation. This example contributes new research findings for zoo education and out-of-school learning in general. I propose that variation theory provides a useful analytical framework for educators in the informal education sector to collect data on student learning, reflect on teaching practices and revise planning informed by learner perspectives.

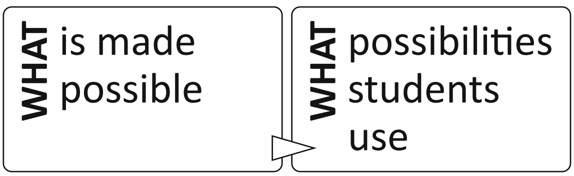


Fig. 20.13 Variation theory foci

20.6.1 Zoo Educator Benefit

Using variation theory to research practice and seek evidence of learning is beneficial to zoo educators, because the theory may provide insight into what key ideas students did and did not learn. Lo (2012) explains, "students cannot naturally discern the critical features of the objects of learning" (p. 54). The zoo educator must make this learning interaction possible. When zoo educators better understand the objects of learning, they can modify their teaching to maximise student learning.

20.6.2 Use of the Theory as a Research Lens

I used variation theory as a conceptual framework to understand the relationship between teaching activities and learning outcomes as indicated/inferred from comparison of pre-post lesson drawings. The theory framework was then used as a tool to guide lesson revision where needed after inferring students' learning difficulties (Bjorkholm, 2014, p. 196). Variation theory applied retrospectively in lesson analysis gave some insights into the impact on students' science ideas and understanding. The lessons observed were not designed in accordance with variation theory; hence, patterns of variation and invariance were not deliberately built into the lesson structure. Variation theory enabled a multi-perspective analysis of lesson design and teaching. The lesson design included the unique classroom context and live animal use. The process I described contributes to theorising the value of knowing the specific object of learning (Carlgren et al., 2015). Professional learning is integral to establishing a research-validated pedagogical framework (Thomas, 2018). The educator's learning intentions can be revised based on evidence of what was made possible to learn. Importantly, out-of-school teachers should actively develop their professional practice. This study aided zoo educators to identify gaps and use the knowledge gained as evidence to promote changes in beliefs and actions (Dwolatzky et al., 2021).

20.6.2.1 Implications for Zoo Educators

Exposing zoo educators to the variation theory of learning and involving them in reflective practice provides professional development benefits. The application of variation theory to analyse the lessons does more than provide evidence of student learning. The theory highlights possible shortfalls and identifies areas for potential improvement. From this example, we can see that variation theory provides a way for zoo educators to theorise their practice. The zoo educators in this study embraced the chance to look inwardly at their practice as a group. There was evidently a collegial environment focused on high quality teaching and an ethos of continuous improvement amongst the education team.

20.6.2.2 Implications for Research in Zoo Education

The application of variation theory in this example through an analysis of students' drawings immediately after the lesson provides evidence of what 'stood out' to them. The theory spotlights to what learners paid attention and reveals what possibilities the learners used (and chose to represent) in their drawings. Cross-checking with the lesson observation notes highlighted the elements of the enacted learning effective in creating patterns of variance the zoo educators opened-up. Given that out-of-school visits to zoos and other LOtC venues are frequently one-off lessons, this analysis has implications for determining ways to increase impact of the experience through elevating the likelihood that the intended object of learning is evident in student learning outcomes.

Continual collaborative work with zoo educators is needed to increase their awareness of the potential of identification and implementation of patterns of variance and invariance. This represents an opportunity for zoo educators to utilise variation theory as a tool for constructively improving lessons (where required). Research-based evidence of quality teaching practice and educational impact is crucial for zoos to justify the effectiveness of their role as education providers (Wagoner & Jensen, 2010).

20.6.2.3 Implications for Out-of-School Teaching

The theory has implications for other out-of-school learning contexts, offering a way of assisting teachers in the field to think about their own practice. Variation theory has the potential to increase the learning impact of engaging, immersive environments by going beyond experiential/affective factors to making strong cognitive gains. We know that science taught at novel venues and in new and exciting ways enthuses students (Braund & Reiss, 2006). Doing more to increase learning outcomes could influence the value of out-of-school teaching.

20.7 Conclusion

This chapter demonstrates that variation theory presents a useful means to plan, implement, and analyse lessons in out-of-school settings to concentrate on the teaching of science concepts. I highlighted students' understandings of critical aspects and identified ways of enhancing possibilities for learning. There is scope for additional research analysing the teaching and learning with learners of different ages, different topics, and various localities. Testing the application of variation theory in other out-of-school contexts requires further study. The analysis of examples of zoo education practice using variation theory provides opportunities for enhancement of pedagogical knowledge and lesson productivity. If out-of-school educators combine reflective practice with a view of student science learning, educators can become more conscious of their actions. Variation theory can provide teachers in out-of-school settings with a theoretical framework to better understand the connections between teaching activities and student learning. Application of a theoretical knowledge base such as variation theory to educator practice has the dual potential of enhancing student learning along with the professional standing of teachers in out-of-school contexts (Tran & King, 2011). Taking a theoretical stance offers educators in out-of-school settings the power to silence the critics by elevating the teaching value and learning potential beyond a 'nice day out'.

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Part VII
Theory Development

Chapter 21
Developing Natural History Museum Object-Based Inquiry for Museum's Group Visitors

Jung Hua Yeh

21.1 Introduction

Informal science education institutions are well-known places of science learning, among which are science museums that include a variety of objects to facilitate learning (Leinhardt & Crowley, 2002). Leinhardt and Crowley (2002) indicated that objects in museums have four characteristics that make object-based learning a unique feature: (a) resolution and density of information, (b) scale, (c) authenticity, and (d) value. Abu-Shumays and Leinhardt (2002) developed the Object-Based Activity Model (OBAM) to explain how docents could make sense of and connect with an exhibit by interacting with the objects in a natural history museum. In Abu-Shumays and Leinhardt's work, OBAM offered a frame to analyze how docents learn by observing objects, framing their understanding of the purpose of an exhibit. As experienced learners in the natural history museum, the docents can focus on the exhibit's purpose while interacting with objects. Meanwhile, most science museum visitors are not familiar with learning from objects alone, often discouraging visitors' learning and making objects' functions ineffectual. Museum science educators may coach visitors to experience learning by observing objects and cultivating personal awareness of science and technology for learning. However, if museum educators are not experienced enough in learning from objects alone, they cannot coach visitors well to learn from objects. As a result, educators' lesson plans might only involve sharing scientific knowledge with visitors directly. From the perspective of a science museum, we expect visitors to learn science concepts from mind engagement and interaction in the exhibit. However, the manner visitors obtain science concepts is related to how science museum educators adopt science education theories to practice—the latter aids visitors in achieving cognitive change during the visit.

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Furthermore, this study introduces a case in which the Taiwan National Museum of Natural Science (NMNS) adopted the OBAM, the Posner, Strike, Hewson, and Gertzog (PSHG) model of conceptual change (PSHG) (1982), the Personal Awareness of Science and Technology (PAST) model (Stocklmayer & Gilbert, 2002), and the Predict-Observe-Explain strategy (POE) (White & Gunstone, 1992) to design an education program.

21.2 Literature Review

There are four theories included in this study. The OBAM is the basic guideline for how people learn from objects in the field of museology. Conceptual change is an important purpose of science teaching and learning. Posner et al. (1982) proposed the PSHG model widely accepted by science educators and is easy to comprehend and apply to learning activities. The PAST model developed in a science museum setting is a good model for explaining how people learn from exhibits. On the other hand, the POE strategy frames the practice and enhances task-related conversations between learners and educators. Below is a brief introduction to these theories, including their definitions, functions, and educational implications in this study.

21.2.1 Object-Based Activity Model (OBAM)

Leinhardt and Crowley (2002) argued that museum objects possess four unique characteristics that enhance learning: (a) they present information in 3-dimensional space, (b) they present in their real scale, (c) they represent reliable and accurate details of the material world or culture, and (d) have uniqueness or monetary value. Due to these four unique characteristics, museum objects could elaborate on the messages embedded in the objects. Abu-Shumays and Leinhardt (2002) proposed the OBAM as a framework that examined two museum docents' learning from exhibits. As described in the OBAM, the docents learned from objects through two main activities: identifying individual objects or sets of objects or processes and then interpreting these objects or processes. This study adopted the OBAM in the context of natural history museums for science teaching preparation (see Fig. 21.1).

'Identify' and 'Interpret' are two main nodes in this model. Interpret comes after Identify. Each of the three sub-nodes (classify, source, and context) under Identify represents a set of activities where an individual identifies objects in the exhibit. Subsequently, the results of Identify enable an individual to Interpret by direct response or transformational communication. Different activities take place during direct response or transformational communication.

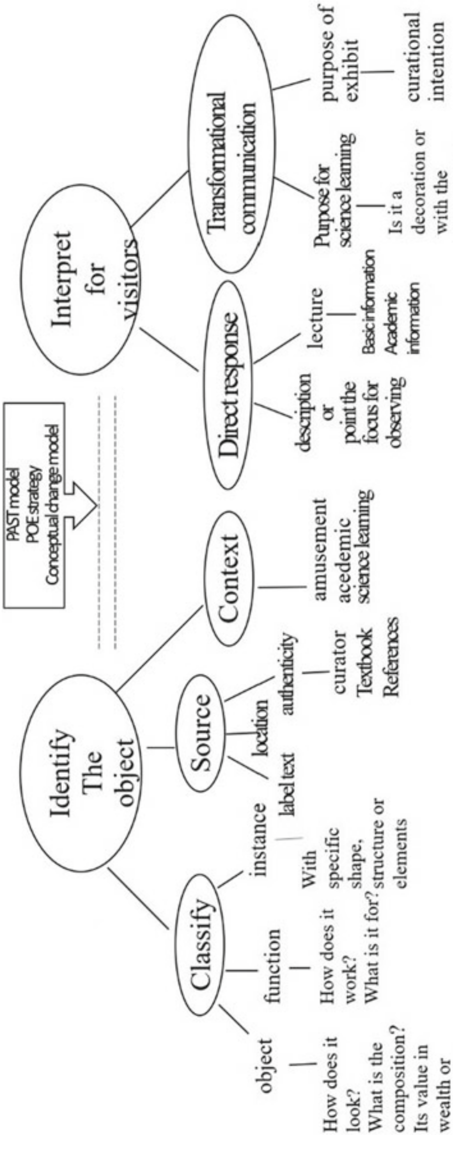

Fig. 21.1 Object-Based Activity Model adopted in the natural history museum science learning framework

In the museum, we followed the interpretations of the science curator, highlighting knowledge and information about certain objects. These interpretations made scientific knowledge a way of presenting in the exhibition. In addition, the science education program presents overwhelming scientific information rather than showing the direction to help visitors think and reason through objects in the exhibition. Thus, to respond to the literacy approach for science education, science educators must put more consideration when preparing lesson plans.

Based on the OBAM, science educators must identify each object/exhibit in the exhibition to re-interpret with some other science education theories to help visitors engage in science exploration activity. In Fig. 21.1, the researcher introduced the PAST, PSHG conceptual change model, and the POE strategy to help museum educators create their interpretations for visitors and design teaching plans.

21.2.2 Posner, Strike, Hewson, and Gertzog (PSHG) Conceptual Change Model

Since the 1980s, several theoretical perspectives have given rise to various notions of conceptual change. The PSHG conceptual change model of learning is a seminal model (Posner et al., 1982). Posner et al. (1982) proposed four conditions that facilitate conceptual change: (a) helping the learner become aware of the inadequacies in their conception (dissatisfaction), (b) helping the learner identify how an appropriate concept works (intelligible), (c) getting the learner to perceive the new concept would be a reasonable explanation of the phenomena (plausibility), and (d) making the learner capable of applying the new concept to other areas of inquiry (fruitfulness). Many conceptual change models came after the PSHG model. Constructivism during the 1980s and social constructivism in the early 1990s led to the rise of social and cultural orientations in the late 1990s. Today, the multi-perspectivism of the social-cultural framework is predominant (Duit et al., 2003; Duit & Treagust, 2013; Tyson et al., 1997). Though the social culture theory well illustrates how conceptual change works, the PSHG model provides practical guidelines for museum science educators in making their lesson plans.

21.2.3 Personal Awareness of Science and Technology (PAST) Model

Writing about their long-term interest in researching visitor experience in science centers, Stocklmayer et al. (2010) used the term 'Public Awareness of Science' to illustrate their research that investigated visitors' experience in science centers through behavioral observations. Their data indicated that exhibit users come to the exhibit with a personal level of attitudes and skills. Therefore, they proposed the PAST model to interpret the learning resulting from interactions in the exhibits (Stocklmayer & Gilbert, 2002). As Stocklmayer and Gilbert (2002) introduced in their study, the PAST model describes a science-based experience designed to present a specific target area of science or technology to the visitor, whose PAST dictated the interaction and informed the reminding associated with it. The quality of the reminding associated with PAST and experience was seminal in deciding the consequences of the interaction.

In particular, the visitor accessed one exhibit and formed Experience1. Though Experience1 only has a weak linkage with the target science concept, experience retrieved their PAST1 and shaped it as reminding. When the visitor accessed the next related exhibit and formed Experience2, it drew similar reminding and retrieved PAST2, which has a stronger link to the target. Then, both experiences shaped PAST3, forming a stronger link to the target. Under this situation, the visitor learned target concepts from exhibits. If the visitor accessed the exhibit related to the target but created and separated reminding/memories from Experience1 and Experience2, they would not catch the target science concept and be unaware of its relationship between exhibits. At times, the visitor would retrieve a strong PAST1 but weak link to the target science concept, possibly connected to another science concept that was not the target concept in exhibits. These situations meant the visitor did not acquire target science concepts.

21.2.4 Predict-Observe-Explain (POE)

Since the late 1990s, constructivist-oriented instructions or strategies have been found to promote students' meaningful learning (Chiu, 2007; Kearney & Treagust, 2001; Tsai, 1998, 1999). Educators seem to have a growing recognition of the need to refocus on students' learning outcomes derived from meaningful learning and their conceptual understanding of scientific ideas (Black, 2005; Chi et al., 1994; Venville et al., 2010).

White and Gunstone (1992) proposed the POE procedure for eliciting and promoting discussions of students' science conceptions. This strategy engages students in predicting the results of an experiment demonstration, expounding on their prediction, observing the demonstration, and explaining why there are discrepancies between their prediction and observation. Further, POE tasks can help students explore and justify their own individual ideas, individually or in collaboration with other students, especially in the prediction and reasoning stage. If conflicts arise with the students' earlier predictions in the observation phase, it is possible to subject initial ideas to reconstruction and revision (Tao & Gunstone, 1999). The POE strategy effectively reveals a student's pre-teaching idea, shapes the context of dissatisfaction with the idea, and introduces plausible explanations. In addition, the said strategy is also an adequate operating protocol of the PSHG mode and can work on a visitor individually or in collaboration with others, which is fit for practical application in the science museum education context.

21.3 Methodology

This qualitative case study documents the working history of the development of the science museum education program. Initial data were collected during the lesson plan preparation workshop for museum staff. The data collected includes field notes and recorded discussions during the workshop. Both cases followed the frame of OBAM in documenting how the science museum educator identified an object while preparing the program and referenced the PSHG model and PAST model in interpreting the object during the program. Further, educators took the POE strategy as their basic teaching procedure. The educators invite visitors to guess how specimen work or moving, the educator asks visitors to observe the shape or specific structure which would be the key points about its function, then invite visitors engage in explaining how the specific structure work on the function. Additionally, data were collected from student participants, and students were observed while participating in a program presented by the museum educator. The participant observation looked at whether students engaged in the task through didactics or inquiry. After the program activity, a group interview with the students was conducted to investigate whether they mentioned the target concepts.

21.3.1 Setting

Case 1: The Giant Squid exhibition—"The Cephalopod family"

This program was designed for a single exhibit of *Architeuthis sanctipauli* captured off of the coast of New Zealand and donated to the National Museum of Natural Science (NMNS) by researchers from the New Zealand National Institute of Water & Atmospheric Research in 2000 (NMNS home page, 2021). In 2002, it became the representative exhibit standing at the main entrance of the Earth Environment Hall (Fig. 21.2). Five presenters and a researcher prepared this program together. At the end of 2003, in an educational staff workshop, the five presenters presented a proposal, adding more knowledge to introduce the giant squid to visitors. They had met the invertebrate storage manager, who showed the presenters the collections of squid specimens in the NMNS and provided them with textbooks on the invertebrate taxonomy of squid and some papers related to classifying squid.

The NMNS employs these five presenters for museum exhibitions. The presenters must take five hours of exhibition presentation for visitors per day, participate in science-related training courses related to temporary exhibitions, and develop educational activities. Although none of these five presenters were college science majors, all took the job after more than eight years of involvement in preparing the giant squid's presentation. Meanwhile, the researcher was the collaborator and evaluator in the project, helping the presenters review the information about the giant squid and evaluate the activity.

Fig. 21.2 The exhibit of a giant squid

Case 2: Storytelling by the Ancient People gallery—“Inquiring the ancient life”

Ms. T is a volunteer of the NMNS who participated in my education staff workshop in 2016. She majored in Chinese literature and is known for evoking children’s inquiry about the natural world by maintaining the campus butterfly ecological garden while leading the teaching affairs of a public primary school. The researcher invited Ms. T to renew the learning sheets for the dioramas in the gallery: “Storytelling by the Ancient People”. She felt the diorama itself was much more interesting than the learning sheet–guided prehistoric potteries and ages. She thought the inquiry of the diorama was hard to navigate without a teacher’s or presenter’s face-to-face interaction.

The gallery included prehistoric age dioramas, pottery, animal bones, and tools. Some exhibits were excavated before the 1980s from China, and many stone artifacts were excavated from different sites in Taiwan from the 1970s to 2019 (Fig. 21.3).

The five dioramas are placed along the main path cut through the gallery. Only dioramas c and d are right next to each other, with several cabinets or show windows in between these dioramas.

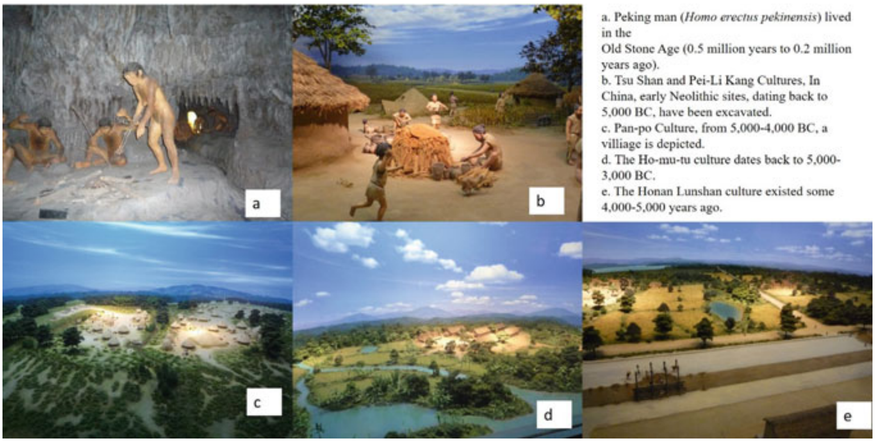

Fig. 21.3 Dioramas in "Storytelling by the Ancient People" gallery

21.3.2 Case Study 1: The Cephalopod Family

21.3.2.1 Identify Object-Related Target Concepts

This project is aimed at developing a single exhibit educational interpretation. The main object of the exhibit was the specimen of giant squid. We also used five kinds of squids and one octopus immersion specimen from the zoology collection—each of them a stretched body fixed on a glass plate and put in a specimen jar with 75% alcohol. All these specimens and teaching aids were loaded in a trolley for the giant squid education program (see Fig. 21.4).

The textbooks provide an understanding of anatomy, taxonomy, physiology, fishery, and evolution. Although several hours of lecture on the introduction of squid is enough, primary school children only have 50 min at this exhibit during their field trip.

Based on the visible parts of the specimens that might look different from human features (prior knowledge), we listed the characteristics in Table 21.1. People often see these animals on their dining tables from October to December in Taiwan—squids' breeding season. Dried squid, which looks like a 5-cm strip, is a popular snack in Taiwan.

The researcher suggested adding a model or specimen of Nautilus, so our objects could provide a brief picture of the entire Cephalopod family. The giant squid exhibit is big enough for visitors to see its body structure clearly. In this case, if the activity focused on introducing the external anatomy of the squid, perhaps we could convince the visitors to view the exhibit and watch the introduction of each part. The exhibit stood between the entrance to the second temporary exhibition room, the up/down stair entrance, and the main connection corridor to the next exhibition hall. Hence, we could not put any fixed shelf, desk, closet, or chair to store teaching aids—the

Fig. 21.4 Teaching aids trolley

staff for this activity put all aids on a trolley. The activity focused on the squid's taxonomy and external anatomy, with 4 kinds of squid species common in Taiwan and only one octopus specimen to show the morphology different from squid.

21.3.3 Transforming Linear Lecture to POE Modular

21.3.3.1 Clarify the Purpose of the Activity

In the beginning, presenters proposed their outline for the presentation: the origin of the giant squid, how it became the exhibit, what the giant squid eats, and who hunts them; the external and internal anatomy, physiology, and taxonomy of Cephalopods and the giant squid as one of them, how they move and hunt, and their life cycle, and the 4 different squids common in Taiwan and how they are hunted and made into food.

The lesson plan is outlined, as illustrated in Fig. 21.5. The presenters set the following objective of the activity: "to know things about the Cephalopod Family".

Table 21.1 Identify information about the object

Object	Academic content	Possible conflict of concepts	Visitor's prior experience
The giant squid	External anatomy	Body structure: trunk, head, 10 appendages (8 arms, 2 tentacles), beak	My body structure: head, trunk, 4 appendages (2 hands, 2 legs), lips, teeth
	Internal anatomy	Two hearts Gills Ink sac	One heart Lungs
	Locomotion	Water jet by hypogastric Mantle and muscle for locomotion	Legs for walking Bone and muscle for locomotion
	Physiology	Blue blood	Red blood
Specimens of squid	External anatomy	Same as the giant squid's description above	Same as above
	Internal anatomy		
	Locomotion		
	Taxonomy		
	Physiology		
Specimen of octopus	External anatomy	Body structure: trunk, head, 8 appendages, beak Interbranchial membrane	Same as above
	Internal anatomy	Similar to squids	
	Locomotion	Water jet by hyponome (swim) Creeping on the bottom of the sea by 8 arms	
	Taxonomy	Similar to the Squid	
	Physiology		

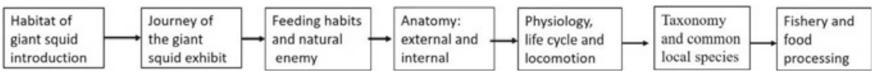

Fig. 21.5 Linear arrangement lesson plan of the Giant Squid

The teaching trolley included 5 specimens and over 60 plates, which could not be seen from the exhibition or specimen. Based on Table 21.1, among the 7 topics in Fig. 21.5, only the 4th and 6th topics were provided for visitors to observe, think, and reason. Most topics relied on A3 size plates in the trolley to present.

The researcher reviewed the National Curriculum Standard of Science of Taiwan, which requires that during the 8- to 9-year school period, science classes must introduce both terrestrial and aquatic animals' locomotion. Most school science classes used to introduce aquatic animals using fishes in a classroom aquarium, which means students might understand aquatic breathing by gills and swimming by fins and tails. The researcher suggested elaborating the purpose of the project as devoted to building students' awareness of aquatic animals with locomotion and body structure different from terrestrial animals.

21.3.3.2 The Situation for Visitors to Predict-Observe-Explain

The presenters thought the dried squid was familiar to 10-year-old students as a kind of snack food—thus, showing the dried squid snack to students might motivate learning. Once the presenters had the visitors' attention, the presenters could quickly go through the academic content about the Cephalopods. The researcher asked the educators to simulate questions for each topic they introduced to visitors. Visitors could answer these questions when they closely looked at the specimens or the exhibit.

The researcher and presenters checked these questions to see how students would respond and if they were capable of reasoning by observation. This mechanism ruled out any content that relied only on pictures or photos to introduce the objects. The proposed questions by the presenters are listed in Table 21.2.

The column "content knowledge" contains what presenters insist on including. Observation linked visitors' attractions to objects they could find clues to identify. The presenters used to talk content knowledge to visitors and leave a few seconds for visitors to view the objects. We asked them to question visitors, help them reference object observation, listen to their reasoning (to understand what visitors have known or not known), and respond by explaining or refining visitors' thoughts.

The first row of Table 21.2 talks about the external anatomy of the squid, which arouses students' enthusiasm and engages them in observing. The presenters also expected to introduce the internal anatomy, considering these are unobservable from the specimens, and most organs have similar functions to human organs. Therefore, the internal anatomy and a diagram for introduction are made as supplements for older students who show interest.

In the second row of Table 21.2, the presenters analogize the ring gear around the sucker to the teeth because the plate beside the exhibit described the giant squid using its arms to grab a sperm whale, and its sucker left a circle-like mark on the whale. The main function of the sucker is not to tear or cut things into pieces for eating, but it could do this occasionally. Subsequently, the content about suckers moved into introducing the arms and tentacles. Preparing small balloons demonstrates how Newton's third law explains how things move.

Based on Table 21.2, the presenters reorganized their lesson plan, as shown in Fig. 21.6. The topics were modified to modular: the first row of Table 21.2 involves the starting point to motivate visitors' curiosity and associate related experience of

Table 21.2 Questions for inviting visitors to observe specimens

Content knowledge	Observation	Question	Plausible answers by students
The Cephalopods' heads connect to their body and legs Their digestive and reproductive organs are in the trunk, which extends from their head	The giant squid exhibit	Can you identify its head, body, and arms?	It is easy to identify the eyes located on the head, and those arms were for movement
The Cephalopods' arms surround the mouth. They have a parrot-like beak, and suckers on arms	Squid immersion specimen Dry specimen of the beak	What do you think their mouth looks like? How does the squid tear food into small pieces?	The beak was embedded deeply in the center of the arms Students might guess it has teeth inside the beak
The Cephalopod pumps water out of its body, pushing them forward—Newton's third law of motion	The giant squid's funnel The Octopoda immersion specimen's funnel Shell of Nautilus	Can you describe how the giant squid moves?	Students might reason by their own way of swimming and that of fishes to guess the Cephalopod swims by its arms
Taiwan's common species of squids: Myopsida, Ldigindae, Sepiida, Oegopsina	4 jars of squid immersion specimens	Can you recognize their names?	Students might know its common name in Chinese and might have seen them in fish markets

the Cephalopod. The presenters could respond by one of the four strands according to visitors' interests. In addition, the presenters could decide to go on one or more strands depending on visitors' interests, cognitive ability, and time.

21.3.3.3 Evaluation

Five classes with four grade students attended the teaching trial; each class had 30 students. The five classes came from the same primary school located beside the NMNS. The distance from the school to the museum is less than 2 km. Each class came in the morning on the same Wednesday and took 45 min to participate in the activity and 15 min in a group interview with the researcher.

The teaching sequence is as follows: (1) opening remarks (show students the dried squid snack); (2) ask students to identify the external anatomy (reference the exhibit); (3) introduce the squid's beak and its manner of eating (dried specimen of squid's beak); (4) give students a balloon to blow up and tell them about Newton's third law; (5) show them the four common squid specimens, and tell them how to recognize them. Each presenter took one class for trial. Presenter A attempted to introduce

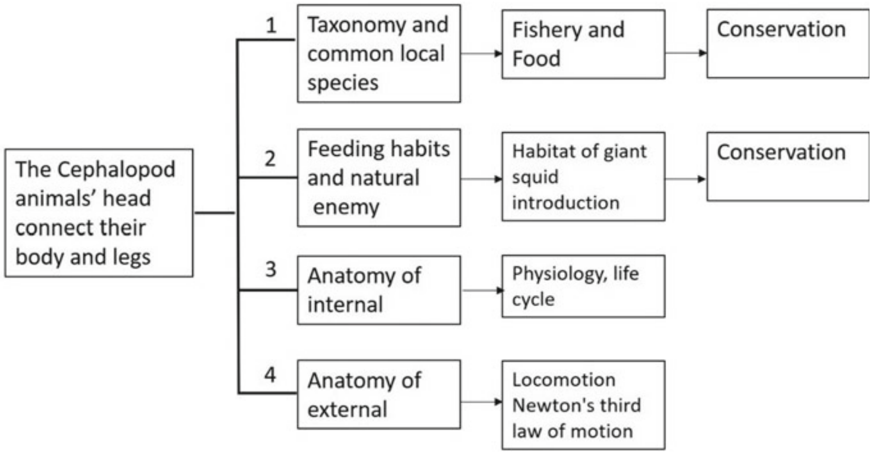

Fig. 21.6 Modular lesson plan of the Giant Squid

all four content sections. However, he had to ignore some students' questions and requests in each section to go at his pace.

The other four presenters covered two or three topics by their own standards. Table 21.3 summarizes students' responses during the activity. The presenters felt anxious because they could not go through all the topics as planned. They found that letting students observe the exhibit or specimens to answer questions is more efficient and attracts children's attention more quickly than just letting them see a poster or diagram or listen to something. The presenters were amazed that students observed the specimens or the exhibit closely and expressed curiosity about more topics that were not in the presenters' sequence or were more advanced than the presenters' information.

Though every class was excited when they saw the dried squid snack, they did not mention it in the after-activity interviews. Most students described their impression of the activity by what they discussed in the activity: Did the giant squid live upside down? Were the eyes on the same plane or on both sides of the body? How big could the squid's mouth open? Could suckers help tear food into small pieces? Did its arms help it push out water from its body? Students felt they learned from the activity about the squid's anatomy and locomotion and found the experience more interesting because the presenter spoke less. This way, the students could examine the specimen to find answers or initiate discussions.

Table 21.3 Summary of students' responses during the activity

Class code	External anatomy	Beak and eating	Locomotion	Taxonomy
A	1. The dried squid triggered a lively side talk 2. Excited about the head being connected to the arms directly 3. Internal anatomy lasted for 2 min	1. Students were noisy about where is the beak 2. Confused about why the dry beak is so big and the beak in the specimen looks so small 3. Side talk about the size of their food	1. The presenter gave them a balloon to blow up and observe the moving direction when released; students were too excited to maintain order	1. Left few minutes to introduce the taxonomy of cephalopods 2. The presenter showed them the four common squids, and the students observed them closely
B	1. Same as above 1, 2 2. Before the presenter began the internal anatomy part, students asked about locomotion	–	1. Looked at the suckers on the arms very closely. (exhibit) 2. Discussed the shapes around the sucker: function and shapes similar to Octopoda's	The presenter introduced the fin on the trunk as a kind of index for taxonomy; students asked more about the function of the fin for swimming
C	1. Same as A 1, 2 2. Before the presenter began the internal anatomy part, students asked about taxonomy	–	1. Discussed with the students the function of the arms and tentacles, as well as fishery tourism	1. Students viewed the specimens and posters of squids very closely 2. Some side talked about fishery tourism
D	1. Same as A 1, 2 2. Before the presenter began the internal anatomy part, the students asked about eating	1. Took some time for all students to view the beak in the specimen 2. Side talked about eating the beak in a wedding banquet	–	Students wondered if the squid's orbicularis oris were as big as they had eaten. There is a common dish named "dragon ball" made of orbicularis oris
E	1. Same as A 1,2 2. Before the presenter began the internal anatomy part, students asked about locomotion	–	Students were interested in the function of the arms and tentacles and why they were not the main power when swimming	Observed the specimens for the small sac under the eyes, which keeps the tentacles while not hunting or does it with/without a nictitating membrane

Note: The cell marked '—-' mean students skipped the topic

21.3.4 *Case Study 2: Inquiring About the Ancient Life*

21.3.4.1 Identify What We Can See from the Diorama

The teaching goal of "inquiring about the ancient life" is to make reasoning according to evidence. People visit archeology dioramas and take them as a kind of "truth". Diorama construction follows what the archeologists found on site. If new findings represent advanced engineering or technology, these new findings will change our understanding of the past. Accordingly, the diorama content might change.

The researcher and Ms. T walked along the main path of the "Storytelling by the Ancient People" gallery, with Ms. T thinking out loud about what she saw in each diorama and what she thought could facilitate students' inquiry. The researcher discussed with her to clarify her idea or supplement some information, such as how the museum built the diorama according to archeological findings. After three hours of discussion, Ms. T summarized what she obtained from the dioramas: "…dioramas A and B are where people lived; there might be one family living in the cave. Diorama B reveals more relations between people living in the same village. Dioramas C and D enlarge the scale to include more natural environmental characters, revealing people living in two different places with different lifestyles…". The researcher outlined her ideas in Table 21.4.

21.3.4.2 Scaffolding Diorama Inquiry by Questions

Ms. T thought bringing students to the museum for a half-day field trip would give her at least one hour in the gallery. An hour-long visit activity was not enough for 10-year-old school children viewing and thinking about all five dioramas. Thus, she suggested that each class send students into four groups and that each group take only one diorama. After 20 min of inquiry, each group will have a five-minute oral presentation with their poster to introduce their diorama to the other students. Before the group inquiry, she would use diorama A to have a conversation with the whole class to demonstrate how to observe the diorama for about 15 min and how to reason about the ancient people's life. The researcher outlined her scaffolding questions as follows:

1. What are the basic needs for a place to live?

    (1) How did they create a house to fulfill these needs?
    (2) How did the ancient people adapt their houses to the local climate?
    (3) Where did they get material to build the house?
    (4) Did the family build the house, or were there specific workers?
    (5) Why were there different styles of houses?
    (6) What were the relationships making people live in the same house?

Table 21.4 What Ms. T read from the diorama

Diorama	Things	Relationship
A Paleolithic age	1. In the outer cave, three people sit around the fire, and one stands beside them. Each person with a stone or twig in their hand is doing things 2. In the inner cave, one female adult hugs a child in her arms 3. A child and a thin man are standing in the deepest part of the cave 4. No one wears clothes	1. The four persons may hunt together; they stay at the entrance of the cave, perhaps, to protect others in the cave from enemy or animal attack 2. A woman takes care of a child 3. A child and an elderly man are staying inside 4. They do not have the skill to make clothes
B Neolithic age	1. There is a foxtail millet farm, several houses, a corral, and an open-air kiln 2. One house section can see the construction and furnishing in the house. There is a small fire 3. People do different jobs: farming, pottery, sharpening stone tools, cooking, fishing, or hunting	1. Agricultural society, where all people wear clothes 2. Semi-burrowing; no technology to build high buildings—the place has no flooding and is a little cold 3. The people may have occupation differences. People can barter with others
C Neolithic age- inland area	1. Looks like three or four groups of houses. There is a farm, a corral, different shapes of houses, and open-air shelves with leather on them 2. Each group with a big pyramid-shaped building at the village entrance. People do different work 3. One group of houses without a pyramid building seems separated from the others by a ditch. There is a big kiln with shelter and a place with several people are doing a ritual	1. Different shapes of houses might have different functions. People wear clothes; they process leather and dry in the sun. An occupation-diverse society 2. Pyramid-like building with an entrance might be the village meeting place 3. Different zones might have different usage. The big kiln and ritual place (funeral) are far from other villages and separated by a ditch
D Neolithic age- coastal area	1. Tropical plants grow prosperously in all areas, with river and coastal landscapes 2. A stilt architecture long house, with chickens and pigs feeding under the house. One long house is under construction—the structure and compartment inside are visible 3. Several small boats are on the sea, each boat for one or two persons, and some of them have fish nets. No paddles 4. There is a paddy field near the river, and some cows bath in the river	1. The climate may be warm and have heavy humidity 2. Each long house has 3 to 4 rooms; each room could house 5–6 persons (with the scale of humans in the diorama). People living in the same long house might be relatives who share labor for farming, fishing, and housekeeping 3. They may get food from the sea. A paddle is not found on the site 4. They may gather food from paddies, and cows may be fed by humans or the wild

(continued)

Table 21.4 (continued)

Diorama	Things	Relationship
E Bronze Age- inland area	1. A huge earth wall with a gate and several guards with metal weapons stand on it. A wide dirt avenue runs through the diorama. No horse, cow, or carriage on the road 2. Several houses are surrounded by large farms with ponds nearby. Farms are separated by trees 3. Several persons carry burdens and trunks, come along the wall, and head to the gate 4. There is a majestic palace inside the wall; its height and style are different from other houses 5. The farmers, wall-makers, soldiers, and travelers dress differently	1. In a stratum society, the ruling class may live in a palace. The wall means they need to defend against a strong enemy. Such a big avenue might be needed for an army marching or a carriage; however, there is no evidence of these 2. The ponds are close to all houses, so they must be constructed by humans. They have the concept of property 3. They may have business between different cities 4. Different house style represents the owners' social classes 5. They have the technology to create big construction, make metal weapons, dig ponds, and make different textiles

2. How did the ancient people acquire food?
   (1) Gathering? Hunting? Farming?
   (2) Did they prepare food alone, with family members, or with a cooperative group?
3. Did they make tools or things they need alone?
   (1) Was there a professional tool maker?
   (2) How did people get the service?
   (3) Do you think there was someone in charge of organizing work?
4. Why did they dress like this?
   (1) Are they dressed all the same or different?
   (2) How did they get their clothes?

Each question would be followed by sub-questions if the group reported their findings without corresponding to those sub-questions. During the group discussion process, the educator should keep students' interactions focused on the basis of the inference rather than going to cooperative fantasy. The educator should ask them, "What did you see in the diorama to support your theory of their life?" and encourage the group to take short notes or mind maps and present their results.

21.3.4.3 Students' Prior Knowledge and Experience

The researcher reviewed the National Standard of Curriculum (Taiwan), the social study field at the primary school level, the history of regional reclamation, and the indigenous people from the seventeenth century to the present for 4th graders (10-year-olds). There are some supplemental readings introducing prehistory archaeological sites from 6000 B. P. to 400 B. P. in Taiwan. Students might have a blurred image that Taiwan had gone through the Neolithic age (6000 B. P. to 1600 B. P.) and the Iron age (1600 B. P. to 400 B. P.) and entered the historical era in the seventeenth century. No Bronze Age remains have been found in Taiwan. However, there were several popular children's books introducing the prehistorical culture found in China and mentioning in detail the Bronze Age in China. Though these dioramas were not built to show the prehistory-era lifestyle of Taiwan, they offer the image of craftsmanship, engineering, and technology for students.

This activity did not include specific concepts to learn, and no instance might arouse conflict with students' pre-existing concepts about ancient people. In the activity, students must include a large amount of their prior daily-life experience to infer how the ancient people's life looks.

21.3.4.4 Evaluation

Three classes of 10-year-old 4th graders (a total of 56 students) participated in the activity trials. Ms. T hosted the three classes. Each class had students form into four groups in front of the entrance of the gallery, and every group took one exhibit to introduce to the others. Students were told they had to find answers from the diorama by themselves. Ms. T took diorama A as an example of how to look for answers from observing the diorama. Each group assigned one student to take notes and one student to decide the sequence of questions for which they looked for answers.

All group members engaged in the task seriously and responded to most questions in the presentation. Every class's diorama B and C groups had a problem finding the water supply for the village to live in, and diorama C groups thought it was a desert. After the educators reminded them, they found remarkable clues to refine their reasoning about the environment of the diorama. All diorama E groups focused on the palace in the wall first. The educator had to remind them of other instances in the diorama.

One of the class teachers sent the researcher five different students' weekend diaries, one-page articles written during the weekend after the activity. In the articles, the students expressed interest in examining the diorama closely and learning by themselves.

21.4 Discussion

The two case studies introduced above were the NMNS attempt to adapt science education theories as guidelines in our practice. In the first case, the OBAM is a basic framework for museum staff to prepare their activity and meet the requirement that enables visitors to learn from objects. The second case used the OBAM framework to identify the information in dioramas, and the educator listed questions as scaffoldings for students to reason (relationship in Table 21.4) by their observation.

Both cases completed the development of the education program, and the evaluation confirmed both cases achieved their purposes. The two programs first started with questions. Participants needed to find clues by themselves; the presenter responded by revealing something that would amaze others instead of judging their answers as right or wrong. It is an unusual experience in Taiwan's social culture.

Furthermore, the following will be discussed: the POE strategy works in museum practice, the role of science education theory in museum practice, and the vision of object-centered learning in a science museum.

21.4.1 The POE Strategy Provides a Pattern for Recognizing Visitors' Thinking and Giving Them Adequate Feedback

The OBAM suggested that museum learning is a collaborative conversation between learners and educators. A guided routine tour in a science museum gives a brief lecture for each exhibit, where visitors often ask the scientific terminological questions. It is rare to have a conversation about observing, reasoning, and discussion.

The POE strategy is a behavior pattern. The learner expresses their ideas about predictions and observes to get proof of their predictions. If the experiment did not support the prediction, the learner had to give an explanation. In the two cases, the educator asked the learners to give their instinct or inference about the animal or prehistoric age of the diorama rather than predict motions or trends. Learners elaborated their inference and came up with explanations by observing the object. The behavior pattern shaped a situation for learners to present their original idea about the topic. Then, the educator could determine if the learner is a beginner or is at an advanced level and coach them to find more information or switch to the next topic.

The first question to learners in the "Cephalopod Family" was, "Can you identify its (the giant squid) head, body, and legs?". The question invited the learner to the inference: tube-like eyes and mouth located in the head. Then, the learner would contrast their own body structure: the head should connect to the body, and the body should link to the hands and legs—what a weird animal this is. When the learner perceived the inconsistency with their common sense, they would seek more information by observing or asking questions. If the educator could respond to the learner's question by looking for clues from the object and encourage the learner to infer or guess instinctively, the learning would revolve around the object (the giant squid exhibit or specimen).

In the case of "Inquiring about the ancient life", the educator told students at the entrance of the gallery, "I'll not teach you anything; you have to answer the questions that I ask according to what you see in the diorama". In front of Diorama A, the educator asked each question to students and followed up on their responses by asking sub-questions or clarifying how students interpreted their observations. This mechanism built the pattern of conversation, allowing students to realize how they need to see and think. Then, the educator assigned each group one diorama to do a presentation with the meaning of "to make inference and find instances from diorama to proof". It also followed the framework of POE.

21.4.2 The PSHG and PAST Models Provide a Perspective to Check if the Educational Program Created an Appropriate Situation for Learning

In the Cephalopod Family, the researcher drew the criteria of the PSHG model to check whether there was information that might arouse the students' dissatisfaction with their prior knowledge and applied the object to provide an intelligible instance as a replacement. On the other hand, the PAST model reminds us that some prior knowledge or experience awareness by visitors might not produce fruitful learning.

In Case 1, the educators expected the dried squid snack to motivate the children's learning, but the children associated the snack with other life experiences and had unstoppable side talks, which interfered with the progress of the activity. The common wedding dishes, dragon ball, a squid's beak with surrounding muscle, and the four common Taiwan squids are common on the children's dinner tables. Once these past experiences were evoked during one topic, they did not gain more content knowledge but accelerated much more side talk about life experiences. In the analysis of content knowledge in Case 1 in the column "Plausible answer by students", the useful prior knowledge or experiences were those that compare one's body to the Cephalopod Family's body and build understanding.

For "Inquiring about the ancient life", the core concept revolves around the application of the learner's life experience to infer how ancient people live. The archeology information is so complicated to clarify what might cause the contrast between two different ages. Thus, identifying what might be the related prior experience is complex. Learners might associate the pyramid-like building with the image of Egypt and the desert, even though the diorama's detailed landscape is not the same as the desert in Egypt. Learners' camping experience might also help them understand the importance of getting water, the safe place for the tent, and the difficulty of building a house higher.

According to Duit and colleagues' review, the PSHG model for conceptual change is efficient in well-defined subjects, such as physics concepts not so useful for biological concepts (Duit & Treagust, 2003). In the two case studies, the biological subject matter (the Cephalopod Family) is more systematic than the archeology subject matter (Inquiring about the ancient life). The PSHG model is more useful in Case 1 than in Case 2.

21.4.3 Object-Centered Learning in Future Museums

Object-centered learning is associated with all kinds of science equipment and the professional laboratory. The two cases introduced how we use exhibits and dioramas to create object-centered learning. A single exhibit and a gallery could make object-centered learning projects without specific space or expensive equipment. This type of education program is the entry point for coaching people on reading from objects and learning by themselves. Once people get used to reading objects and learning from objects, they can widen their imagination and interpret things from diverse perspectives.

The museology maintained that the exhibition should follow the interpretation of its curator. In Case 2, the educator presented the belief: conduct an exhibition with its curator's interpretation, while the educator can still present interpretations for education. I agree with the opinion. Learning from an object means getting information from an object and reorganizing the information by the learner—one learning is their interpretation of the information.

Apart from the inquiry objects in the exhibition hall, the NMNS is preparing new science labs for all ages. Museums have many activity styles: guided tours, exhibit explorations, experiment demonstrations, lecture rooms, science camps, hands-on activities, film festivals, science dramas, and speeches. Regardless of the program style, the object-centered program is always more popular than others. Although the COVID-19 pandemic stopped all realistic activities, science museums offered short lectures, science films, and online podcasts. There are also countless science films or podcast competitions for audiences. The NMNS provided the webcast lecture with free access to specimens online and in a digital collection. However, the question lies in how we can ensure these unique virtual services enable people to learn by objects.

Furthermore, the study found that the PSHG and PAST models could help check whether a program can adequately introduce science concepts to target audiences. Meanwhile, the POE strategy can also be used in face-to-face interactions and in online programs to improve the quality of interactions in the future.

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Chapter 22
Merging Three Learning Theories to Understand How Learning Outside the Classroom Institutions Learn Themselves

Suzanne Kapelari, Theano Moussouri, and Georgios Alexopoulos

22.1 Introduction

Scientists from many different fields provide evidence that climate change has multiple impacts on the global eco-system and, consequently, on human life on this planet. Biotic, economic, and social interaction and feedback processes lead to a highly complex non-linear response and small selective changes already may have a profound impact. In a piece published in the New York Times in 1946, Albert Einstein raised his voice and asked for, "two hundred thousand dollars at once for a nation-wide campaign to let people know that a new type of thinking is essential if mankind is to survive and move toward higher levels" (Atomic education, 1946, p. 11). He called this 'atomic education'. At the time, scientists had learned how to release atomic power and thus sent this appeal after a, "long consideration of the immense crisis we face" (Atomic education, 1946, p. 11).

Today, scientists and education scholars address a similar need and, much like Einstein did more than seven decades earlier, they urge society to develop competencies and skills to change traditional thinking patterns. This requires new educational approaches. Not only formal but also informal education institutions, such as museums, science centres, or botanic gardens (henceforth, BG), should stop treading the traditional path and play their part in social change. Currently, the European Union's educational policy puts significant effort into implementing 'new

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types of thinking' such as engaging the public in 'Responsible Research and Innovation' or in 'Co-creation' processes (Smallman & Patel, 2018) to face global challenges addressed by the United Nations Sustainable Development Goals (United Nations, 2020). Formal and informal education institutions should contribute to this endeavour. However, hardly any research exists on the reasons why many informal learning education institutions do not engage in large-scale national, international, or global educational reform efforts (Phillips et al., 2007) and how these institutions may become platforms for societal change and dialogue. One reason might be that educational institutions are rooted deeply in their culture and history and, thus, equally challenged when it comes to changing perspectives and adopting new ways of thinking and acting. However, it is necessary to understand the complex interplay that allows or prevents informal learning institutions from adapting non-familiar educational approaches actively to support these institutions to become active change agents in education.

This chapter addresses the theoretical framework applied in a study carried out as part of the European Commission (EC) funded Horizon 2020 'Science with and for Society' funding scheme (European Commission, 2018). The Botanic Garden Conservation International (BGCI) coordinated the project, which brought together educational departments of BGs, universities, and other knowledge organisations from 12 European countries and one from Uganda, Africa. The main goal was to support BG practitioners in gaining the knowledge, skills, and experience to engage the public in participatory processes and transdisciplinary dialogue addressing the global challenges of food security (BGCI, 2020).

This project posed many challenges for BG educators since both the topic of 'food security', the concept of RRI, and the notions of 'reflective' practice and 'co-creation' were, by and large, unfamiliar to them. Hence, participation in the BigPicnic project was not without conflicts and contradictions for BG educators. Conflict created a space for learning and reflection, and from an education theory perspective, it gave rise to a highly complex learning system at two levels: [1] at the consortium level on which Partner organisations shared their ideas and [2] at the individual BG level at which members of the educational departments tried to implement BigPicnic ideas in their institution and their social environment.

This chapter aims to provide an insight into the theoretical background that was the leading action in the H2020 project BigPicnic and shows how and why the merging of three theoretical perspectives helped us to observe and explain complex learning systems active in an interdisciplinary and multicultural settings. Engeström's Cultural Historical Activity Theory (Engeström, 2000), Organisational Learning Theory (Argote, 2013; Kim, 2004), and situated Learning in Communities of Practice (Lave & Wenger, 1991) are helpful perspectives to explain multifaceted learning in a multicultural project consortium. This chapter offers a meta-analytical perspective and as such its findings are applicable in other similar organisation settings. The aim is to offer a meta-analytical framework for studying organisational learning in informal learning institutions (Kapelari, 2015).

22.2 Application in the Literature

Our understanding of knowledge and how people acquire and apply knowledge plays a key role in how we conceptualise education, in general, and Western educational goals and educational systems, in particular. In addition, it is important to conceptualise knowledge as supporting individuals or groups or even organisations. To gain knowledge is a central goal for any educational activity. Sfard (1998) used two metaphors to explain creation of knowledge. The most broadly accepted one sees knowledge as a property of each individual's mind. "Concepts are to be understood as basic units of knowledge that can be accumulated, gradually refined, and combined to form ever richer cognitive structures" (p. 5). The acquisition contrasts with the participation metaphor. The latter sees knowledge as a process of participation in various cultural practices and jointly negotiated. "The context [in which it takes place] is rich and multifarious, and its importance is pronounced by talk about situatedness, contextuality, cultural embeddedness, and social mediation" (p. 6). Knowledge is also a matter of enculturation and learning thus situated in this culture.

22.2.1 Communities of Practice

Situated learning draws attention to the idea that knowledge creation happens jointly and is unique to a given situation. Each participating individual may construct and acquire knowledge to a given extent while participating in a situated learning process (Lave & Wenger, 1991). However, this knowledge is not equal for all members of the group. Learning is not something that takes place in the mind of the individual in the process of acquiring new ideas, concepts, and knowledge. Instead, the social interaction of individuals when participating in society produces and reproduces learning. Lave and Wenger (2004) coined the term Communities of Practice (CoPs) to describe groups of people sharing and improving their knowledge collectively. They viewed CoPs as important change agents for organisational development. Wenger (2000) argues: "Communities of practice grow out of a convergent interplay of competence and experience that involves mutual engagement. They offer an opportunity to negotiate competence through the experience of direct participation. Consequently, they remain important social units for learning even in the context of much larger systems" (p. 229). According to Wenger (1998), Wenger et al., (2002), the distinctive characteristics of a CoP are its members' commitment to a *domain* of knowledge, the relationships developed between the members of the *community*, and the advancement of their *practice* through the development of a shared repertoire of resources. Informal education institutions, such as zoos, BGs, and museums provide the organisational context within which CoPs are situated. CoPs associated with museums may include museum educators, scientists, or the management, the members of which interact with each other at various levels and to various degrees. The extent to which these interactions help museum professionals to organise themselves within a community of practice is crucial to the development of the organisation itself and for the ability of the latter to adapt and to thrive in an ever-changing environment.

Within the context of BigPicnic, a reflective-oriented approach to evaluation, namely Team-Based Inquiry (TBI), was a key means for mediating BG educators' interactions (*community*). TBI is a type of action evaluation, originally developed to help teams of museum education professionals incorporate evaluation into their practice, collaborate to collect evidence, and reflect on its value. This collaborative reflection-oriented approach to evaluation as a way of developing understanding of food security as a source of topics suitable for BGs to address (*domain*) enabled the group of BG educators who participated in BigPicnic to reflect on and make sense of the cultural and historic patterns of their institution, with its social norms and hierarchies. This reflection, in turn, informed how they thought about their practice and became the catalyst for transforming their practice and, to various degrees, the practice of their institution (*practice*).

However, Amin and Roberts (2006) argue: "Alongside the increasing popularity of communities of practice research, the approach has begun to attract criticism concerning, for instance, the neglect of power, its failure to take into account pre-existing conditions such as habitus and social codes, as well as its widespread application within organisational studies beyond its original focus on situated learning, and the term 'community' itself, which is problematic, embodies positive connotations and is open to multiple interpretations" (p. 4). Engeström and colleagues (2000) try to explain interaction taking place in organisations with a model called Cultural Historical Activity Theory (CHAT). This model is helpful to observe and explain why some BGs are open to change whereas others are reluctant.

22.2.2 Cultural-Historical Activity Theory (CHAT)

CHAT is not a theory but a theoretical framework that focuses on new forms of learning and social practices while it considers the history and culture of a collective developmental process (Engeström & Sannino, 2010). Engeström (2000) argues that CHAT is a general cross-disciplinary approach offering conceptual tools and methodological principles tailored to the specific nature of the system observed accordingly. Sociocultural approaches to learning and development have the potential to recognize the essential relationship between learning processes and their cultural, historical, and institutional setting. CHAT argues explicitly that any activity connects to cultural as well as historical processes. In addition, it provides a link between individual learning and learning taking place among organisations. As an analytical framework, it helped us analyse the developmental processes occurring in the multicultural European BigPicnic consortium.

According to Engeström (1987), an activity system is object-oriented, mediated by artifacts, a community, applied rules, and a particular division of labour (Fig. 22.1). In the context of the BigPicnic project, the *subject* is a person or a group of individuals representing a particular BG participating in the international consortium. These

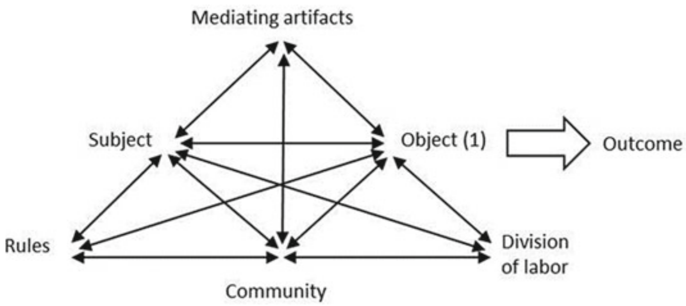

Fig. 22.1 A botanic garden is an activity system (Engeström, 1987, p. 78, cited by Kapelari, 2015)

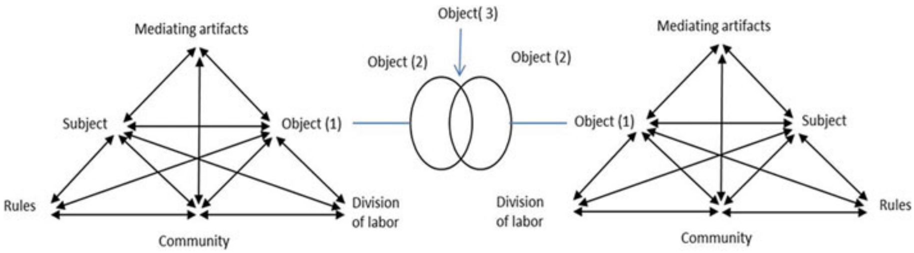

Fig. 22.2 Two botanic garden activity systems interacting as a minimal model for inter-organisational learning (Engeström, 2001 p.136, cited by Kapelari, 2015)

people meet on a regular basis and exchange knowledge and experience gained while working towards project-specific objects. In CHAT terminology, the consortium is the place where inter-organisational learning takes place and activity systems work together to produce shared *objects* (see Fig. 22.2).

The BG team (subject, Fig. 22.2) works towards one or several *objects*, which are the BigPicnic project goals and objectives. *Outcome* in this respect are exhibitions, workshops, and science cafés designed and implemented to engage a given target group of people in a debate on food security-related issues.

To transform *objects* into *outcomes* the BG education team needs *tools*, instruments, or *mediating artifacts* (Fig. 22.2). These *tools* are either individual knowledge or situated knowledge created in the setting of a co-creation event or of a TBI evaluation study. Facilities in the garden or a particular exhibition hall or science café setting also are *tools i*n this respect.

Each BG is an organisation in which the activities take place. This organisation consists of a larger group of garden employees, which share more or less the same *objects*. The organisation consists of people personally engaged in the implementation of BigPicnic goals on-site and people working in the garden who are involved in different ways and to different degrees in this process. The members of the organisation *divide labour* amongst them, for example gardeners nurturing plants, graphic designers producing leaflets, and the garden directors or ticket vendors working at the exhibition entrance. Finally, this organisation has its own *rules* and conventions that make members of the BG behave in a particular way. These rules are norms and traditions, which more or less explicitly are understood and accepted by *community* members.

To understand inter-organisational learning, we need at least two activity systems, for example two BGs sharing knowledge and experience at the consortium level (Fig. 22.2). In this case, the BGs have a shared *object*, such as a project report, policy paper, or a science café tool kit. BGs work together to produce these collective *outcomes*.

A fundamental assumption of sociocultural approaches to learning and development is that actions—rather than human beings or the environment considered in isolation—provide the entry point into the analysis. In this respect, Engeström's 'Expansive Learning Theory' adds another set of 'somewhat philosophical' perspectives to consider in this framework.

An Activity System respectively, such as a BG, "resolves its pressing internal contradictions by constructing and implementing a qualitatively new way of functioning for itself" (Engeström, 2007, p. 24). However, this is not a one-way movement from incompetence to competence. It includes horizontal movement while learners construct new concepts or objects for their activity. Thus, expansive learning concerns the learning of new forms of activities as they are created rather than the mastery of already known and well-defined existing knowledge and skills (Kapelari, 2015). It mainly concerns collective learning rather than individual learning and, although it acknowledges vertical learning, Engeström (2000) suggests, "we focus on constructing a complementary perspective, namely that of horizontal or sideway learning and development" (p.533).

Activity Theory and expansive learning theory enable insight into the variety of BG activity systems active in this project consortium. To deepen and broaden our understanding of how these different systems work together, we consider it important to bring CHAT in conversation with system thinking theory.

22.2.3 Organisational Learning

Many scholars attempt to bridge the gap between learning as an individual task and learning as participation in a team. One such approach—the so called 'integrationist perspective'—developed a theory of 'organisational learning' (Starkey et al., 2004). Working within this perspective, Dyck et al. (2005) argue that, "organisational learning begins with the cognitive processes of individuals and is enhanced and preserved by organisational processes" (p. 388). If learning has value as a situated process in a social context, the individual learner cannot be the only centre of attention. The social group, subgroup, or organisation in which this learning takes place is an entity for learning. In CHAT terminology, the organisation is an activity system and organisational learning the object to achieve. Thus, it is necessary to understand the process through which individual learning advances organisational learning. Individual knowledge and memory play an important part in the process of embedding knowledge and experience in the organisational memory and its structures (Kapelari, 2015). Organisational memory and knowledge are the capability all members of an organisation develop collectively over time. Its application depends on historically evolved collective understanding and experience (Kim, 2004).

The way in which educational activities are expected to take place, what type of activities are valued, and what is assumed to be ‘good education program’ or a ‘successful exhibition’ in a BG setting are not only matters of each educator’s own interpretation. They are also shaped by organisational traditions, knowledge, and experience accumulated over time. However, the role these organisational processes play when it comes to implement innovative ideas or unfamiliar educational practices may or may not be recognized or valued explicitly.

Organisational knowledge can be embedded in a variety of repositories, such as written educational programmes, process documentations, staff members routines, or memory systems such as archives or online repositories. A collective understanding of organisational knowledge is a key to understanding the growth of an organisation. This knowledge enables the organisation to use its resources accordingly. It is a distinctive way of thinking and acting in the world (Kim, 2004).

Thus, from this perspective, organisational learning is a change or growth in the organisation’s knowledge that occurs as a function of experience. Organisational knowledge herein includes declarative knowledge, such as facts, and procedural knowledge, such as skills and routines, which members of a particular community share. Organisational knowledge may be measured either by the cognition of organisational members or by taking a behavioural approach. The latter focuses on knowledge embedded in performance such as accuracy or speed, in practices, or routines. Changes to the latter are changes in knowledge. Thus, organizational learning is a change in the range of potential behaviours. However, organisations may acquire knowledge without a change in behaviour (Argote, 2013).

Research in organisational behaviour studies the impact that individuals, groups, networks, or structures have on how an organization works. The purpose is quite similar to education research, namely, to apply knowledge to improve an organisation’s effectiveness (Kapelari, 2015). Referring to the work of the French sociologist Pierre Bourdieu, Splitter and Seidl (2011) posit: “Social practice performed by individual actors is influenced not only by the actors ‘individual disposition’ (such as origin, education, and identity) but also by supra-individual ‘objective structures’ (such as socially defined interests, beliefs assumptions and resources)” (p. 103). Research and praxis are different social spheres, which exhibit different structures associated with different types of knowledge. Actors belonging to one or the other sphere carry out their activities while facing different structural possibilities and constraints, such as being guided by different domain-specific interests, beliefs, and assumptions and are limited or supported by particular sets of resources. Particular conditions that exist in one or the other sphere lead to specific ways of perceiving the world and even to using different language (Kapelari, 2015).

22.3 The BigPicnic Analytical Framework

22.3.1 Setting the Scene

A key objective of the EU Horizon 2020 funding programme, 'Science with and for Society', is to build effective cooperation between science and society and to pair scientific excellence with social awareness and responsibility. It allows all societal actors (researchers, citizens, policy makers, entrepreneurs, third sector organisations, etc.) to work together in innovative ways to, "better align both the process and its outcomes with the values, needs and expectations of European society" (European Commission, 2018). This approach to research and innovation is Responsible Research and Innovation (henceforth, RRI).

The project, 'Big Picnic: Big Questions—engaging the public with Responsible Research and Innovation on food security', asked 13 BGs to apply a co-creation approach to develop outreach activities not just for but also with societal actors in their region. The aim was to address the multifaceted global challenge of food security through linking food security, climate change, and plant diversity. Finally, the project encouraged BG educators to reflect critically on their existing education provision and to explore ways of working with actual and potential audiences that allow hearing marginalised voices and promoting dialogue around food and the future of food.

BG educators participated in an intense programme of upskilling and capacity building aligned with issues of food security. The project also asked them to understand and put into practice the concept of RRI, to co-create educational activities, and to evaluate continuously those activities to learn more about the ideas and needs of their participants regarding food security. We embedded TBI evaluation in the co-creation process, adding a reflective element in the implementation and the outcomes of co-creation. BG educators undertook designing and implementing exhibitions and science cafés while putting this knowledge and skills into practice. For this purpose, each partner institution established an in-house working group that supported its work and facilitated the delivery of its goals.

The topic and the processes to design and to evaluate educational activities were unfamiliar to those directly involved in the project. We asked each partner institution to shift perspectives, work outside its comfort zone, and tread a new path while serving as a platform for inter- and transdisciplinary as well as intercultural public discourse. Alternative ways of thinking require new approaches to learning, "especially for understanding and supporting practices where people are creating or developing useful and reusable things in collaboration" (Moen et al., 2012, p. ix). Collaborative knowledge creation processes not only lead to new types of thinking but also to a better understanding of, 'good teaching and learning', while adapting a theory-informed, critical, and reflective approach (Kapelari, 2015).

22.3.2 The Big Picnic Analytical Framework

When researching complex learning systems such as those in an international European education project, no one general theory or model is comprehensive enough to compare and contrast socio-culturally different learning environment. Thus, merging Cultural Historical Activity Theory (CHAT), Situated Learning (CoP), and Organisational Learning (OL) Theory into an analytical framework was the strategy of the BigPicnic approach.

Each theory helps elucidate different elements of the BigPicnic complex learning system, as seen in Fig. 22.3. CHAT enables us to address different components of a highly complex activity system and it helps to develop a better understanding of how these components interact with each other.

The BigPicnic project asked BGs to adopt unfamiliar approaches to develop educational activities addressing topics related to food security issues (*objects*). Goal directed individual and group actions (exhibition design, science café development and implementation, TBI report, posters presented at meetings, etc.) are relatively independent but subordinated units of analysis, understandable only when we interpret against the background of the entire activity system.

We used co-creation, TBI, and RRI as *mediation artifacts* to support BGs in their aim to implement educational reform ideas and develop innovative educational activities.

We used a situated-learning approach (TBI) to reflect on and improve the quality of the educational activities, and co-creation to develop a better understanding of topic-related knowledge systems and the needs of the target group.[1] Both approaches contributed to the development of educational activities taking into consideration the idea of RRI in the context of food security.

The BGs used *objects* (educational activities, exhibitions, and science cafés) to facilitate implementation of the given educational goals. These tools became organisational memory in educators' minds as well as in repositories such as reports and dissemination activities the course of the project produced.

We describe the *subject* not as a single individual but as a CoP uniting all those members of an educational department actively involved in project-related tasks and activities (educators, BG Director, project staff) and all members of the group of organisations working together in an inter-organisational consortium (for example, the international BigPicnic consortium).

The learning organisation usually includes various departments involved in this educational reform process (for example, science department, administration, garden staff).

[1] The NISE net (Nanoscale Informal Science Education Network) originally developed Team-Based Inquiry (TBI), as a form of action evaluation. In complex social interventions it can help practitioners and other stakeholders to define and then formatively re-define project effectiveness as well as to forge effective action/practice (Pattison et al., 2014; Rothman, 1997).

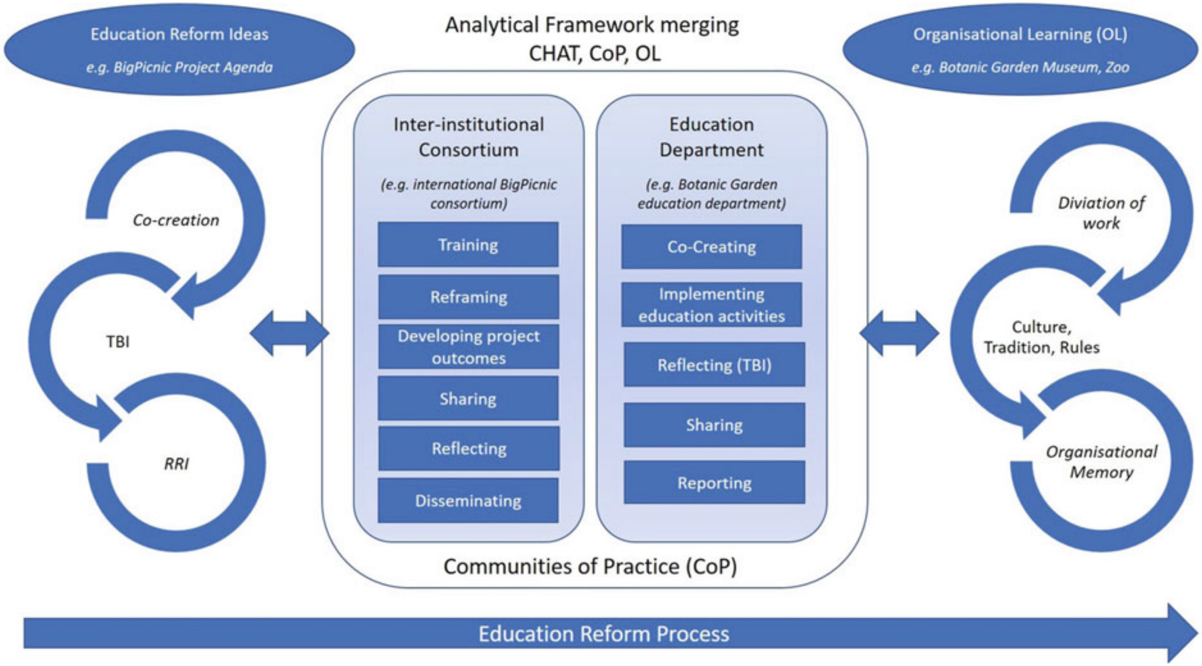

Fig. 22.3 Analytical framework merging Cultural Historical Activity Theory (CHAT), Situated Learning (CoP), and Organisational Learning (OL) using the BigPicnic Project as an example

The organisational *community* has explicit and implicit *rules* that determine how to do the work and the 'right way to do it'. The division of work outlines opportunities and obstacles the education department experienced when putting knowledge and skills into practice. The division of labour creates different positions for those working in a BG hierarchy. Employees bring with them their own diverse histories and the activity system itself carries multiple layers and strands of history encapsulated in its objects, rules, and conversations (Kapelari, 2015). The network multiplies this 'multivoicedness' and is a source of both problems and innovation, demanding actions of translation and negotiation.

Time transforms and shapes activity systems: We need study of the history of the entire activity system (BigPicnic organisation) both as a 'local history of the activity and its objects' and as a 'history of the theoretical ideas and tools that shape the activity'. Organisational learning theory (OL) helps us to observe and understand whether and how individual knowledge, or, in our case, the knowledge of the BG educators, becomes organisational memory. Organisational memory is sustainable, as it is a guiding approach in the future.

22.3.3 Analytical Methods

We employed a naturalistic methodology (Huberman & Miles, 2002, p. 90) using mixed methods to identify changes in practice brought about through reflection shown in reports and other text-based and visual documentation across time and BG settings. We also conducted reflective interviews with BG educators.

22.3.3.1 Interviews

We conducted semi-structured interviews with all BG educators. We transcribed and analysed the interviews following the content analysis approach of Mayring (2008). We used a deductive as well as inductive coding scheme for analysing interview transcripts. In addition, we included in this analysis procedure interview transcripts an external evaluator provided.

22.3.3.2 Artifact Analysis

'Artifacts' become data through the questions the researcher poses about them and the meanings the researcher assigns to them. There is no one right way to analyse artifacts. A wide range of disciplines inform the analysis of artifacts, including anthropology, archaeology, art history, history, human geography, ethnography, and sociology. In the process of analysis, we ask the data to tell us something. An artifact has a story to tell about the person who made it, how anyone used it, who used it, and the beliefs and values anyone associated with it' (Norum, 2008, p. 1).

We analysed artifacts such as reports, Science Café case studies, posters, co-creation activity reports, deliverables, outcomes of group work done during meetings, etc.. Whenever applicable, we applied to text-based artifacts the same coding scheme we used for analysing interview transcripts.

22.3.4 Examples of Findings

Evaluation questions targeted the central goals of the BigPicnic project. Understanding food security as a source of topics suitable for BGs to address is a crucial learning goal. TBI provided BG educators the ‘conversation space’ they needed to define and reinforce their *domain* (Wenger et al., 2002). BGs in general do not focus on food plants but on the conservation of autochthonous plant diversity. Thus, BG partners had to tap into a new field of action, which may cause frictions and less acceptance in their own organisational environment. Understanding RRI as a participatory and reflective approach to research and practice is another challenge BG partners faced. The traditional way of designing educational activities is predominantly didactic in a broader sense. The BG as a scientific authority is usually in charge of selecting the knowledge considered appropriate to communicate to the public. BigPicnic asks gardens to approach a new path and co-create the content as well as the design of exhibitions, science cafes, and workshops jointly. These collaborative element of BigPicnic helped BG partners to create a sense of shared identity as a community, exchange knowledge and start improving their shared *practice*. Not only scientist and educators but also people with different backgrounds, expertise, perspectives, and interests were working and creating new and sometimes unfamiliar learning environments, hence, building on and expanding the *community*.

Finally, we asked BGs to adapt a reflective approach and apply TBI to further improve and hone in their *practice* systematically. This was another challenge not particularly unique for BGs but for many informal education institutions. However, adopting co-creation and TBI is fundamental to becoming a hub for RRI. RRI asks the scientist and the public to take over responsibility and become inclusive and reflective citizens. If BGs want to use their full potential of being a platform for people to participate actively in research and innovation, they should become reflective and inclusive practitioners themselves.

We applied a broad range of evaluation questions to the data. The next section of this paper examines the following question and presents key findings associated with it.

– To what extent do BG partners engage with ‘Mediating Artifacts’ (RRI, TBI, and co-creation)?

CHAT addresses CoPs as always in larger societal setting that has a major impact on their progression. Engeström’s (2000ff) CHAT model explains how the social context in which the national BG educator performs mediates activities toward

BigPicnic goals and objectives. The BigPicnic community ranged from a larger institution, such as a university or a BG in which the BG education team plays a minor role, to smaller teams that employ only a few people to help with administrative tasks. For the latter, most of the staff is part of the BigPicnic team. Although the size varies the components of the activity system, and their interactions are comparable.

BG educators frequently reported how their institutional environment impacted the ease with which they could communicate project-related information to decision makers or scientist in their own institution or outside their institution. Rules and deviation of work have an impact on the objects and how innovations are integrated in existing organisational structures. Large organisations seemed more impersonal, and co-workers rather stick to given rules. The educators had to conquer the fact that they were in different buildings and larger distances (geographically as well as emotionally). BG educators perceived BigPicnic activities and events as an opportunity for the BG to work closely with other members of the organisation, no matter the organisation size. For these gardens the project had an impact on organizational community conditions. Some BG educators did not experience size of the organisation as a barrier, for example, for attempts to improve sustainability of the food supply for staff members. For others, size as well as the particular role of the individual person or BG in the organisational hierarchy hinders BG educators even to consider approaching a particular BigPicnic task. As mentioned above rules and deviation of work as well as how the organizational community is established could have a not to be neglected impact on project outcomes and organizational development.

Some BG educators took for granted institutional traditions of communication and traded rules, whereas others saw opportunities for potential change. This had an impact on the range of expansive learning movements BG educators were confident to explore. Rules, such as who makes decisions on the accuracy of scientific knowledge when it comes to selecting and communicating food-related issues to the public or to exploring the idea of co-creating a new exhibition on site, had an impact on the decision a BG educator takes in the course of approaching BigPicnic tasks. In addition, people working in the communication or administration department may support or hinder innovative approaches that do not follow traditional procedures. Whether the immediate superior takes part in BigPicnic projects meetings appeared to be important in terms of institutional support of project activities. However, the particular ways of thinking and acting of the superior mediated this support.

The way division of work amongst BG partners as well as internally within each organisation goes some way towards explaining some of the obstacles partner institutions or project members faced while working towards BigPicnic objects. Interview data provided evidence that BGs who ask temporary staff members (for example, those specifically hired to work on project-related tasks) to do the work independently, had difficulty using the full potential of their own organisation as well as the potential capacity-building opportunities the project offered.

BigPicnic employees well integrated in a staff group working at the organisation reported both positive as well as negative impact of existing traditions and rules on how they pursue their work. Working independently, however, was a source of creativity and innovation for the organisation because project employees were able to try out ‘new things’ (Quote A) and to walk non-traditional paths (Quote B). In those rare cases in which there was hardly any involvement of permanent staff with the project, the data suggest that knowledge gain and skills improvement by this particular temporary employee would leave the organisation as soon as the project ends. Permanent staff involved, however, reported on a variety of plans to take BigPicnic ideas and skills further. Most BGs tried to implement BigPicnic knowledge and individual skills sustainably by developing teaching material, reports, or handbooks/kits to support others within their organisation or amongst the consortium to implement their ideas more easily.

Following this evaluation question, it is obvious that BG educators in BigPicnic were active participants in a complex system in which they experienced opportunities as well as barriers to professional learning and development. This system had an impact on who was able to learn and why, as well as what and how they learned. Contradictions were driving forces for expansive learning cycles and possible forms of transformation in any activity system (Engeström, 2000).

After the BigPicnic kick-off meeting in Thessaloniki, many Partners were unsure how to approach project-related task and what the expectations of them were. However, at the end of the project most partners valued the BigPicnic approach. As one participant put it, “Freedom to develop a project is good, but can be hard to begin with” (Quote C). Many partners came to value the variety of approaches, topics and ideas the BigPicnic consortium addressed. As one partner noted, “Okay, it was a good decision, because we discovered this methodology step by step. And when we discover, we get a very great value of this, and, we learned and we understood a lot of things, we did it. Okay, a good way” (Quote D). The expansive learning environment helped them to discover the task in new and creative ways while becoming empowered to reflect, evaluate, and judge the quality of their approach themselves.

Organizational learning theory argues that individual learning is essential for building a organisational memory and thus for organizational development. The organizational traditions, knowledge, and experience embedded in the BG partners shaped and contributed to the nature and success of the educational activities. However, what also contributed to these activities was the knowledge acquired through participating in the BigPicnic project. The process of reflecting and sometimes even challenging already accumulated organizational knowledge was crucial in this process of learning. The resulting change or growth was not necessarily a radical change in the organizational behaviour of each partner. It, nevertheless, was a learning experience which resulted from both the experience of the project and the interactions it facilitated.

22.4 Importance to Research

The complexity of learning systems in operation within interdisciplinary and multicultural settings such as the BigPicnic project, as well as the conflicts and contradictions the BG educators experienced, highlight the need to use complex theory. In this chapter, we discussed how we drew on Engeström's CHAT (Engeström, 2000), on Organisational Learning Theory (Argote, 2013; Kim, 2004), and on CoP (Lave & Wenger, 1991), and fit them together into a theoretical framework underpinning and shaping our research.

Education is a key function for BGs, museums, and other informal education institutions and that makes them important actors in the educational ecology. Many museums strive to enhance their visitor experience and understanding of topics and phenomena that exhibitions, workshops, or school programs address. However, educational activities often are designed and implemented by content knowledge experts, who decide what knowledge to address and how to present it. Participatory approaches that offer a systemic path toward designing educational offers together with representatives from various demographic backgrounds are rare. Collaborations with scientists from related or non-related disciplines, with diverse publics or marginalised groups more particularly, are rarely part of the museum's core function. The reasons for this are manifold and often relate to the hybrid nature of these collaborations, which are both formal and informal at the same time (Bevan et al., 2010).

Informal education institutions are complex activity systems and act in an even more complex informal education system. To better understand the complex interplay amongst members of the institution itself, as well as about the informal education system as a whole, we need further research on how informal learning institutions learn themselves and what they need to support their professional development in education. Educational reform programmes, such as the one that funded the BigPicnic project, can be more successful if we understand the type of support informal education institutions need for their individual professional growth.

Applying an analytical framework merging three learning theories to understand how Learning Outside the Classroom Institutions learn themselves is particularly useful in helping us understand the complex interplay of factors and multiple layers and strands of history encapsulated in project processes and outcomes. Yet, we know very little about how action-guiding factors such as culture, tradition, division of work, financial resources, or support measures affect a learning process in informal education institutions. It requires systematic comparative analysis to generate robust data and draw thoughtful conclusions. The theoretical framework and methodological approach we present in this chapter can help guide future research in this area.

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Chapter 23
"Grilled is Better Than Fried Chicken.": Exploring a Participant Model for Designing and Evaluating Children's Museum Health-Related Cooking Classes

Dawn Nguyen Truong and Patricia G. Patrick

23.1 Introduction

Food is an important part of today's museum experience (Levent & Mihalache, 2017). Museums are devoting exhibits to healthy food choices (Coats, 2020) and some museums are dedicated to food (e.g. foodseum.org). Cooking activities, such as cooking classes for children and families, especially are increasing (e.g., Teaching Kitchen, Children's Museum of Denver; Pies and Sides, Greensboro Children's Museum; Kitchen Science, The Franklin Institute). These cooking programs focus on fun and cooking tips and techniques. Some programs include healthy cooking as the topic; however, educators may not discuss health overtly.

Museum cooking programs are expanding the scope of informal educators to developing and promoting health and well-being programs (Camic & Chatterjee, 2013; Chatterjee & Camic, 2015; Dodd & Jones, 2014). These programs are important for many reasons; however, one notable reason is childhood obesity affects youth and adolescents 6 to 19 years old and is more prevalent among Hispanics (25.8%) and non-Hispanic blacks (22.0%) than non-Hispanic whites (14.1%) [Centers for Disease Control and Prevention (CDC), 2016]. A factor contributing to childhood obesity is poor eating habits (CDC, 2016; Wang & Lobstein, 2006). Defining children's eating habits and understandings of healthy food is important because the poor eating habits of children more likely will follow them into adulthood (Llewellyn et al., 2016). Research shows health programs focusing on nutrition and beliefs about healthy eating practices may influence unhealthy habits positively (Acheampong & Haldeman, 2013; Ammerman et al., 2007). Museums are important in this

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effort, because they are community institutions who offer health programs and can strengthen the relationship between institutions and the community (Glanz et al., 2008; Lackoi et al., 2016).

In this chapter, we complete an exploratory case study and develop our work through Nutbeam's Outcome Model for Health Promotion (OMHP), an established health education model (Nutbeam, 2000), addressing the question: What can Nutbeam's OMHP add to our understanding of best practices in designing and evaluating museum health and nutrition related cooking programs? We provide a short description of the OMHP and examples that represent its core stages. Using data from a study completed at a Children's Museum in the Southeastern United States, where children engaged in a cooking class, we contemplate the connection between the OMHP levels and its use as a tool to design and evaluate cooking programs.

23.2 Relevant Literature

23.2.1 Healthy Cooking Classes for Children

To combat high childhood obesity, learning institutes and schools implement nutrition education programs, which promote healthy eating and physical exercise (Abma & Schrijver, 2019; Bryan et al., 2019; Olfert et al., 2019; Pelletier et al., 2019; Schuler et al., 2019). Some extant research indicates out of school cooking classes (1) increase children's nutrition knowledge, confidence in cooking skills, and frequency of cooking at home, (2) influence children's food choices, attitudes, and behaviors, (3) encourage family conversations about healthy food, and (4) foster child participation in meal preparation. Examples include LA Sprouts', an afterschool cooking and health intervention program focusing on gardening and nutrition (Davis et al., 2011), chef instructed afterschool cooking classes (Edens et al., 2016; Jarpe-Ratner et al., 2016), and summer camp cooking classes (Ehrenberg et al., 2019; Harmon et al., 2015; Williams et al., 2019). Even though research indicates food classes are successful and the most successful provide children with hands-on opportunities to prepare food (DeCosta et al., 2017; Raber et al., 2017; Williams et al., 2019), evaluation methods and results vary (Hersch et al., 2014). Therefore, research is needed to "fill knowledge gaps" (Hersch et al., 2014, p. 1) about best practices for cooking classes.

23.2.2 Museum Cooking Programs for Children

Because museums are community venues reaching a diverse population across rural and urban settings, these venues are an ideal community resource to develop and implement nutrition education programs (Camic & Chatterjee, 2013). To aid museum educators in designing and implementing effective and creative programs, researchers must understand children's interest in cooking and engagement in cooking at home. Children have learning experiences in museums and informal settings (Jose et al., 2017; Idema & Patrick, 2016; Moorhouse et al., 2019; Tõugu et al., 2017; Uzick & Patrick, 2018). However, children learning in informal settings is a complex process and takes place with and without family members (Ash, 2004; Haden et al., 2014; Idema & Patrick, 2019; Mai & Ash, 2012; Tunnicliffe, 2008; Zimmerman et al., 2010).

Even though studies in healthy cooking programs in museums are few, we found two focusing on children. The first study completed by Freedman (2010) studied 200 children who participated in Healthy Pizza Kitchen at a children's health museum. During Healthy Pizza Kitchen, children put together faux pizzas using a menu showing healthy ingredients. Children did not cook their creations but used plastic toppings to design healthy pizzas. After the museum pizza activity, children's knowledge about healthy pizza toppings and healthy food groups increased. The second study was a meta-analysis of 19 non-peer-reviewed, unpublished evaluations completed in health promotion programs and exhibits in children's museums (Christensen et al., 2016). Researchers could not locate published health-related museum studies.

Museums, who responded to a call for written materials, provided the evaluations. Even though the evaluations showed an increase in knowledge and understanding of health-related topics, the researchers cautioned the methods and conclusions were not transparent. They suggested further studies be well-defined and clearly describe the methodologies and their successes and/or failures. As museums interact with food and the community, they have much potential to provide hands-on cooking and meal preparation programs. However, published research in museum cooking classes is lacking.

23.2.3 Aims and Significance

Museums build the community's trust to engage in issues that influence or shape community health and well-being (Crooke, 2008) and contribute to improving the health of the local community (Dodd & Jones, 2014). Successful nutrition education programs, which may influence behavior, must be creative (Freedman, 2010; DeCosta et al., 2017; Raber et al., 2017; Williams et al., 2019). Even though museum health program data show an influence on community health (Christensen et al., 2016; Crooke, 2008; Freedman, 2010), little research focuses on nutrition programs (Freedman, 2010) and cooking programs for children. Museum educators have a unique opportunity to influence healthy food knowledge, cooking, and food eating among the families in the museum audience, especially the children. Therefore, we began our exploratory case study with the notion of investigating how an existing health education model might be adapted to aid museum educators and evaluators in designing and evaluating museum health and nutrition related cooking programs.

23.3 Conceptual Framework

Nutbeam (1996, 2000) stated we underestimate the power of health education and health education goals as a tool to support public health. He explained health program outcomes must be defined before they can be evaluated and deemed successful. In support of evaluating health education, Nutbeam developed the OMHP. The OMHP consists of four levels: Health Promotion Actions, Health Promotion Outcomes, Intermediate Health Outcomes, and Health and Social Outcomes. Each Outcome includes specific measures. The measures indicate the immediate impact of a health promotion program (see Nutbeam, 2000 for all measures).

Nutbeam considers Health Promotion Actions a catalyst for Health Promotion Outcomes and the remaining Outcomes (Intermediate Health Outcomes, and Health and Social Outcomes) as lateral and vertical links to other Outcomes. An institution spearheads Health Promotion Actions (e.g., education, social mobilization, advocacy). Health Promotion Outcomes are health literacy, social action and influence, and healthy public policy and organizational practice. Healthy literacy is a "key outcome from health education" (Nutbeam, 2000, p. 263) and focuses on the capacity and tools to put words into action. In addition to measures for health literacy.

Intermediate Health Outcomes are the goals of health education and include healthy lifestyles, effective health services, and healthy environments. Health and Social Outcomes (e.g., mortality, morbidity, disability, dysfunction, quality of life and functional independence) are the end-stage of health programs (Nutbeam, 2000). The purpose of this paper is to determine if a health-related cooking class represents Nutbeam's Outcomes and if the OMHP might be utilized to design and evaluate museum cooking classes.

23.3.1 Methods

We chose an exploratory single case study because we investigated a distinct occurrence (cooking classes) that has not been studied. This exploratory study is the start of defining the OMHP as an evaluative tool for cooking classes (Harrison et al., 2017; Yin, 2014). Nutbeam (1996) stated programs must determine if the intervention (cooking class) achieves its stated outcomes. We bound our case by place and activity (Harrison et al., 2017). The phenomenon of children participating in a museum cooking class was defined within a Children's Museum in the southeast USA. We analyzed what the children described after the cooking class to determine how Nutbeam's OMHP could aid museum educators as they link cooking class program goals to health and nutrition goals. The difficulty following up with participants after a museum visit makes evaluation challenging for researchers to determine the long-term effects of the visit (Christensen et al., 2016; Patrick, 2017a). Therefore, we were not seeking to determine if and how students used the information after the class. We sought to explore what children were thinking at the time, how their thoughts related to the class and how the class might influence future actions. We asked children to take photographs during the class of what they thought represented health. We used photo-elicitation (see methodology) to stimulate conversation after the class.

23.3.2 Setting and Cooking Classes

The location of the Museum was a southeastern USA city, population of 816,450, median household income of $52,247, and poverty rate of 15.1%. The Museum is a nonprofit education institution and provides accessibility to educational programming for underserved children and families. In 2018, the Museum had a visitorship of approximately 216,000 with over 54,000 visiting for free or with reduced admission. Additionally, they served 12,581 students on field trips. Over 5000 people attended the museum's health programs. The programs promote healthy eating and encourage heart, oral, and overall health.

We collected data from four different classes on four different days in Spring 2018. The cooking classes focused on increasing health knowledge, healthy cooking skills, ability to recognize healthy food, and motivation and self-confidence to cook. The goals were for children to (1) have fun as they prepared recipes, (2) increase likelihood they would prepare meals at home, and (3) learn about healthy diets and food choices. Children engaged in food preparation (e.g., cutting) and meal creation (e.g., putting ingredients together). The cooking classes lasted approximately 30 min and took place during weekdays in the afternoon. The museum educators (who were not trained chefs) talked about the food triangle, healthy food choices, and meal preparation at home, read a book about healthy eating, and provided children with recipes to take home. Children received direction to complete the steps of preparing the meal, including cutting the fruits and vegetables.

23.3.3 Participants

The study participants were a convenience sample of 22 students from a local school district who participated in the cooking classes. The participant number is considered an acceptable case study sample size. The school district is one of the largest districts in the state and children were from rural, suburban, and urban schools. We asked children, accompanied by a legal guardian during the field trip, to participate in the study. Children and guardians who agreed to participate signed assent and consent forms granting permission for the child's participation. After receiving permission, we assigned the children a code for anonymous identification. The participant group consisted of 15 elementary (ages 5–11 years) and seven middle school students (ages 13–14 years). The 22 children were 12 African Americans, 10 Caucasians, 13 females and nine males. The elementary groups prepared yogurt parfaits with apples, blueberries, granola, strawberries, and yogurt. The middle school group prepared pasta salad, which consisted of bell peppers, black olives, carrots, cucumbers, purple onions, tomatoes, and pasta.

23.3.4 Data Collection

To collect data during the class, we employed photo-elicitation. After the class we used photo-elicitation interviews (PEI). PEI participants take photographs and during an interview describe the meaning of the picture (Bigante, 2010; Glaw et al., 2017; Ortega-Alcazar & Dyck, 2012; Torre & Murphy, 2015). PEI allowed us to access children's "feelings, memories, and information" (Harper, 2002, p. 13). We used PEI because it has been used as a data collection tool at places of informal learning (Bapiri et al., 2021) and with children to determine food routines (Green et al., 2021). Photographs represent information not communicated through words (Guest et al., 2013) and provide young children a way to express their perspectives and interpretations of the experience without writing (Clark-Ibáñez, 2004). Additionally, the photographs represented what the child saw during the class and took the child back to the class being discussed (Clark-Ibáñez, 2004).

We asked children to use their guardian's cellphone to take photographs during the class of what they thought represented healthy eating. We did not provide children with a specific number of photographs they should take. After the class, the 22 children texted 91 photographs to the first author along with their identifying code.

After the class (with a guardian present), we discussed the photographs with the children using the following prompts as guides (1) explain what the pictures represented, (2) pick one that best showed what they learned, and (3) pick one that best presented health. When children no longer talked about the photographs, we used the photographs as a catalyst to ask children: (1) which ingredients they saw in their home, (2) if their parents used the ingredients, (3) if they cooked at home, (4) their favorite thing to cook, (6) to describe a healthy meal, (7) what healthy food they ate at home, (8) if they would use the information from the class at home, (8) why understanding ingredients is important, and (9) their source of knowledge about healthy eating. We asked these questions to determine how children talked about the class and described their knowledge of healthy eating. The interviews lasted approximately 10 min and we recorded them using a digital recorder. Using the student codes, we paired the photographs and interviews.

23.3.5 Data Analysis

We printed the photographs and analyzed them by grouping and regrouping them in piles based on the items in the image foreground (Orellana, 1999; Stockall, 2013). We did not include items in the background. We determined the photographs focused

Fig. 23.1 Student photograph showing the themes *ingredients* and *utensils*

on three themes: ingredients, utensils, and the final meal. We recorded the data in an Excel file. For example, the photograph in Fig. 23.1, which focuses on an apple slice, cup, cutting board, knife, spoon, and strawberry, we placed in two piles—ingredients and utensils. No differences were found between the ages of the children.

We transcribed the PEI and used an open coding process to analyze the data (Charmaz, 2014). We assigned codes to the patterns of related phenomena (words and phrases) emerging from the participant's responses. Having developed the codes, we determined if the codes fit within the OMHP following the work of Luna-Reyes and Andersen (2003). The Health Promotion Action represented was education, which was the cooking class. We determined the best way to illustrate how the data fit within the OMHP was to use the Outcomes as themes (Health Promotion, Intermediate Health, Health and Social) and the measures for each outcome subthemes. We determined if our codes represented the measures (subthemes) and aligned the measures with the Outcomes (themes). Table 23.1 includes the Outcomes, measures and codes we used to analyze the data. The data reflected students mentioned nine measures across the three Outcomes. We found one Health Promotion Outcome, which was Health Literacy. Intermediate Health Outcomes included Healthy Environments and Healthy Lifestyles. Health and Social Outcomes were represented by one Outcome—Social. Applying the codes, we analyzed the 22 interview transcripts and did not find additional codes.

Table 23.1 Participant data in the Outcome Model for Health Promotion

Outcome	Measure	Code
Health promotion outcome		
Health literacy		
	Health related knowledge	
		Foods associated with healthy eating
		Link between food and health
		Understanding ingredients
	Self-efficacy	Ability to make the recipe
	Health related attitude	
		Positive comment
		Negative comment
	Behavioral intention	Intention to prepare meal at home
Intermediate health outcomes		
Healthy lifestyles		
	Food choices	Food children cook at home
Healthy environments		
	Supportive social conditions	
		Sources of information
		Social interactions
	Good food supply	Healthy food eaten at home
Health and social outcome		
Health and social outcome		
	Functional independence	Cook at home

Adapted from Nutbeam (2000)

23.4 Results

23.4.1 Photo-Elicitation

Given the constraints of the context associated with the images, we cannot overstate the representation of the images. The emphasis in the photographs was not a surprise. However, we were not focused on the data elicited from the images. We were interested in the photographs as a catalyst for defining the Outcomes related to Health Promotion, Intermediate Health, and Social. We found that all (N = 22, 100%) children took photographs of the ingredients, 21 (95.4%) took photographs of utensils (bowl, cup, cutting board, knife, plate, spoon), and eight (36.3%) included images of the final meal. All final meal photographs were of the parfait. No children took photographs of the completed salad.

23.4.2 Photo-Elicitation Interviews

As shown in the Participant Model for Health-Related Cooking Classes in Fig. 23.2, Health Promotion Outcomes, Intermediate Health Outcomes, and Health and Social Outcomes emerged from the data. Below, we report the results for each Outcome. Even though we collected data from four different classes over four days and ages varied, the data were similar. We aggregated the data and present it as one group of 22 children.

23.4.3 Health Promotion Outcome

Health Promotion Outcomes were reflected by one Outcome, Health Literacy. Health Literacy included four measures related to the OMHP: (a) health related knowledge, (b) self-efficacy to cook/personal skills, (c) health related attitude, and (d) behavioral intention. The data demonstrate that children described foods they associated with healthy eating. The foods children mentioned most were fruits/vegetables, dairy, and grains. For example, Betty (all names are pseudonyms) stated, "I like to eat apples." Interestingly, children described a link between food and health. Mike stated the recipes were, "… all like good veggies for your health. They don't make you have cholesterol.", while Lillian referred to the food prepared in the class as having, "good bacteria for your stomach". Herbert described chicken as, "Grilled is better than fried chicken". Moreover, children understood the importance of ingredients. Children articulated their knowledge of the class recipe ingredients by explaining, "They may seem weird [ingredients in picture], but they taste good when mixed together (Abdul)". Furthermore they describe where you could find information about ingredients found in food, "You can read about the ingredients on the side of

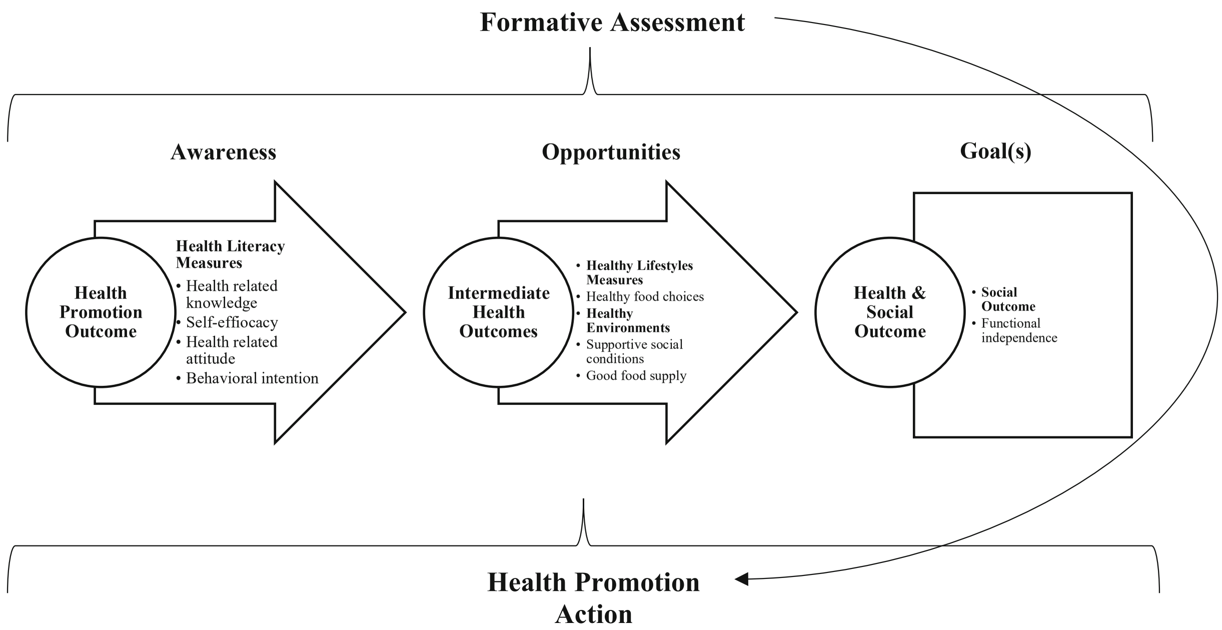

Fig. 23.2 Participant model for health-related cooking classes

the label (Victoria)". Half of the children described their ability and self-efficacy to make the recipe and just over half of the children believed they could and would prepare the class recipe at home.

When we asked about the food children prepared during the class, most of the children held a positive attitude toward making healthy food at home, such as, "I like to cook broccoli." or "… it's important, because you always eat fast food, but it's important to incorporate those things in the cooking class into your other meals." Children with positive attitudes stated they liked the class prepared food and wanted to eat healthier foods. Their attitudes toward food may be related to their beliefs about their self-efficacy/personal skills to prepare a meal and their intention to prepare the meal at home. Students who described a positive attitude toward healthy eating believed they possessed skills related to meal preparation and indicated their intention to prepare the class meal at home. For example, Juan stated, "At home I make turkey sliders and I use veggies." and continued with the following, "I can use the different varieties of things [ingredients] from the pasta salad to make something else."

23.4.4 Intermediate Health Outcomes

Children described two Intermediate Health Outcomes: Healthy Environments and Healthy Lifestyles. Healthy Environments measures included supportive social conditions and good food supply. Supportive social conditions involved sources of information and social interactions. Even though students described several sources of information, most often they mentioned family members as sources of information about healthy eating. In the social family context, Betty declared her Dad as, "… making us eat healthy." Betsy stated her, "… Dad is a biochemist and he knows about nutrition." Children described family members as knowledgeable about healthy eating. Rebecca stated, "My grandma and my uncle tells [sic] me what's healthy because they like eating healthy". Next most mentioned as a source of information was school. For example, Cooper explained, "In gym, we hear about eating healthy eating and there are learning activities at school that help." While, Juan said, "Fruits and veggies are healthy and my teacher showed us in class." Children specifically mentioned their teacher as a source of information at school. Cooper thought he, "… learned it in school … my teacher tells me". In addition to supportive social conditions, students referred to healthy food they ate at home. With respect to healthy foods children ate at home, children included fruits and vegetables most often. Lillian commented her family, "eat[s] watermelon". Betsy declared she ate, "…a salad with asparagus".

Healthy Lifestyles encompassed one measure—healthy food choices. We coded when children noted the healthy food choices they made at home. We discovered half the children described healthy food at home, such as salads, turkey sliders, healthy muffins, asparagus, and broccoli.

23.4.5 Health and Social Outcome

We identified one Health and Social Outcome—Social Outcome, which included one measure Functional Independence. Functional Independence is reflected in the cooking class goal, which was for participants to learn about healthy diets and food choices and prepare the recipes at home. However, because we did not follow up with children after they returned home, we were not able to determine if they prepared the meals. Therefore, we coded Functional Independence when the children expressed a desire to prepare the class meal at home. Nearly half of the children thought they would prepare the meal. Children who were not interested in making the recipe said they did not like the food prepared in the class or explained, “I don’t like healthy food.”

23.5 Limitations

We did not collect pre-/post-class data; therefore, we are not able to determine if children’s knowledge changed due to participating in the cooking class. Determining learning was not the intention of the study. The main focus was to define how museum educators might use the OMHP model for museum program design and evaluation. We did find that some children possessed the intention to prepare the meal at home, but without follow up after the class we do not have data supporting their claims. The ability to prepare the meal at home is not limited to the child’s desire. Guardians may not be willing or able to provide the ingredients. The data did show that children, who asserted they cooked at home and were more likely to prepare the meal at home, mentioned the Health Promotion Outcomes level and their understanding of preparing healthy meals—Intermediate Health Outcomes. Moreover, the data indicated children related the course to personal experiences and prior knowledge about food. We collected data during a short time to assess the children’s perspectives on a cooking class and how the cooking classes related to their cooking at home. Even with a small data set, we were able to connect the results to Nutbeam’s OMHP model with the notion a new model will be fertile ground for future studies.

23.6 Discussion

We completed an exploratory single case study using PEI to understand how children talked about healthy cooking. While our goal was not to define the enhancement of knowledge, we did determine what children described related to healthy food and healthy eating and cooking. Children have some prior knowledge of cooking and food and rely on social interactions at home, such as conversations about food, to make decisions regarding daily food choices. Anderson and Lucas (1997), Chatterjee and Camic (2015), Falk and Adelman (2003), Franse et al. (2020), Patrick (2017b), Patrick and Tunnicliffe (2013) well documented the importance of educators reflecting on their teaching and recognizing visitor prior knowledge and social interactions before and during a museum visit. This knowledge is valuable when designing a cooking class because prior knowledge and experiences and their activation during the class are important aspects of learning about health (Gewurtz et al., 2016). Even though our study confirms previous museum literature about the importance of prior knowledge, our work adds to the literature by (1) defining the factors museums should address to advance learning about healthy eating and (2) depicting the stages of understanding museum cooking class programs should address. Defining healthy eating and depicting the stages of understanding health within the museum context will aid educators as they navigate best practices, which lead to Functional Independence.

23.6.1 Social Interactions

Children rely on reinforcing factors, such as social interactions with caregivers, to develop their perspectives on daily food choices and the distinction between healthy and less healthy foods. Social interactions, such as conversations about food and cooking together, in the home are important as children develop knowledge of healthy cooking and eating. Like Velardo and Drummond (2019), we found children stated parents and school influenced their food choices and cooking competencies and skills. Parents play a major role in developing and reinforcing their children's ideas about eating and food possibly leading to eating habits (Marty et al., 2018; Rhee, 2008; Vandeweghe et al., 2016; Velardo & Drummond, 2019).

Many of the children described cooking with or watching a family member cook, which supports (Williams et al., 2019) the notion that children may be change agents for healthy meal preparation in the home. Additionally, children may be a catalyst for conversations about healthy eating and nutrition. The myriad of ways children think about food and the role of food in their family are intertwined in their everyday family engagement. Museum educators should appreciate the power and responsibility families hold in respect to food and healthy eating. Parents and their roles as facilitators for healthy eating in the home should be taken into consideration when designing a cooking class.

23.6.2 Participant Model for Health-Related Cooking Classes

Our aim was to define how the OMHP might be used to design and evaluate museum cooking classes (Nutbeam, 2000). As shown in Fig. 23.2, based on our data we adjusted Nutbeam's OMHP to determine how the Health Promotion Action of a museum cooking class catalyzed how children talked about Health Promotion, Intermediate Health, and Health and Social Outcomes. Nutbeam defines Health and Social Outcomes as the "end point" (Nutbeam, 2009, p. 29) for a program or program goals. For the Health and Social Outcome(s) of museum cooking programs, we focused on participants becoming Functionally Independent or the desire to prepare the meal. We named our model Participant Model for Health-Related Cooking Classes due to the focus we placed on the program participants, not the development of the program. However, we do believe this Model can be extrapolated to program development and evaluation.

In Fig. 23.2, we present the Health Promotion Action as the foundational force for the Participant Model for Health-Related Cooking Classes. The *Health Promotion Action* was the cooking class. The *Action* museum educators choose when designing a cooking class must promote participant development and understanding of the Health Promotion Outcomes. Health Promotion Actions foster Health Promotion Outcomes (Nutbeam, 2000), which are the *Awareness* or health knowledge participants have of the topic. Health Promotion Outcomes lead to Intermediate Health Outcomes.

From the data, we identified the targets for Intermediate Health Outcomes as living a Healthy Lifestyle and participating in Healthy Environments. Nutbeam (2000) stated the Intermediate Health Outcomes will determine the likelihood of reaching the Social Outcome; therefore, museum educators must scaffold the program (Health Promotion Action) to connect the Intermediate Health Outcomes with the Social Outcome. We believe the Intermediate Health Outcomes are the *Opportunities* for participants to involve in healthy food choices and interact socially with cooking food and eating. The Social Outcome or *Goal* of the program was the children's desire or ability to prepare the meal at home. Recognition, or self-identity, of participating in cooking was not an issue for the children. Even though not all children thought they would cook the meal at home, most children claimed they cooked or would like to cook at home. Even though the ability to cook may not manifest from the cooking class, some children, who did not cook, stated they would like to prepare the class meal at home.

23.6.3 Applying the Participant Model for Health-Related Cooking Classes

23.6.3.1 Program Design

Children coded in the Functional Independence theme referred to all of the measures, which supports the notion the Participant Model for Health-Related Cooking Classes may be sequential. The *Action* should relate to and increase *Awareness* of health-related cooking and support participants current and future *Opportunities* to cook healthy food. Even though we recognize the data are limited, museum educators must contemplate the levels of their learning model and the steps that must occur between levels to reach their *Goals*. The Participant Model for Health-Related Cooking Classes infers that educators should consider the *Awareness* and *Opportunities* of participants when considering the development of healthy cooking classes. Participants do not come to the classes with the same knowledge, ability, and support needed for healthy cooking.

23.6.3.2 Program Evaluation

Evaluators should determine the *Goals* of the program. The *Goals* should define the *Awareness* educators would like participants to possess when they leave the program and how the *Awareness* could influence the *Opportunities* participants have at home. Museum educators often do not receive feedback about their programs or do not receive complete program evaluations. Even when feedback and evaluation are available, museum educators may ignore the information and take no action. The aim of the Participant Model for Health-Related Cooking Classes is to commence the process of developing the Health Promotion Action (cooking class/program). Figure 18.2 presents a model of the process. We suggest educators: (1) Use the model to understand how the program feeds forward to the next stage of advancement. (2) Design the *Action* to promote and evaluate during real time (formative evaluation) participant *Awareness* during programs, how the program bolsters *Opportunities*, and how the programs and *Opportunities* support program health goals. (3) Provide concrete experiences during the program relating to prior knowledge (*Awareness*) and focus on *Opportunities* outside the class to practice healthy choices, an experience that leads to functional independence (*Goals*).

The model outlines an approach to program design and evaluation that acknowledges the importance of designing the program based on goals. Because obtaining feedback and completing evaluations *after* a program is so difficult for museum educators, the model illustrates the need for completing formative evaluation and capturing feedback *during* the program and for closing the gap between program design and desired goals. This model of health promotion and literacy, if educators consider it when developing programs, will enable educators to iteratively redevelop the program to reach their audience and achieve their goals.

23.7 Conclusions

We intend the Participant Model for Health-Related Cooking Classes for use as a tool for evaluating and developing healthy cooking programs. Although we do not expect museum educators to have degrees in health education, we encourage them to use evidence-based work to deliver impactful and meaningful health promotion programs. We suggest developing programs with formative evaluation components and Social Outcomes (long term goals) in mind. Additionally, museums should consider professional development in health education for those who provide health-related museum classes.

The cooking class was designed for one-time attendance. If this were a reoccurring program with the same participants, additional data could be collected. A recurring cooking class designed to promote knowledge over time could lead to a better evaluation of the different perspectives. In our study, additional data would have provided a more detailed analysis. Future research could investigate how museum classes can develop a child's self-identity as a cook and behavior of cooking healthy food. This will expand the model we propose. The exploration could include observations and recorded conversations to define how children discuss food during the cooking class. Researchers should seek to develop methodological approaches that provide a view of naturally emerging knowledge of food, cooking, healthy cooking, and family engagement around food. The findings could be useful to identify the trajectory for children self-identifying as cooks and seeking to cook healthy food, which includes informal contexts, such as social interactions with family and museum cooking classes. To better understand how cooking classes can advance self-identity as a cook and healthy cooking, future research should compare different cooking classes and focus on ability, agency, family participation, meaning making during the class, and construction of knowledge.

23.7.1 Translation to Health Education Practice

While we recognize museum educators have different goals for programs and evaluating the long-term impact of a health-related cooking class is difficult (Christensen et al., 2016), the findings of this study provide museum educators views of participants' ideas about cooking and how prior knowledge links previous experiences to the cooking class. To overcome the evaluation of long-term impact, we suggest evaluating the *Opportunities* provided for visitors and visitor learning in real time (i.e., formative evaluation). The findings from our study bring to light important ideas for researchers and practitioners who focus on informal health and nutrition learning. Museum educators must remember the program should be about meeting the needs of the learners and ensuring visitors understand the topic and can apply the information after the visit. Museum educators should design innovative programs, which encourage engagement among participants and stimulate conversations and cooking after the class. Additionally, previous studies indicate successful cooking classes were led by a trained chef. If museums cannot afford to hire a trained chef or nutritionist, educators might consider asking a chef or nutritionist to review the menu and establish nutritional value, ease of preparation related to age level, and relationship to health and nutrition goals.

Even though we mentioned best practices above and designed the Participant Model for Health-Related Cooking Classes, we agree with Hersch et al. (2014) who stated more work is needed to fill the gaps in museum cooking class research. Research needs to address if increased *Awareness*/interest persist, or is temporary, followed by a return to previous behavior. Our findings do not definitively support or rebuff Nutbeam's statement that health education does little to promote behavioral change. Behavior change is a more difficult question to pursue, especially with limited or no follow-up opportunities. The cooking classes do seem to influence what people say about their *Awareness*/interest in cooking at least initially. However, there are no data to support the permanence or impermanence of their self-stated *Awareness*/interest. Even though we unquestionably are far from identifying best practices for cooking classes, our Participant Model for Health-Related Cooking Classes provides a framework for designing the program and evaluating the potential long-term impact.

Just stating the program goals are to have fun, learn about healthy diets and food choices, and increase at home meal preparation is not enough. Cooking program designers should consider how the program goals align with and will achieve the Participant Model for Health-Related Cooking Classes Social (and/or Health) Outcomes. Using the Participant Model for Health-Related Cooking Classes can aid museums as they develop programs that continue to support how food and museums borrow from and inform "each other's meanings, structures, and practices (Levent & Mihalache, 2017, p. 4). There is still much research needed to "fill knowledge gaps" (2014, p. 1) about best practices for cooking classes.

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Chapter 24
Adaptation of Constructivist Learning and Teaching Models for Non-formal Science Education Research

Anastasia Striligka, Kai Bliesmer, Christin Sajons, and Michael Komorek

24.1 From the Constructivist Learning Theory to Models of Teaching–Learning-Interaction

24.1.1 Criteria for Teaching–Learning Models

In the three studies we present, we investigated the actions and cognitive processes of students and adults in the non-formal learning environments when they interact with exhibits or work on problem-solving tasks. We conducted the studies because, especially in Germany, very high expectations exist for learning in non-formal educational environments: They aim to inspire students, stimulate interests on a long-term basis, help with career orientation, and support the school. In addition to motivational effects, informal institutions should support subject-related learning. In the studies, we ask in what form this is the case, to what extent the exhibits and tasks are suitable for cognitive activation, and what role the special atmosphere of the non-formal learning venue plays in this context.

The studies we present are in the postgraduate program *GINT—Learning in Informal Environments*. GINT stands for geography, computer science (informatics), natural science, technology education. The Ministry of Lower Saxony in Germany

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funds the GINT program. Five universities in Greece, Denmark, and Germany participate in the program.

Empirical research requires methods that allow the researcher to be close to the students, to accompany them in the non-formal learning environment, and to question and observe them. Research in out-of-school learning venues places special demands on the modeling of the processes taking place. From an epistemological point of view, we proceed from a constructivist view of learning (Duit & Treagust, 1998), according to which learning means the self-activity of the learner in the construction of meaning, building up knowledge, and developing explanations.

We follow the basic constructivist belief that learning, and teaching are mutually dependent subjective constructions. Scientific subject structures are constructions in which priorities and contextual embedding of subject-related content are made. Representations of subject-related structures pursue certain educational aims with a certain freedom and the need to analyze and reconstruct subject-related structures. This view is part of our self-image as science education researchers. Within this view, subject-related education is not just a mediator between the given knowledge and the learner. Rather, subject-related education is the authority that re-structures the subject-matter structure for specific purposes, strictly considering the possibilities and limits of the learner and empirically checking the fit between the re-structured subject matter structure and learning again and again. Therefore, this requires models that meet certain properties; they must be complementary, critical-analytical, and adaptive–recursive at the same time.

24.1.1.1 Complementary

The models must look at learning and teaching equally concerning one another. Thus, the models explicitly must represent and emphasize the complementarity of teaching and learning.

24.1.1.2 Critical-Analytical

The models must allow critical analysis of learning environments. This includes the design of entire learning environments, learning materials (such as exhibits or tasks), and subject-matter structures constructed with educational intent. It is precisely the critical-constructive approach to subject-matter structures that distinguishes genuinely subject-matter-oriented education from those of general didactics and educational sciences.

24.1.1.3 Adaptive–Recursive

The models must have an adaptive–recursive approach. This means on the one hand; the models allow modeling processes. On the other hand, the models explicitly must support the repeated adaptation of constructed subject-matter structures, teaching designs, and educational products based on empirical findings.

In the following, we present models that either fulfill all three properties (models of genuinely subject-related education) or largely do this in a combination of various general education models. We argue that subject-related education very often uses models from other branches of science, such as social sciences, general didactics, or educational science, and adapts them to tasks of subject-related education. This approach always is allowable if results demonstrably improve educational reality inside or outside of school. The first study from Sajons (2020) considers the combination of the offer-usage model with the design-based research approach (Chap. 24.4.1), in order to redesign an already existing learning environment in an out-of-school student laboratory. The second and the third study both rely on the Model of Educational, a proven, genuine subject-related model: In the second study we use the model to design a *new* learning environment in a national park house (Chap. 24.4.2) and in the third study, we use the model to improve an *already existing* learning environment in a science center (Chap. 24.4.3).

All three presented studies have three main steps, or so-called tasks, in common. As presented in Fig. 24.1, the first task is the "Analysis". In case the educational structure already existed, the researcher first must analyze the existing learning environment and identify its strengths and weaknesses. In case a new learning environment was designed, the subject matter structures must be analyzed first. The second common task is the "Empirical study". In this step the learners' perspectives and, in some cases, the perspectives of other stakeholder groups were investigated. The third Task is the "Design" or, in case an educational structure already existed, "Redesign" of the learning environment, based on the previous analysis and empirical study. Because the models have an adaptive–recursive approach, the repeated adaptation of constructed subject-matter structures, teaching designs, and educational products based on empirical findings, is a key element of each model.

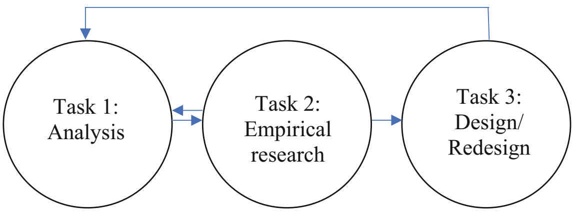

Fig. 24.1 Three tasks that all models used have in common

24.2 Combination of the Offer-Usage Model and the Model of Design-Based Research (Used in Study No. 1)—And Their Application in the Literature

If using models of general didactics or educational science for subject-related tasks, one must combine them in such a way that they meet the criteria we set out above. Our aim is to show this is largely possible for the combination of the offer-usage model (Helmke, 2012) and the design-based research approach (Design-Based Research Collective, 2003). Only the critical-analytical characteristic concerning subject-matter structures is not referred to by the combination of the two approaches. This is unnecessary in the present study because the out-of-school student laboratories we examined offer predetermined subject-matter.

The offer-usage model which is widely used in the German tradition of educational effectiveness research reflects the constructivist view of learning (Helmke, 2012), according to which the learning environment has no sole and direct influence on the actual learning, because many factors on the part of the learner are jointly responsible for the learning process and the learning outcome. Similar to the internationally used CIPO model (e.g. Scheerens, 1990) the offer-usage-model is based on a system theory that describes student learning by a transformation process of inputs (e.g. teacher background, given tasks, used material and objects) into outputs (e.g. student learning processes, motivational processes and effects). Accordingly, the transformation process is embedded in a context providing enabling or disabling conditions that influence how learners perceive the instructions offered. The offer-usage model by Helmke systematizes the various influencing factors as the teacher, classroom instruction, individual learning potential, learning activities, family, the context in order to analyze the transformation process and to integrate empirically grounded aspects of instructional quality into a comprehensive model. While Helmke focuses primarily on school processes, Meier (2015) transfers the model, also concerning Labudde and Möller (2012), to non-formal learning environments: The effect of the individual learning process and outcome depends on the background and goals of the learning location, the educational structure of the offer, the individual perquisites of the students as well as the preparation and follow-up in school lessons (Meier, 2015) (Fig. 24.2).

The offer-usage model by Meier used in this study, therefore, fulfills the above criterion of the explicit complementarity of learning and teaching. However, it is not intended to be a recursive model. To meet the requirement of recursivity, we added the cyclical approach of design-based research (Design-Based Research Collective, 2003) to the offer-usage model (Fig. 24.2). The design-based research approach fulfills the criterion of recursivity particularly well because it pursues the goal of improving the design by gradually adapting a design to the conditions of real learning, thus generating innovative educational practice. The goal of gaining generalizable and transferable knowledge (Tulodziecki, 2013) supplements this fundamental idea of optimization. These should make it possible to grasp and model the complex dynamics of real learning environments. Particularly, the focus of the design-based

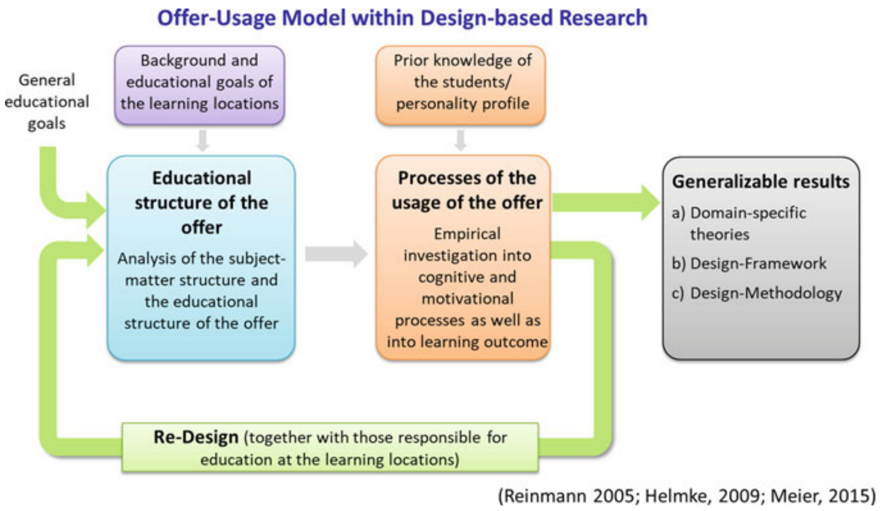

Fig. 24.2 Offer-usage model combined with the design-based research approach

research approach is to obtain general knowledge about, "how students and teachers respond to specific features of the design suggested by the theory" (Walker, 2006, p. 9). Accordingly, Reinmann (2005) formulates three levels of generalization based on Edelson (2002):

- *Domain-specific theories:* These are contextual theories that involve understanding teaching and learning from, and learning about, the effects of a design.
- *Design frameworks level:* Representing guidelines for the design of learning environments and formulated in a practical manner using tried and tested designs, these are transferable to other learning situations.
- *Design methodology level:* These relate to collaboration between researchers and workers in the formal learning environment. Joint educational development and personal interactions between both groups are central to the research and development process. Findings of this serve other research and development communities.

Reports of the combination of both models hardly exist in the extant literature. Figure 24.2 shows the combination of both models in a schematic and simplified manner. The offer-usage model expands in that way; that the empirical knowledge about how students use the tasks and objects offered in a learning environment leads to further development of learning environments based on empirical data. This yields implementation of the basic idea of the design-based research approach, providing an empirical check again of the changed offer.

24.3 The Model of Educational Reconstruction as a Genuine Subject-Matter Education Model (Used in Studies No. 2 and No. 3)—And Its Application in the Literature

Only through the constructivist view, learning gained recognition as a knowledge construction process decisively influenced by the learners' perspectives (Ausubel, 1968), which are worth examining. In the sense of the constructivist view, one must see the subject matter structures, as part of the teaching side, as constructions created by scientists. As Duit et al. (2012) point out, one cannot simply adopt subject-matter structures for teaching–learning environments but must *re-construct* to adapt them to the learners' perspectives. While reconstructed subject-matter structures must be scientifically adequate, there is a lot of freedom of representation, accentuation, setting priorities, and contextualization in the process of reconstruction for creating a new learning-teaching environment (Kircher, 2015).

This illustrates that in every teaching–learning situation three areas play a role, from the interplay from which construction of new knowledge arises: scientific content, perspectives of the learners, and design of the teaching–learning environment. The Model of Educational Reconstruction (MER) (Duit et al., 2012) represents the connection between these areas. The MER aims to address the scientific content from the perspectives of the learners through teaching–learning environments. The base of the model is thus a constructivist epistemology (Duit & Treagust, 1998). Moreover, the MER is a genuine model from science education because it explicitly considers a *reconstruction* of the subject-matter structure. Here, we do not interpret the perspectives of the learners as annoying misconceptions to eradicate, but as a necessary additional source of inspiration for the design of scientifically adequate and effective teaching–learning environments that one cannot create solely considering the scientific content. This expresses the content and needs of learners are symmetrical and equally important.

MER can serve as both a recursive research and a development approach (Duit et al., 2012) (Fig. 24.3). On one hand, we can investigate an existing teaching–learning environment by examining what construction of scientific knowledge is the target and to what extent we consider the learners' perspectives. On the other hand, we can develop new teaching–learning environments by analyzing scientific subject-matter structures, empirically examining the learners' perspectives, and ultimately relating both. Regardless of whether we develop new teaching–learning environments or further develop existing ones, we always examine them empirically for their learning effectiveness. The generated data leads to empirically justified changes to the educationally reconstructed subject-matter structures to adapt further the teaching–learning environment to the perspectives of the addressees. We again empirically examine the revised teaching–learning environments after the adjustments. We use this recursive research-and-development process steadily to approach

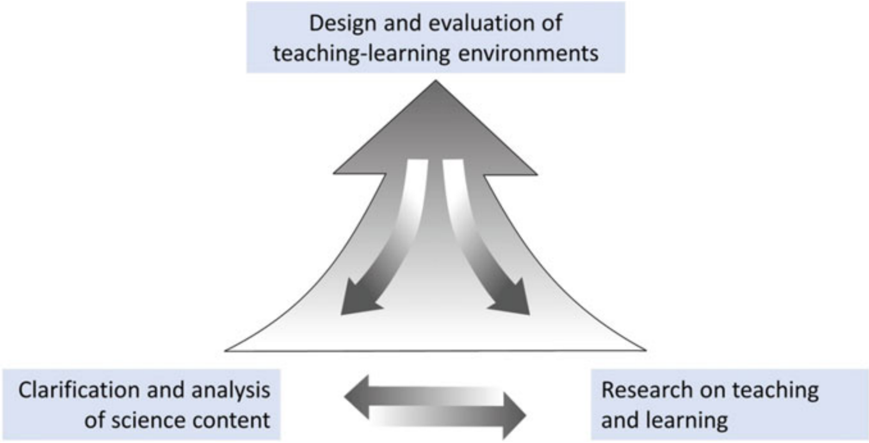

Fig. 24.3 Model of Educational Reconstruction (MER)

a learning-effective environment based on empirical data. The process of Educational Reconstruction is recursive in much the same way as the cyclical progression in design-based research (Psillos & Kariotoglou, 2016).

Although traditionally used for classroom purposes, there are attempts to transfer MER to out-of-school learning environments. Following Rennie's (2007) approach that the processes of learning are not restricted to certain settings, the findings of research on science education combined with the findings of museum research are useful when laying the groundwork for changing existing teaching–learning environments or constructing new ones (Laherto, 2013). Out-of-school learning environments such as a science center have the advantage of no imposition of constraints by a curriculum. Therefore, they can provide a wider range of cutting-edge topics and highlight socio-scientific issues while MER helps to address the topics from the learners' perspectives. For example, Stavrou et al. (2018) used MER as a theoretical framework to develop an inquiry-based teaching–learning sequence on nanoscience and nanotechnology topics that incorporates socio-scientific issues and out-of-school learning environments.

Laherto (2013) uses MER as a theoretical framework to develop new exhibits but specifically with an interpretation of visitors' interactions with the exhibits and the aim of the visit. Therefore, he suggests using the model as a general framework to involve analytical and empirical research in the development of learning environments to improve the long-term learning profit of exhibition visits. However, he points out that MER is unusable as a complete model of exhibition engineering, as there are more complex variables to take into consideration beyond the reconstruction of subject-matter structures based on empirical investigations of learners' perspectives. Laherto (2013) furthermore points out the need to adapt MER in such a way that it can model the visitors' learning through the interaction with exhibits.

24.4 Examples of the Application of Science-Education-Research Models to Non-formal Learning Environments

In this chapter we successively present the three studies in which the two models described in Chaps. 24.2 and 24.3 (the extend offer-usage-model and the Model of Educational Reconstruction) were used.

24.4.1 The Offer-Usage Model in a Study to Investigate the Cognitive and Motivational Dynamics in Out-of-School Student Laboratories (Study No. 1)

This example shows the application of the offer-usage model in combination with the design-based research approach in a study with three out-of-school student laboratories to model/describe teaching–learning processes in student laboratories. We use the findings to develop further their offers. The three laboratories are the ZNT in Aurich, the Learning Center Technology and Nature in Wilhelmshaven, and the DLR_School_Lab in Bremen.

Student laboratories are important elements of non-formal STEM education in central Europe. The so-called "student laboratories" are institutions that exist independently of schools. They belong to companies, to research institutions, to regional environmental education institutions, and sometimes are part of science centers. There are around 400 of these in Germany (Lernort Labor, 2019). Most often, classes attend a specific course for a day to stimulate scientific thinking and working, as the student laboratories claim that students can work there independently and the laboratories are more self-determined, more problem-oriented, and more context-oriented than at school. Because of that, some say student laboratories compensate for certain deficits in central European schools. The specific offers sometimes complement school lessons on topics found in the curricula and sometimes go beyond and focus on non-curricular topics such as space travel or biotechnology.

There is empirical evidence of the impact of student laboratories on situational interest and students' motivation. Through a focusing, semi-structured, qualitative guideline interview with the pedagogical staff of the student laboratories, we see that the learning venues pursue not only the development of interest in STEM topics, but also the professional learning and the understanding of contexts such as sustainability. We see a lack of research concerning cognitive and motivational processes taking place there. Besides, there is little research on how to develop learning environments in student laboratories regarding specific educational goals. The aim of the study was therefore to elucidate the complex dynamics in STEM student laboratories and to model how the characteristics of the offers (tasks, material, objects) stimulate students to cognitive processes. These findings will be used to further develop the three specific student laboratories in this study as well as to learn more about how further to develop student laboratory offers in general concerning generally discussed educational goals.

To achieve these goals, we need a research model that explicitly distinguishes between the structure of the offer and its usage by students, systematically relates both sides to each other, and allows a recursive adaptation of the offer to the needs of the users. The combination of an offer-usage model and a design-based research approach seems to meet these requirements. Thus, the first task is to analyze the educational structure of the offer. Subsequently, we must investigate the cognitive and the motivational processes of the students (usage side) to find out what effects the educational structure of the offer show. This information can be useful in the design-based research process to consider how to develop further the educational structure (design). The DBR approach does not prescribe a specific procedure but leaves didactic and methodological freedom. Therefore, the analysis of the educational structure (the design), the empirical survey of its impact, and revision of the design are the three central tasks in the present study. The analysis of the educational structure is a strength-weakness analysis, which also highlights opportunities and risks (Task 1). The results of this analysis are then hypotheses regarding the actual cognitive and motivational processes (usage processes) of the students, which we must survey (Task 2). From this, we will derive reasoned suggestions for changes to the offers, which should lead to an optimization of the structure of the offers and provide more general knowledge about learning in student laboratories (Task 3).

24.4.1.1 Task 1 "Analysis": Identify the Strengths and Weaknesses of the Educational Structure

The educational analysis aims to find out how the tasks and didactic means fit in with the goals of the course and to what extent they are suitable for stimulating and supporting certain cognitive processes (e.g., perception, concept formation, learning) in the students. In this way, we can identify potential strengths and weaknesses, as well as development opportunities and risks. This analysis of strengths and weaknesses is a necessity for a recursive approach, which constitutes the DBR approach. The analysis tool allows us to develop an understanding of processes and to interpret problems in practice. The study focused on three aspects we can legitimize by current educational concepts in the field of STEM education (including scientific literacy (Organisation for Economic Co-operation and Development, 2019)) and by the expressed goals of the student laboratories. The three aspects are the contextualization (contextualized vs. decontextualized) during the offer, the integration of problem-solving tasks, and the support of student autonomy (self-directed vs. externally controlled). Regarding these three aspects, we examine cognitive and motivational processes the program potentially can support on the students' side. These processes include perception, conceptualization, contextualization and decontextualization, planned action, and problem solving (see Anderson, 2013; Edelmann & Wittmann, 2012), as well as the perception of autonomy, competence, and relevance as motivational processes (Lewalter, 2005).

Example Below, we illustrate the analytical procedure using an identified weakness in terms of contextualization as an example. In the DLR School-Lab, students investigate various vacuum phenomena in a vacuum bell, which stands for space. They test various everyday objects in a vacuum. The students make hypotheses about what happens to objects in the vacuum bell, where sucking out the air reduces the pressure. They should describe the behavior of the objects and explain what they see. Explanations from the laboratory staff supplement the students' hypotheses. The objects are a balloon and a marshmallow, which expand when the pressure drops in the vacuum bell, and an alarm clock, whose ringing is no longer audible in a vacuum.

> A didactic weakness regarding contextualization is that these student experiments do not address explicitly the context of space travel. Thus, didactic dramaturgy is lost, especially because the transfer of the students' experiment results back to the context of space travel is not supported explicitly. This may affect how relevant the students' perception of the vacuum experiments is for the context of the laboratory visit, to learn something about space travel/space.

On the aspects of problem orientation and autonomy, we found further examples that show explicit strengths of the offer.

24.4.1.2 Task 2 "Empirical Research": Examination of the Identified Strengths and Weaknesses

Whether strengths and weaknesses we analyzed from a didactic point of view come to bear and to what extent or with which students, we must test empirically. For this purpose, we must investigate which cognitive processes we can reconstruct from observation data and interview data. We equally use this data for confirming and refuting arguments regarding hypothetical strengths and weaknesses of the offer structure (the design).

Methods

We observed and interviewed some of the students using a semi-structured guideline. We used interview techniques from the ethnographic field research (see Döring & Bortz, 2016). We asked the students about their current activities, the subject matter they perceive, the connections they make between actions or objects, and motivational aspects. We pre-formulated and specifically integrated short, understandable questions into the flow of the conversation. For example, with the question, "What are you doing right now?", we intended to examine the extent to which students can understand and describe their activities and the task, or the extent to which they can appropriate the task. When joining a group of students during a laboratory day, we observed the activities and interactions of the students and we asked about certain aspects, if possible, without disturbing the students in their activities. As part of the group, the researcher adopts the students' perspective and thus can understand better how the students perceive and use the tasks and the means they used.

Example We asked the students about the vacuum experiments. In most cases, they cannot answer, for example, how the experiments on the expanding marshmallow relate to phenomena in space travel. The following transcript excerpt of the ethnographical data illustrates this, giving insight into the failure of students to think about the astronauts' food; they fail in establishing a concrete connection between the experiment of the expanding air-filled marshmallow and problems in space travel:

Interviewer: Why did you test the marshmallow there; what does this have in common with space or with space travel?
Student 1: Because if you have food in space, for example, I don't believe that you have…
Student 2: Strawberries with cream.
Student 1: Yes, and then you want to eat it and then like this [makes an extending movement with her hands]?

The weakness we identified in the analysis, that the rather context-free vacuum station is an obstacle to understanding properties of space/space context, we confirmed by the empirical data. Although the students make a general reference of the station to the context of space travel, the concrete examples, balloon or marshmallow, cannot refer to situations in space. However, in the sense of the offer-usage model, not only is the cognitive inability of the students the sole explanation of the problem, but also the educational structure is an explanation for cognitive processes that do not occur or occur with restrictions.

24.4.1.3 Task 3 "Redesign": Consequences for the Educational Structure

Due to the Design-Based-Research approach, the research process does not stop at this point. We are developing ideas for changing the educational structure of the learning environment. The goal is to exploit the potential of the student labs in terms of contextualization, problem orientation, and autonomy support. To this end, we will compare the results of the analysis of the offer structure with the empirically determined cognitive and motivational processes to identify the need for change and derive ideas for change. This requires creativity because there can be many solutions for changes based on the identified need for change. Following the design-based research approach, we then re-implemented, analyzed, and empirically investigated this changed structure of the offer.

Example In the example of the vacuum experiments, we need to establish explicitly the connection between the phenomena studied and the context of space travel. Therefore, in cooperation with the school lab operators, we further developed the offer so the students investigate different materials in a vacuum to find out what a spacesuit must do because it must not expand; even if there is overpressure in the spacesuit, it must be airtight and movable. We show that by further developing the vacuum experiments in this way, students can establish a clearer and more explicit relationship between the experiments and the spacesuit as part of the overall space/space context, as illustrated by the following quote from one student:

Interviewer: What did you just do now?
Student: Well, we talked about the vacuum. And… a balloon was our model of a spacesuit. We tried to adapt it in a way that it wouldn't burst. But that it's not stiff either so that it cannot stand in one position only. So, that it is movable. Yes.

24.4.1.4 Results of the Study Regarding the Optimization of the Offer

The modeling approach of the study allows the investigation of the educational structure of the offer as well as cognitive and motivational processes. Additionally, the approach allows us to relate both levels of results to each other and to derive ideas for change. We can show that in all the student labs we considered, similar strengths and weaknesses in stringent contextualization, integration of problem-solving tasks, and support for student autonomy are present. The contextualization, for example, shows that, although their focus is on contexts to motivate and introduce scientific topics, hardly any reference occurs during the offer to the established context or new sub-contexts included in the experimental activities, which are not well anchored in the overall context. These "context levels" and the change between them are not transparent for the students. The potential for integrating problem-solving tasks in the programs is not fully exploited and support for autonomous action by the students is limited. The significance of the offer-usage model is that recognized problems are not one-sidedly attributed to the students, but the influence of the educational structure on successful cognitive and motivational processes is high priority. The changes in the considered offers mainly are found in these areas:

- Increasing use of narrations anchored in the context (narrative anchors) and the contexts are explicitly a subject of discussion. This way, the tasks of the laboratory day relate to the context. Decontextualizing phases became emphasized as such in their meaning.
- Increasing embedding of contextualized problem-solving tasks; however, phases of direct instruction still had their place by creating a good sequence. Cognitively more challenging problem-solving tasks and increased perception of the relevance of the tasks and the perception of self-efficacy.
- Explicit establishment of phases of self-determined working with problem-solving tasks. They increased the students' perception of autonomy and overall motivation. Externally determined plenary phases, however, retained their function in that way that the students can become aware of the importance of individual activities for the overall goal of the laboratory.

Through these measures, the students gained a better understanding of the subject matter and the interrelationships, as the empirical data show. Besides, their motivation to deal with the tasks could increase while at the same time intensifying their perception of self-efficacy.

24.4.1.5 Results of the Study Regarding Generalizations for Learning in Student Laboratories

In addition to the optimization of offers, generalizations play an important role in the design-based research approach. In the present study, we achieved the following levels of generalization (according to Reinmann, 2005):

- We achieved area-specific generalizations concerning the offer-usage-processes by obtaining findings for all considered student laboratories. It was possible to formulate a generalized description of how we used the offers concerning contextualization, integration of problem-solving tasks, and support for student autonomy. This was possible because we recognized the educational structure and processes on the student side as equally important factors for the improvement of the offers. The recursiveness of the DBR approach allowed an adaptation to the needs of all participants.
- The "Design Methodologies" (according to Reinmann, 2005) provided insights for the cooperation between researchers and practitioners at the learning sites. In particular, the ethnographic approach not only referred to investigating the student's side, but also to the social context of the employees of the student laboratory. We can show how it is beneficial to the quality of the joint work to find a mutual hearing.
- At the level of "design principles", it was possible to formulate guidelines for the analysis and further development of offerings that relate to the three aspects of context orientation, problem orientation, and autonomy support.

On the one hand, the offer-usage model supports considering both an analysis of the educational structure of the offer as well as the survey of the learning process of the students. On the other hand, the design-based-research approach supports comparing the results of these two sides to optimize the offer and therefore represents a recursive approach. To sum up, the combination of these two models allowed elucidation of the dynamics of teaching and learning processes in student laboratories and development of their offers based on the findings.

24.4.2 *Model of Educational Reconstruction in a Study to Develop an Exhibition on the Physics of Coastal Dynamics and the Exploration of Learner Perspectives (Study No. 2)*

To illustrate the MER (Duit et al., 2012), we describe a project in which we used the model in cooperation with an out-of-school learning venue. The project aims to investigate and to develop new exhibits on currents and structure formations in the Wadden Sea. The project came about because there are many out-of-school learning venues in the German Wadden Sea, which use exhibitions to inform visitors of all ages about the Wadden Sea. However, the learning venues primarily are run by biologists and environmental scientists. According to Roskam (2020) and Bliesmer (2020), this results in two deficits:

- Thematic: The exhibitions are mostly about biology or ecology. Physical phenomena such as currents and structure formations (for example, ripple marks and dunes) so far are unaddressed, although they occur everywhere in the Wadden Sea.
- Disciplinary: The operators of the learning venues are unable to develop new exhibits based on findings from science education research. Exhibits are developed only together with exhibition agencies, whereby the learners' perspectives are systematically absent.

Because of these deficits, we established cooperation between physics education research and the out-of-school learning venues. The operators report that visitors often observe currents and structure formations in the Wadden Sea and seek more information about them. However, so far no related exhibits are present in the out-of-school learning venues. Through cooperation, development and examination of new exhibits happen with methods from science education research. The researchers chose MER as the conceptual framework.

The model demands both an analysis of the scientific content and an investigation of the learners' perspectives to develop new teaching–learning environments. Therefore, it fits very well with the objectives of the project: On the one hand, we must analyze the new topic (currents and structure formations) to clarify the subject-matter structure. On the other hand, we must appreciate and examine the learners' perspectives on the topic, since their pre-knowledge and their conceptions are important predictors for the construction of new knowledge (Ausubel, 1968; Duit & Treagust, 1998). We must then relate the scientific knowledge and the subject-related perspectives of the learners to one another. On this basis, we developed teaching–learning environments that have the pursuit of continuous learning pathways or that deliberately trigger cognitive conflicts (Scott et al., 1992; Duit & Treagust, 1998). We investigate whether we achieved this through an empirical study of the developed teaching–learning environments, then used the empirical data for revision and improvement.

24.4.2.1 Task 1 "Analysis": Clarification of Subject Matter Structures

From a constructivist perspective, the subject-matter structures in the scientific literature express a consistent representation of scientific knowledge. However, as stated in the introductory chapter, they are usually unsuitable for learners and therefore must undergo *reconstruction* with a special emphasis on the learners' perspectives to support the addressees to construct scientific knowledge. In preparation for reconstruction, we must analyze the subject-matter structures in the scientific literature. We used the concept of elementarization for this, which means we analyzed scientific literature to clarify the elementary scientific ideas (key concepts) suitable to explain the topic and related phenomena (Duit et al., 2012). To elucidate key concepts for currents and structure formations, we analyzed scientific literature from the fields of continuum mechanics (Haupt, 2002), non-equilibrium thermodynamics (Demirel, 2014), and complex systems (Bar-Yam, 2003). Besides, we examined journal articles on various structure formations: ripple marks (Anderson, 1990), dunes (Durán et al., 2010), and tidal channels (Fagherazzi, 2008). The following are examples of key concepts we worked out for the topic "currents and structure formations".

(1) *Gradients cause currents:*

Currents occur in fluids such as air and water. They are collective movements caused by temperature and concentration gradients (natural convection) or when external forces act on a fluid (forced convection). The latter means that momentum density gradients arise.

(2) *Currents are equalization processes:*

Currents caused by gradients reduce the gradients. That means currents counteract their cause. Therefore, currents are a phenomenological expression of an equalization process in nature.

(3) *Irregularities and currents initiate structure formations:*

When water or air currents move sand, irregularities, such as a shell in the sand, cause sand to get caught and accumulate there. These obstacles represent the trigger mechanism for structure formations in the sand.

(4) *Positive and negative feedback lead to self-organized structure formations:*

An obstacle, which acts as a trigger mechanism, results in positive feedback: If sand sticks to the obstacle, it becomes larger and even more sand piles up there. At some point, however, the build-up reaches a size and steepness at which more sand rolls down from the pile. Besides, the currents become turbulent through a larger pile of sand. Both have the effect of preventing further growth (negative feedback). In total, the structure formation stabilizes due to the interplay between positive and negative feedback, which is self-organization.

24.4.2.2 Task 2 "Empirical Research": Investigating Learners' Perspectives

We pursue two research approaches here. The focus is initially on what the terms "currents" and "structure formations" mean for the learners. This is relevant because phenomena and contents presented in the scientific literature often are named and described using terms that occur in everyday life but have a completely different meaning there. In German, this is the investigation of "Begriffsbildung" (Edelmann & Wittmann, 2012) and means the features and meanings of the terms from the learners' perspectives are under investigation. Subsequently, we examined the pre-knowledge and conceptions (Posner et al., 1982) learners use to explain the topic. Therefore, we conducted two interview series of semi-structured and problem-centered guideline interviews (Witzel, 2000) for both research areas. We described them below and anyone can use them in the same way for a topic other than currents and structure formations.

Interview series 1: Investigating what features learners associate with the phenomena

Research question: What are the features of currents and structure formations from the learners' perspectives?

We used 30 images as stimuli in the first interview. They show currents, structure formations, and phenomena that are scientifically neither currents nor structure formations. We asked the interviewees to select images they believed to represent currents. We then discussed the features for classifying currents. We asked them to name synonyms and antonyms of currents and justify them. We repeated the entire procedure for structure formations. We interviewed 16 out-of-school learning venue visitors (ages 15–75). We recorded and transcribed all interviews to evaluate them using a qualitative content analysis (Mayring, 2014). Exemplary results are as follows:

- Currents: They are dangerous because they can put people in the water at risk. Furthermore, currents are collective movements of individual parts, whereby the extent of the parts must be small compared to the overall movement.
- Structure formations: Central features are irregularity and regularity. With "irregularity", they make clear that structures stand out from a homogeneous environment. "Regularity" refers to the spatial and temporal periodicity of structures. Interviewees consider them unique and call them "nature's fingerprint", as they only reappear similarly, not exactly.

Interview series 2: Investigating how learners explain the phenomena

Research question: What scientific ideas do learners use to explain currents and structure formations?

We carried out two experiments, which act as stimuli. We structured the interview using the POE procedure (White & Gunstone, 1992). The letters stand for predict, observe, and explain. We asked the respondents to name and justify their predictions before experimenting. While carrying out the experiment, the respondents are to

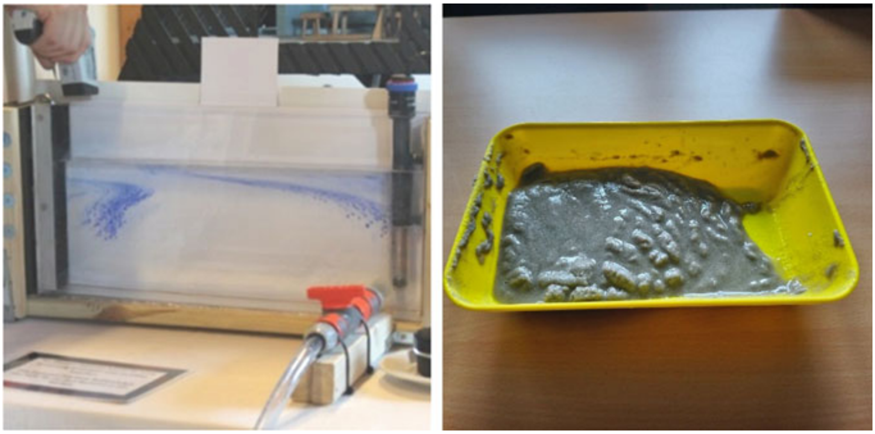

Fig. 24.4 Experiments are to create convection cells and structure formations

verbalize their observations. Finally, we asked them to explain their observations. The first experiment is a water basin heated on one side and actively cooled on the other (Fig. 24.4 left). The resulting temperature gradient creates a convection cell made visible by adding ink. The second experiment consists of a bowl of sand and water (Fig. 24.4 right). By moving the bowl back and forth rhythmically, one causes structure formations to develop inside.

In the later course of the interview, the questions also went beyond the specific experiments concerning currents and structure formations in general. We interviewed 15 of the people from interview 1. We transcribed the interviews and performed a category-generating, qualitative content analysis (Mayring, 2014). Exemplary results are as follows:

- Currents: Although the phenomenon in the experiment is natural convection, the respondents focus on forced convection caused by external forces. In this regard, they argue with a *transfer principle*, according to which matter already in motion transfers its dynamics to air or water. The learners are unable to explain the natural convection that occurs in the experiment.
- Structure formations: Learners argue that irregularities in environmental conditions (for example, temperature or sand speed) produce irregularities in the sand. Learners interpret these irregularities as structures. However, the learners cannot explain the processes in structure formation. Furthermore, respondents apply a *transfer principle* here too; they assume that pre-structured matter (a water wave) transfers its structure to unstructured matter (sand), which leads to structure formation (ripples marks). Because they explain structures with structures, they create an argumentative dead-end, a chicken-egg problem.

24.4.2.3 Task 3 "Design": Design and Evaluation of Teaching–Learning Environments

Here we relate the results of the two previous tasks to each other by systematically comparing the scientific key concepts with the examined learners' perspectives (Duit et al., 2012). The aim is to reconstruct the subject-matter structure of the subject area in such a way that the learners' perspectives serve as a starting point for building up new knowledge (Scott, 1992). Teaching guidelines express the reconstruction of the subject-matter structure (Niebert & Gropengiesser, 2013) for the creation of new exhibits that address currents and structure formations. We then use the guidelines in cooperation with an exhibition agency to jointly develop new exhibits. The guidelines are therefore not recipes for the creation of exhibits (or teaching–learning environments in general), but rather emphasize what to consider from the viewpoint of physics education research to create new teaching–learning environments. We described three exemplary guidelines:

Guideline 1: Focus on features of the phenomena from the learners' point of view

The learners see currents as dangerous. That is why we introduce "collectivity", the directed movement of water, as a central feature of currents. We explain that currents are dangerous because the directed movement pushes people far into the sea. Concerning structure formations, we introduce "similarity" as a feature, because this ties in with the learners' perspective, as they explain characterization of structures by periodic sequences and patterns that repeat imperfectly but similarly and therefore stand out from their homogenous environment.

Guideline 2: Address forced convection before natural convection

Because the learners concentrate on currents that, from a scientific viewpoint, are forced convection, an exhibition starts with this type of convection. The *transfer principle* the learners use will link to the scientific concept of energy transmission: Energy transfers to water or air and converts into kinetic energy. Based on this, we introduce that currents represent an equalization process (a scientific key concept). The kinetic energy distributes in the fluid, gradients reduce, and ultimately disappear. Finally, we thematize natural convection, which results from temperature and/or concentration gradients; we also represent free convection as an equalization process because it reduces the gradients as well.

Guideline 3: Interpret irregularities as the starting point of structure formations

Learners explain structure formations with irregularities in environmental conditions. Because this is also the first step in a scientific explanation, we take into account the learners' perspectives as follows: We reinterpreted the irregularities as starting points for structure formations but clarified that irregularities in the environmental conditions cannot explain the processes in the formation of structures. To motivate the need for further clarification, we confronted the learners with their *transfer principle*. We underlined that by using that principle they explain structures with structures. This creates a chicken-egg problem. To show them a way out of the problem, we offered explanations based on feedback processes. Proceeding from irregularities that function as starting points, positive and negative feedback processes set in, which establish self-organization.

24.4.2.4 Conclusion and Further Tasks in the Recursive Research Approach

Because we chose MER as conceptual framework in the present study we did consider both the scientific content (through elementarization) and the learners' perspectives (through empirical research). Only if we examine both can we systematically compare them with one another. This comparison represents the nature of MER since the reconstruction of the subject structure aims at the central endeavor to consider teaching and learning equally when developing teaching–learning environments.

In the present project, we used the guidelines in cooperation with the operators of out-of-school learning venues and exhibition agencies. By using the guidelines, we fed a perspective from science education research into this cooperation, in which new exhibits developed. After integrating the exhibits into the exhibitions, we examined their effect on visitors in another empirical study. Using the data from this empirical study, we will revise and improve the exhibits. MER therefore represents a recursive approach in which research and development closely link (Duit et al., 2012).

24.4.3 Model of Educational Reconstruction as a Framework to Study Students Learning Through Exhibits of a Science Center (Study No. 3)

In this study, we applied the MER (Duit et al., 2012) to situations where learning takes place by interacting with exhibits in a science center during a school visit. We needed to analyze the scientific and educational structure of the exhibits (Task I). From a constructivist point of view, we must relate the results of these analyses systematically to the empirical results of the learning processes (Task II) to suggest changes (Task III) that could support the learning processes of the users. The current example study took place at the Phänomenta Bremerhaven science center in Germany, where we selected five hands-on exhibits (Camera obscura, Visible light, Bernoulli Effect, Pulley system, and Brachistochrone) with varying interaction challenges. We used the four interaction challenges to explore fourth-grade students' learning processes as they interacted with the exhibits. Our goal was to investigate to what extent learning of scientific content occurred and what actions could be observed while interacting with the exhibits. Additionally, we wanted to determine to what extent the intentions of the science centers' administrators and the classroom teachers fit the learning processes of the students.

24.4.3.1 Task 1 "Analysis": Analysis of the Teaching–Learning Environment

It is necessary to clarify the scientific concepts represented at the exhibit. One of our objectives was to determine to what extent the understanding of visitors deviates from the socially shared knowledge of science. Afterwards, we consider how scientific knowledge is restructured and acquired by learners on the basis of their preinstructional conceptions. To clarify the preinstructional key concepts of the exhibit, we completed an analysis of scientific literature and journal articles.

For example, the Visible Light (Fig. 24.5) exhibit includes three colored filters (red, green, blue) and a prism. Each filter and the prism may be folded down one by one or simultaneously in front of a light source. The written task at the exhibit is: "Look at the spectrum of visible light with the prism, and the filters will let the light pass only through a certain area". Key concepts from the Visible Light exhibit that were color subtraction and light refraction and dispersion.

To analyse further the educational structure of the exhibit, we formulated the possible interactions with the exhibits. By seeing the epistemological similarities between MER and the anthropological theory of didactics (ATD), the concept of "praxeology" (Chevallard, 2007; Bosch & Gascón, 2006) may be used for operationalizing the link between the identification of tasks proposed for certain exhibits and the conceptual knowledge that is offered by interacting with these exhibits (Mortensen, 2010). The four elements of praxeology proposed by Achiam (2013) are:

(1) Task: Students identify relevant components and perceive the explicit task of the exhibit.
(2) Technique: Students perform or apply a procedure in each situation to solve the task.

Fig. 24.5 Exhibit "Visible Light"

(3) Technology: Students justify their actions. They explain what happens while they interact with the exhibits and why it happens.
(4) Theory: Students justify their actions and the exhibits' response by theoretical concepts.

In each element, cognitive processes play a key role like recognizing, remembering, interpreting, classifying, summarizing, comparing, explaining, executing, implementing, differentiating, organizing, reviewing, generating, planning, developing etc. (Bloom, 1956; Anderson & Krathwohl, 2001).

Example: Potential praxeology at the exhibit Visible Light

We took into consideration the key concepts the exhibit could support when someone interacted with it. We used these concepts to create a praxeology showing the possible actions and learning processes that could occur. We describe these below.

(1) Task: Identifying all components of the exhibit (Lamp, Button, Three Colored Filters, Prism, Text). Retrieving previous knowledge about the subject (visible light) and how to use the recognized objects.
(2) Technique: Understanding/interpreting objects and text in the exhibit and applying previous knowledge to conduct the activity and observe what will happen at each step. For example: press the button to turn on the lamp, place the prism in front of the light source, place the filters between the light and the prism, etc.
(3) Technology: Explanation of the user's manipulations at the exhibit and their reasoning, explanation of the phenomenon observed, and differentiating between relevant and unrelated variables that may affect the phenomenon. Users could explain that the prism splits the white light into a spectrum and that each filter lets a different part of the spectrum through.
(4) Theory: Users will be able to justify their observations by using theoretical science concepts, such as color subtraction and light refraction and dispersion (e.g. the prism causes different colors to refract at different angles, splitting white light into a spectrum, the filters absorb different parts of the spectrum). However, we did not expect the fourth-graders (provide ages because this is an international book) in our study to attain this level of knowledge.

24.4.3.2 Task 2 "Empirical Research": Students, Centers Operators and Teachers Perspectives

We should take into consideration the complexity of the learning situation during a school visit in out-of-school learning settings (Griffin, 2012; Falk & Dierking, 2000). Empirical studies should examine students' individual learning processes from a constructivist point of view (Driver et al., 1985). Moreover, researchers should consider the expectations and learning goals of the centers' administrators and the classroom teachers in terms of students' interactions with the exhibits. By reconstructing the expected praxeologies of the centers' operators and the teachers of certain exhibits and comparing them to the praxeologies of the students, which are empirically observed during their interaction with these exhibits, we can suggest possible changes for the informal teaching–learning environment.

Example: Investigated praxeology of center operators' expectations

To learn more about the praxeology the center operators expect from the students, the operator of the science center was interviewed with questions like: "What do you think a student would do and understand when interacting with this particular exhibit?". To determine the actions and learning paths that were expected to occur while interacting with the exhibits we evaluated the empirically obtained data using qualitative content analysis (Mayring, 2014).

(1) Task: Identifying all items in the exhibit (Lamp, Button, Three Colored Filters, Prism) and text. Retrieving previous knowledge about the subject (visible light) and how to use the recognized objects. The students will realize that the task is to look at the spectrum of visible light with the prism and see that the filters will let the light pass only through a certain area.
(2) Technique: Understanding/interpreting objects and text in the exhibit and applying previous knowledge to conduct the activity. For example, pressing a button to turn on the lamp, place the prism in front of the light source, placing the filters between the light and the prism, etc.
(3) Technology: Explanation of the user's manipulations in the exhibit and their reasoning, explanation of the phenomenon observed and differentiating between relevant and unrelated variables that may affect the phenomenon. Users could explain that the prism splits the white light into a spectrum and that each filter lets a different part of the spectrum through. For example, when white light shines solely through the red filter, students see that all colors but red are absorbed by the filter. When red and the blue filters are in front of the light source, students observe that little to no light is shining through, which occurs because most of the light is absorbed by the two filters.
(4) Theory: Students will not use more abstract terms, such as color subtraction, to explain why the light did not go through the filters.

Example: Investigated Praxeology of students

Interview techniques from the ethnographic field research were used (citation needed). While students interacted with the hands-on exhibits, we use participatory observations to observe 24 students. Additionally, we questioned those 24 students in groups of two using a semi-structured guideline to reconstruct their praxeology. For example, we asked, "What can you do about this particular exhibit? Can you explain what is happening to the exhibit?". Furthermore, students completed questionnaires with open-ended and multiple-choice questions before and after the school visit. We sought to determine what ideas emerged from the phenomenon of the selected exhibits and students' expectations of the science center visit. To determine the actions and learning paths, we evaluated the data using qualitative content analysis (Mayring, 2014) and related the data systematically through data triangulation (Flick et al., 2004). By analysing all students' interactions and learning processes with the exhibit we came to a praxeology that represented most of the students:

(1) Task: Identifying almost all items in the exhibit (Lamp, Button, Three Colored Filters, Prism). They understood how to use the recognized objects. However, they ignored the text and did not realize the task was to look at the spectrum of visible light with the prism and determine the prism will let light pass only through a certain area.
(2) Technique: Understanding/interpreting objects in the exhibit and applying previous knowledge to conduct the activity (e.g. press the button to turn on the lamp. Place the prism in front of the light source, place the filters between the light and the prism, etc.) However, as there was no specific order given, in which the students should conduct the possible activities, each student group used each object of the exhibit in a different order.
(3) Technology: Explanation of the user's manipulations in the exhibit and his reasoning, explanation of the phenomenon observed that are not aligning with scientific knowledge that is scientifically accepted. Students explained their actions and the phenomenon observed by using their preconceptions and object-related explanations (e.g. when the light goes through the red filter, the light is being colored by the filter, that's why it's red or when the light goes through the red and blue filters it should become purple if the filters were not too thick.)
(4) Theory: Students will not be able to justify their observations by using theoretical concepts such as color subtraction, as it was expected by the centres' operator.

Example: Investigated Praxeology of the teacher's expectations of students

We conducted video-based interviews with formal classroom teachers to investigate their praxeology concerning the actions and learning processes expected from the students. Because of time limitations, we were not able to interview the classroom teachers simultaneously with the students on the day of their school visit. Therefore, we made videos of the exhibits in which the possible manipulations and the phenomenon shown at the exhibits were presented. By using those videos, we interviewed teachers by asking them questions like "What do you think a student would do and understand when interacting with this particular exhibit?". We implemented complementary teacher questionnaires with open and multiple-choice questions before and after the school-visit, based on categories by Cox-Peterson et al. (2003) and Griffin and Symington (1997). The questionnaires asked about the teachers' views of the learning outcomes they expected from the students' visits, and how the visit to the science center could be integrated into the school curriculum (preparation, expected learning outcomes to be achieved by the visit, etc.).

(1) Task: Identifying all items in the exhibit (Lamp, Button, Three Colored Filters, Prism) and text. Retrieve previous knowledge about the subject (visible light) and how to use the recognized objects. By reading the text students would perceive the task to see the spectrum of visible light with the prism and what filters do with it.

(2) Technique: Understanding/interpreting objects and text in the exhibit and applying previous knowledge to conduct the activity (e.g. press the button to turn on the lamp. Place the prism in front of the light source, place the filters between the light and the prism, etc.).
(3) Technology: Explanation of the user's manipulations in the exhibit and his reasoning, explanation of the phenomenon observed that are not aligning with scientific knowledge that is scientifically accepted. Students explain their actions and the phenomenon observed by using their preconceptions.
(4) Theory: Students will not be able to justify their observations by using theoretical concepts such as color subtraction, light refraction etc.

Merging the three perspectives

The results of this study indicate that when students visit the science center, they recognize how to use the objects (buttons, filters, light source, prism) at the exhibit. However, because they do not read the text they do not realize the goal of the exhibit (Task). Students are nonetheless able to carry out all work procedures (e.g. press the button, place the filters and the prism in front of the light source) (Technique). They can give explanations (Technology) to their actions on the exhibits. However, these explanations do not always agree with the ones desired of the exhibition supervisor (Achiam, 2013). Students tend to explain their actions and the phenomenon observed by using their preconceptions and object-related explanations. Moreover, students have difficulties in justifying themselves with abstract concepts (Theory). Our work confirms previous studies that the students, teachers, and center operators' views are not aligned (Griffin, 2012). We suggest further research is needed to bridge the gaps between the science center operators' intended use and the learning processes experienced by students, the teachers' views of their students learning, and the students' actual use and learning processes while interacting with the exhibits.

24.4.3.3 Task 3 "Redesign": Re-designing the Teaching–Learning Environment

In this final step, we are developing ideas for changing the educational structure of the teaching–learning environment. Our goal is to exploit the potential of school visits at a science center. To this end, we compare the results with the empirically determined cognitive processes to identify the need for change and derive ideas for change. There are three ways in which this study could support the re-design of the teaching–learning environment:

I. Providing guidelines for exhibit developers on how to build a new exhibit or change an existing exhibit based on the empirical data and the literature-based exhibit evaluation.
II. Providing guidelines for teachers for pre-post preparation of a school visit at a science center (Geyer, 2008; Stern et al., 2008; Behrendt & Teresa, 2014; Coll et al., 2018; Lee et al., 2020).

III. Providing guidelines for the centers' educators on how to include certain exhibits during the school visit.

Example for re-designing the Visual Light exhibit

After systematically relating the results of the scientific and an educational structure analysis to the empirical results of the learning processes from a constructivist point of view, we are suggesting some of the following changes/additions that could support the learning processes of the students during a school visit:

- To change the students' idea that the light goes through the filters because of the phenomenon of color addition (e.g. green, blue and red filters makes black light—not the absence of light seen on screen), it is not only important to use monochromatic filters, but also to instruct that the prism should be folded down before the filters are. If the spectrum is explicitly marked on the screen, students should more easily realize the color of the light at that moment and that the other colors of the spectrum are no longer visible on the screen.
- Students believe that the filters do not let light pass through because they are too thick. This belief could be changed by providing an additional exhibit or suggest to teachers to follow up with post-visit experiments (Behrendt & Teresa, 2014; Coll et al., 2018; Lee et al., 2020). Students could experiment with thinner foils in the colors green, red, and blue and varying light source intensity.

24.5 Importance to Research

Our examples show how subject-related models, or the combination and adaptation of general education models can improve research in non-formal learning environments. Our work indicates how generalizable knowledge about non-formal learning arises and how learning objects and exhibition designs can be further developed. The choice of models is tied to criteria that are closely related to the research objectives. In the field of non-formal learning, one research goal is to understand and model the complex dynamics of teaching–learning situations. This is only possible if one does not focus one-sidedly on learning, but at the same time analyzes the learning environment, its educational structure and methods of presentation. A learning environment can take on a broad spectrum of manifestations, starting with simple objects in the museum and interactive exhibits in the science center to guided explorations in an out-of-school laboratory. In all these cases, models are required that explicitly allow an analysis of the learning environment. The learning environment itself becomes the object of research because it is part of the dynamic of the teaching–learning situation and not a simple static prerequisite for learning.

MER as a research and development model allows an explicit analysis of the teaching side. The offer-usage model is also suitable for studies that seek to understand teaching and learning in their complex, complementary interaction. Furthermore, MER explicitly allows and requires the subject matter structures be criticized, questioned, or re-constructed. Educational Reconstruction can be applied in studies in which new topics are prepared for non-formal education or in which the scientific content has so far been insufficiently analyzed and elementalized, resulting in learning difficulties.

In our studies, we present the importance of the enrichment of knowledge about complex teaching–learning dynamics as a goal and further develop the out-of-school learning environment. We conclude models are required, which explicitly represent the development process and suggest a certain expressive approach. These models should be recursive and adaptive. We combine the MER, the complementary offer-usage model, and the DBR to meet the criterion of recursivity by repeatedly testing educational structures and adapting them to the students' recognized learning opportunities and learning difficulties. The merging of the models enables the gradual adaptation and improvement of learning environments for the learners. The MER additionally allows a constant readjustment of the subject-matter structure.

The models shown help to understand the dynamics of a wide variety of teaching–learning environments and thereby allow to develop them further based on empirical data. Therefore, a variety of research questions and development tasks can be approached in non-formal learning environments. This is important because the non-formal learning opportunities are increasing in number and importance, reflecting a world of education that is becoming more differentiated and should be explored. After all, a very large educational potential can be recognized here in terms of supplementing school education and in terms of lifelong learning.

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Chapter 25
In Search of an Articulated and Coherent Theoretical Framework to Inform Research and Evaluation of Learning in Science Centers: A Tale of Two Research Challenges

Elsa Bailey

25.1 Introduction

Frank Oppenheimer, founder of the Exploratorium, perhaps the first interactive science center, famously pointed out, "No one ever flunked a museum" (Semper, 1990, p. 52). Indeed, there are no high stakes tests to flunk in science museums; however, if that is true, how do museum professionals and others recognize learning in such settings? The question, Do people learn in science museums? has confronted and confounded museum professionals since museums evolved from "curiosity shops" to their current position within the infrastructure of society's cultural, educational, and academic institutions (Abell & Lederman, 2014; Andre et al., 2016; Association of Science-Technology Centers, 1996; Horr & Heimlich, 2016; Roberts, 1997).

The field of informal science education had considerable movement over the last decades. Literature from and about informal organizations shows a shift around their attitudes concerning their role in science education and what constitutes learning. They moved from a stance where museum education departments were in the basement (a telling decision as to organizational attitudes about their importance), to a more vital interest in the process of learning and their desire for increasing recognition as a legitimate and integral part of the greater educational infrastructure. We witnessed a change in thinking about museums and learning (Hein, 1998, 2006, 2012). In the mid 1990s, a call to establish a research agenda for informal science institutions, supported by the American Association of Museums and the National Science Foundation, helped promote a self-examination around the unique character and opportunities for learning in science museums (Falk & Dierking, 1995). As a result, through this examination, informal science research gave rise to a deeper

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understanding of the visitor experience and effective ways to present science in these settings. However, questions about the process of learning in informal science settings are still very current (Corin, 2017; Falk & Dierking, 2019).

Literature well documents the quest for, and challenges faced over the last century in actually identifying and even defining learning taking place in science museums (Andre et al., 2017; Leinhardt et al., 2002; Dierking et al., 2004). Professionals stimulated much of this research when faced with the question, "Yes, visitors have fun in museums, but what do they really learn?" (Allen, 2002, p. 262). Those who fund and support museums are particularly intent on validating their investments, an intention that motivates requirements for inclusion of evaluation in many grant-funded exhibits or programs. These policies support a sizable and expanding body of research. Much of this research, however, is specific to particular exhibits or programs. Although they contribute to knowledge in the field, gaps remain for researching these visitor-centered, and for the most part, unprescribed and/or unpredetermined experiences. Particular gaps remain around ascertaining effective and appropriate ways to recognize, document, and assess *learning* during experiences in informal education settings.

The museum experience is complex because the museum does not exist in isolation. It serves as a crossroad for multiple communities, which include the museum itself, the audiences it seeks to serve, and the communities, culture, and contexts in which it exists and receives support, and upon which it focuses. Falk and Dierking explore these ideas in their related volumes from 1992 and 2000. They articulate a model for the museum experience and visitor learning from the perspective of the museum visitors. They posit that to understand learning in the museum setting, we must not only rely on learning theories developed in contexts outside the museum setting, but also consider the critical aspect of the museum experience itself with the important roles the personal, social, and physical contexts play in learning (Falk & Dierking, 1992, 2000). Falk (2009) expands on some of these ideas as he describes the differing agendas and identities each visitor brings to their museum experience. A transactional view of museum experience was put forth by Paris and Mercer (2002). Their research evoked a perspective that visitor experience with exhibits and their associated objects can have a transformative effect on the visitor, evoking "tangential, unintended or novel responses and might change the knowledge, beliefs, or attitude of the visitor" (Paris & Mercer, 2002, p. 401).

As human knowledge and associated understandings are always susceptible to modification and change, my own mental models have been influenced by theories and paradigms around learning. In my work in both informal and formal education, I continue to draw upon a suite of ideas, perspectives, and conceptual frameworks, which together inform my understanding of learning and offer a rich way to think about how people learn. As I gain exposure to new ideas, I consider how they resonate or perhaps conflict with my prior conceptions of learning. This collection of ways of thinking about learning includes constructivism, experiential learning, and sociocultural and social-emotional theories around learning (Fosnot, 1996a, 1996b; Hein, 1998; Kirshner & Whitson, 1997; Kolb, 1984; Lave & Wenger, 1991; Ogbu, 1995a, 1995b; Perry, 2012; Schauble et al., 1998; Senge, 1990; Senge et al., 1994;

Sprenger, 2020). These ideas, under which theories and associated postulates arise, come from a wide array of disciplines including psychology, human development, cognitive science, education, sociology, anthropology, and organizational development. I perceive them to be complementary in relation to learning in informal settings because no single theory addresses the complexity of learning and researching in such settings.

This chapter shares the tale of my own foray toward investigating this question, Is learning happening in science museums? It is a story about a search for an approach and theoretical and/or conceptual framework for researching learning in informal science settings.

For informal science educators and researchers, researching learning in informal environments opens associated questions such as: How do we identify learning in informal science settings? What does it mean to learn science? Ideas about learning have become increasingly complex, moving from an initial perspective focused on a simple accumulation of science content knowledge and methods, to one that includes and considers its social, emotional, and cultural components (Birney, 1986; Davidson et al., 2020; Fenichel & Schweingruber, 2010; National Research Council, 2009; Serrell, 1990). This broader and deeper way of looking at science learning has a profound influence on the ways we think about examining science learning in informal settings (Allen, 2002; Falk & Dierking, 2019; Gutwill, 2016; Kelly, 2003; McManimon, 2021; McManimon et al., 2020; National Research Council, 2009; Price & Applebaum, 2022; Schauble et al., 2002; Tal & Dierking, 2014). This enhanced way of looking at learning prompts innovation toward recognizing, assessing, and understanding learning in informal science settings.

My work in the museum field ranges from being a developer and implementer of museum programs to being an evaluator and researcher of museum programs, exhibits, and organizations. My prior work in formal education with young children provides a grounding for thinking about how children learn and develop in those settings. This diversity of perspectives and experience allows me to view the field of education from both a practitioner's and a researcher's point of view. I conclude that although distinct differences exist between formal and informal learning environments, many ideas and theories about learning are relevant for both environments. It strikes me as unrealistic to think about informal learning, as a separate process. Informal learning is part and parcel of the total learning and development of each person (Crane, 1994). The key for me is to think of the learner as the main focal point for investigation and to look at how the context and situation of that learning opportunity affects that experience. Recent literature discuss a science-learning ecosystem, an idea that resonates with how I perceive the learner's movement across the landscape of available science learning opportunities (Corin et al., 2017; Falk & Dierking, 2019).

Perhaps I eventually will come upon, or possibly contribute to, a greater "learning theory," which can apply across contexts, including museums. In the meantime, I will approach challenges, such as proving learning is taking place in informal science education settings, by investigating the question at hand with methodologies feasible and perhaps innovative for that setting, keeping in mind the unique culture and context of informal learning environments.

25.2 Applications in the Literature

25.2.1 Constructivism

The most profound influences on my research in learning are the ideas of constructivism, a paradigm of concepts about both knowledge and learning, which describe both what "knowing" is and how one "comes to know" (Fosnot, 1996a, p. *ix*). This self-regulated process is relevant around museum's exhibits and programs because visitors bring their personal models of how the world works and further negotiate meaning-making, new representations and models, via their actions and social interactions (Fosnot, 1996b).

Hein has done considerable work focusing on how constructivism relates to learning in museums (Hein, 1998). Hein's ideas on constructivism in museums developed over many years and are informed by the thinking of many others, including Dewey and Freire. Hein believes, as did Dewey and Freire, that we must consider knowledge within the context of the reality through which it arises (Dewey, 1938/1998; Freire, 1970/2017; Hein, 2012). Hein's constructs took shape by closely examining theories of knowledge (epistemologies) and theories of learning, and applying this to a model of how these theories pertain to informal education settings like museums.

Hein maps theories of knowledge and learning on two continua, each representing a range of beliefs people hold, or associate with, the ideas of knowledge and learning. One end of the continuum for theory of knowledge is, knowledge is independent of the learner. The other extreme of this continuum is, knowledge is in the mind and constructed by the learner. On the other continuum, the theory of learning, one end is the belief that learning is incrementally absorbed by the learner overtime. The opposite end of this continuum is the belief that active participation of the mind leads to a restructuring of the mind. These continua "extend from the more formal, structured, and hierarchical to the less formal, more network-like, and more holistic" (Hein, 1998, p. 78). If we intersect these continua they sort themselves into four ways of thinking about different kinds of museum learning environments, each reflecting a different stance as to how those responsible for designing that environment perceive knowledge and visitor learning. These four domains are: Didactic, Expository; Discovery; Stimulus–Response; and Constructivism (Hein, 1998, p. 25, Hein, 2001, pp. 10–11). Differing frames of reference about knowledge and learning lead to distinctly different educational approaches in the museum exhibits, physical arrangement, and programs. For example, Hein (1998) explains a constructivist museum environment reflects the belief that knowledge is constructed by the learner either personally or socially. In a setting designed with these beliefs about learning and knowledge, experience and active learning are key, and exhibits and programs designs are toward interactivity. Visitors receive encouragement to make connections with things they already may "know," and make meaning through interpretive methodologies that enable them to construct their understanding. Hein posits that when researchers are determining their research methods for researching and evaluating museum exhibits and programs, they should consider the museum's stance on learning and knowledge. Researchers should be sensitive to the belief systems and world views that inform the context they examine, to best understand that context (Hein, 1998, 2001).

Viewing learning from a constructivist stance in museum settings, requires recognition and appreciation of the importance of the social context of these settings. Leinhardt and Knutson (2004) pose their concept of learning in museums as conversational elaboration. They view their concept as distinct from a purely constructivist discussion of meaning making in museums. Instead, they emphasize that the museum situation and cultural role is part and parcel of the learning that takes place. They posit that "learning is influenced by conversation, especially conversation that provides explanatory engagement in the exhibition. Both learning and explanatory engagement are influenced by the design features of the environment and by the identities of the visiting groups" (p. 19). Falk (2009) expands on these ideas, by focusing on the variety of identities that visitors might bring with them to any museum visit. Identities are not static, as an individual's identity will change at different times, according to need and situation (Falk, 2009).

25.2.2 Experiential Learning

The concept that learning connects to experience ties to the intellectual work of Dewey, Lewin, and Piaget (Crain, 1992; Dewey, 1938/1998; Falk & Dierking, 1992; Hein, 2012). Although each offered different models and ways to think about the learning process, they all saw experience as a basis for learning. These ideas flow into the concepts in Kolb's (1984) experiential learning theory. As Kolb explains, this theory does not seek to replace behavioral and cognitive learning theories. Grounding his work in the intellectual ideas of Dewey, Piaget, Lewin, and others, Kolb suggests instead that experiential learning theory is "a holistic integrative perspective on learning that combines experience, perception, cognition, and behavior" (Kolb, 1984, p. 21). Experiential learning theory describes learning as a continuous process where ideas form and reform through experience. It conceives learning as a process grounded in experience, requiring reflection and resolution, and transaction and interaction between the learner and the environment. Kolb's (1984) working definition of learning is, "Learning is the process whereby knowledge is created through the transformation of experience" (p. 38). Informal science education venues have become increasingly experiential in their approach to exhibits and programs as they become more about engaging people in educationally enjoyable and perhaps transformational experiences such as affecting science identities (Cohen & Heinecke, 2018; Falk &

Dierking, 2000; Hein, 1998, 2001; National Research Council, 2009; Piscitelli & Penfold, 2015; Rennie & Johnston, 2003; Roschelle, 1995; Shaby & Vedder-Weiss, 2020; Tal & Dierking, 2014; Tal & Dallashe, 2021).

25.2.3 Sociocultural and Emotional Theories of Learning

Situated learning theory came out in 1991 in one of the seminal discussions around the sociocultural aspects of learning. Lave and Wenger (1991) proposed this theory, which focuses upon a re-thinking about how people learn. Lave and Wenger (1991) posit that there is a relational interdependency of agent and world, activity, learning, and knowing, making it critical to look at learning within the context of human activities and social interactions. They presented the concept of "community of practice." Wenger further discussed communities of practice in later writings (Wenger, 1998). Lemke (1997) also discussed these ideas, explaining that our participation and cognition is generally bound up with those of others (Lemke, 1997). Engeström and Middleton (1998) explored this perspective in the context of a variety of work situations (Engeström & Middleton, 1998a, 1998b). In his related discussion of situated cognition, Clancey (1997) posits that "human knowledge is located in physical interaction and social participation" (Clancey, 1997, p. 344).

Because perception and action arise together, and learning occurs within human behavior and interaction, ideas of situated learning are most applicable when investigating interactive contexts, such as science centers and children's museums (Callanan et al., 2017; Dohn, 2011; Engeström 2016; Falk & Dierking, 2000, 2019; Falk & Storksdieck, 2005; Fenichel & Schweingruber, 2010; Hackett et al., 2020; Letourneau et al., 2017; National Research Council, 2009; Nesimyan-Agadi & Ben-Zvi-Assaraf, 2022). Engeström (2016) explains that ideas and ways we think about learning are expanding. Contexts for museum-generated learning are moving beyond the museum walls as museums reach out to broadened audiences through outreach programs and on-line connections (Engeström, 2016). Situated learning is also very much a part of the learning experience for those who work in and with museums, and something I personally experienced and subsequently researched in my doctoral dissertation examining how museum teacher educators build their expertise within their practice at the museum (Bailey, 2003, 2006). Others continue to discuss and investigate this area of inquiry, and associated literature show situated learning to be an important part of their work and findings (Adams et al., 2008; Allen & Crowley, 2014; Bevan & Xanthoudaki, 2008; King & Tran, 2017; McLain, 2017; McManimon, 2021; Patrick, 2017a, 2017b; Tran, 2007; Tran et al., 2013).

Ideas of socially constructed learning have been an important feature in museum learning models over the last few decades. In these settings, people learn together as they share ideas and perspectives. They participate in a process of joint meaning-making where they build on each other's knowledge and understandings (Fienberg & Leinhardt, 2002; Schauble et al., 1998; Wertsch et al., 1984). Mastusov and Rogoff (1995) perceive learning in settings like museums as a participatory process and one that brings together communities of learners. Following Dewey's definition of an educational institution as an opener of the sociocultural environment of its participants, Mastusov and Rogoff posit we can assess visitor's learning by observing changes in learner's participation in different communities and practices. These researchers explain that a community of learners forms in the museum through an interface of three participating communities: the staff, the exhibits, and the visitors (Dewey, 1916; 1938/1998; Mastusov & Rogoff, 1995; Wenger, 1998). The degree to which each of these groups holds the responsibility for the learning process, and the motivations of the respective groups, influences the character and practices of the museum's mission, exhibits, programs, and participants (Hein, 1998, 2001; Simon, 2010).

Wertsch (1991) explains a sociocultural approach to mind theorizes that "human mental functioning is inherently situated in social interactional, cultural, institutional, and historical context" (Wertsch et al., 1991, p. 86). Therefore, we cannot just look at the individual in terms of their learning, but must view them in their sociocultural context. This also gives rise to the idea of distributed cognition: the idea that when people work together, their coordination of efforts involves a distribution of cognition around the task, as well as cognition around their coordination (Hutchins, 1991, 1995). Cole (1991), in considering the emerging theories of socially shared cognition, says the view that cognition can be shared does not break down the basic distinction between the individual and the social. Socially shared cognition does not need to challenge standard psychological theory, rather it can extend this way of thinking into potentially useful areas of education practice, under conditions when children are working together. Cole points out that when we talk about the categories of the individual and the social we also are talking about the context of human culture within which both reside. Thus, when we speak of socially shared cognition, we must not ignore the cultural component (Cole, 1991). Each individual in an informal science public context is likely to have access to the behaviors of others around them. Therefore, the ideas, prior experience, and culture of those around them can affect, inform, and influence a visitor's museum experience. There is evidence in the museum literature, of a broadening perspective on the sociocultural aspects of the museum experience. Outreach into the community, participatory engagement, and partnerships with groups not traditionally involved, moves the sociocultural aspect of learning to new levels. These shifts are motivating new perspectives about the museum learning experience and an influence on how museum professionals think about their work and actions (Falk & Dierking, 2019; Fraser & Switzer, 2021; Simon, 2010; Spitzer & Fraser, 2020).

Beyond the sociocultural aspects of the visitor experience, the emotional, or affective aspect of learning is also significant to that experience (Csikszentmihalyi & Hermanson, 1995; Friedman, 2008; Gardner, 1991; Hein, 1998; Falk & Deirking, 2000; Paris & Ash, 2000; Semper, 1990). Findings from traditional visitor tracking studies conducted in the early and mid-twentieth century highlighted the decidedly individual nature of visitor's museum experience, and stimulated interest in better understanding this phenomenon. The more naturalistic observations conducted in the late 1970s and early 1980s increased documentation of visitor's affective behaviors and engagement with exhibits and programs, providing a more comprehensive story of the visitor experience (Hein, 1998; Falk & Deirking, 2000; Semper, 1990).

Ideas connecting emotion and learning, can be seen beyond the museum field. Csikszentmihalyi and Hermanson (1995), in a discussion of why people want to learn in museums, note psychologists began to write about intrinsic motivation in the late 1950s. In the later part of the twentieth century and early twenty-first century, research and discussions around social-emotional learning are increasingly visible in the literature from multiple fields such as psychology, neuroscience, formal education, and organizational learning (Davidson et al., 2020; Deci & Ryan, 1985; Friedman, 2008; Immordino-Yang, 2016; Immordino-Yang & Damasio, 2007; Immordino-Yang et al., 2019). Recognition of the critical connection between the emotional and cognitive functions of humans has triggered this interest. In neuroscience, researchers Immordino-Yang and Damasio (2007) posit that "the relationship between learning, emotion and body state runs much deeper than many educators realize and is interwoven with the notion of learning itself" (Immordino-Yang & Damasio, 2007, p. 3). In the formal education field, researchers and leaders advocate an emphasis on social-emotional learning for both students and professionals (Frey et al., 2019; Knight, 2022; Sprenger, 2020). In the museum world, advances in technology such as heat maps, eye-movement tracking and skin conductance are offering researchers non-traditional ways to document and measure emotional responses in visitor's museum experience, and consider how such findings can inform learning outcomes (Tinio, 2021). Strategies used to support social-emotional learning (SEL) are moving into the museum literature. For example, Eppley (2021) describes how the trauma of the pandemic and racially charged issues of 2020 motivated at least one museum to become familiarized with SEL research to better support their partner schools (Eppley, 2021). Additionally, museum experts presented research-based principles for supporting families during a health crisis that paid close attention to the social-emotional aspects of learning (Dierking et al., 2020). Luke et al. (2021) has conducted research to document evidence of preschoolers social-emotional behaviors in museums and compare this with their playground behaviors. Their research findings suggest a need for reinforcement of professional development for museum educators toward recognizing developmentally appropriate social-emotional skills for young children, and additional attention paid to these needs in exhibit design.

25.3 Examples of Author Use

The learning theories I discussed above help inform the research design, process, and methods I use to investigate visitor's learning. Although I utilize both qualitative and quantitative methods, I am most interested in pursuing the "whys" and "hows" of the visitor experience. I am very interested in recognizing the process of learning, and if, and how, that process demonstrates itself during an informal learning experience. A naturalistic approach to research in informal settings is very helpful toward finding answers to these questions. Methodologies that consider the context and culture in which the visitor's current experience takes place, including the social and physical aspects of that context, help to build our understanding of learning in these settings.

Typical exhibit evaluations in my field often are based on a particular exhibition or program, where the exhibit and program have a theme and/or message with clearly defined goals or objectives. However, the concept of determining and/or measuring visitor learning always has been a thorny topic for museum researchers, and one with which they have wrestled for many years. An interest and need to verify that learning is taking place in informal science environments continues across the field (CAISE, 2010; Gutwill, 2016; Hackett et al., 2020; Letourneau et al., 2017; McManimon et al., 2020; Panos & Ruiz-Gallardo, 2021; Pattison et al., 2018; Puvirajah et al., 2020; Tal & Dallashe, 2021). Defining learning and capturing evidence of learning within and as a result of an informal experience is a challenge I increasingly confront. A free choice environment, especially one designed for very young children holds particular obstacles when tackling this question (Hackett et al., 2020; Letourneau et al., 2017; Zosh et al., 2017).

It is difficult to draw a single line from what we see visitors do in science museums to any particular characteristic, influence on learning, and/or learning theory. Part of the challenge of conducting informal learning research is to be able to recognize and identify learning moments in progress within the tangled weave of the many things taking place, often simultaneously, during the museum experience.

What follows is a discussion of two evaluations I conducted about a year apart at two very different science centers, which provided opportunities and gave rise to a new approach in researching the idea of learning in science centers. Characterizing both evaluation projects were requests to identify and show that learning takes place for visitors as they interact with exhibits in these science centers. The first was at a small science center for children in the United States and the second at a large science center in Germany. Hurdles my team and I encountered and surmounted in the first project resulted in informing new approaches in the second project. From this second project's inception, my team and I thought about and discussed observable behaviors that were associated with learning. Together, we designed data collection methods which would document these behaviors as well as other behaviors we might observe among visitors in the galleries.

Informing the research design and associated data collections for both projects were the learning theories that have guided my work over the years, most specifically perspectives around learning held by constructivism, experiential, and sociocultural and social-emotional theories of learning. Constructivism applies because the visitors were in a self-regulated process as they interacted with the museum's exhibits. Experiential and sociocultural and social-emotional theories were employed because we were gathering information about the visitor's experience in the context of the science centers, getting details about how that experience transpired, and observing behaviors and interactions, which could provide evidence of the visitor's learning process.

25.3.1 Application 1: Small Science Center Research Project

A small science center for children, to show donors that their young visitors were learning in that science center, requested us to conduct a "proof of concept" study. To accomplish this, we designed and conducted four studies. In the first study, the Exit Interviews, we approached families as they exited the museum, and invited them to answer some questions about their visit experience. We collected a sizable amount of data from these interviews, which included questions around learning. The second study, the In-depth Observations, were detailed documentation of individual children exploring the museum exhibit(s). During these observations, we looked for evidence of visitor engagement with exhibits, including the time they spent at these exhibits and many other details around their actions, behaviors, and interactions. Additionally, we conducted follow-up interviews with the young visitor's caregiver, asking them if they noticed certain behaviors in their children and, if so, to what degree. The third study was a Group Interview with parents of children attending the museum's summer day camp program. In this interview, I asked parents about connections they may have noticed between their child's museum camp experiences and other experiences, such as occurrences at home and/or on excursions. In the fourth study, I observed the museum's outreach program conducted at a local public school.

In a more typical evaluation with clearly stated exhibit, program, or attitudinal goals, similar collected data likely would provide answers to our evaluation questions. However, after careful analysis and review of our data from this project, in the light of our primary research question to determine if learning was happening, I felt that we had limited pertinent data providing evidence for whether or not young visitors experienced learning as they interacted with the museum's exhibits and programs. I thought deeply about this problem, and discussed it with my team. What was missing? As we pondered, we realized the question "Are children learning from their exhibit experiences?" was less about a specific learning outcome and more about identifying or verifying that the process of learning was taking place during their experience.

The learning theories I adhered to in the past were still relevant, but more from an educator's perspective toward exhibition and program design. These theories were proving less helpful toward informing our research analysis process, at least for this investigation aimed at identifying something as complex and seemingly internal as visitor learning. After considerable thinking and discussion with others, I came upon a potential solution to this problem. I needed to better define and describe what we were researching. The resolution to my conundrum became increasingly clear—because we were asked to identify if learning was taking place, then we needed to look for, define, and identify more specific visible and auditory indicators of the learning process. What were observable behaviors, which might be signs of, or characteristic of, learning, which visitors might present during their museum experience? Once we identified such observable behaviors, would our collected data include pointers or markers for such behaviors?

The appropriate next step was to go back into the cognitive development literature of young children. I reviewed this literature with a specific eye toward finding what this research offered in terms of observable behaviors that investigations have shown to be associated with the learning process. Aside from researching and reading the literature, I also had discussions with colleagues pursuing similar questions about learning in informal settings.

I revisited our collected data, this time with an eye for those observable behaviors gleaned from the literature. I looked at behaviors our observations had documented in the galleries and during outreach events, and/or behaviors reported during our interviews with families and parents. I considered these data points to see if they did or did not align with the observable behaviors in the literature. As I did this, I realized our data had the evidence which we sought. I was able to see alignment between many of the behaviors described across the cognitive development literature with behaviors we had documented in our studies. I was pleased to realize we had collected observable data relating to the question of whether these young visitors were experiencing some moment in their process of learning. I was able to re-code the collected data to highlight observed behaviors, which aligned with findings on cognitive development. With this evidence, I was able to build a case that many of these young visitors were demonstrating behaviors characteristic of learning. I was able to suggest in my report to the small science center that because we documented behaviors characteristic of learning occurring at the center's exhibits and programs, that some process of learning was likely in progress for these visitors, at those moments.

In my report, I presented our findings, supported by data, for the following categories: watching and imitating, communicating, making connections, focusing, exploring with senses, critical thinking, adult supporting and scaffolding learning, self-directed engaged learning, and taking on challenges. The narrative of my report drew connections between what we observed and what the literature says about cognitive development of children, with particular emphasis on observable behaviors characteristic of cognitive development. Therefore, I concluded that the center's exhibits appeared to support visitors experiencing and displaying these learning characteristics, and that the center was an environment where learning was likely to spark and take place. I provided a brief literature review in our report, but due to a short time frame for report production and submission, I considered this review only a beginning of what I hoped to develop. I felt motivated to ultimately develop this brief literature review into a more comprehensive review of that literature, so I could feel more confident toward crystallizing this approach for identifying learning in similar science museum settings.

This research path did not shift my thinking and beliefs about learning and the learning theories which informed them, but it did cause a modification in my thinking of how to approach my research projects. It also sensitized my interest in finding other studies that might be taking a similar approach. For example, Barriault and Pearson (2010), a Canadian study, researchers developed a tool that utilized observable visitor behaviors to distinguish three stages or levels of visitor engagement: initiation, transition, and breakthrough (Barriault & Pearson, 2010). Another useful study was the research work of Letourneau and colleagues, which focused on caregiver's observations of children's behaviors in a museum (Letourneau et al., 2017). Although these studies had somewhat different research questions and goals from those I was pursuing, this literature informed my thinking and subsequent research design.

25.3.2 Application 2: Large Science Center Research Project

The opportunity to build further on these ideas came a few years later. A large science center in Germany asked me to conduct an evaluation for two galleries of exhibitions. This science center had similarities to those with which I was accustomed, and its visitors tended to be the familiar groups of families and school groups. One of the galleries attracted mostly young visitors, under the age of 10, generally accompanied by adults. The other gallery attracted teens and adults. There were 122 exhibits in all. Among the primary goals for this evaluation was to provide "a comment" about the learning happening at the exhibits in these galleries. I realized this would be an excellent time to apply the approach of identifying observable learning behaviors that I had developed for the small science center. However, in that prior evaluation, this approach had emerged during the data analysis process, after the research design and data collection phases. For this new evaluation and much larger complex study I would be able to incorporate this approach much earlier in the research design and data collection phases. Therefore, from the outset of this project, my team and I systematically went about developing a flexible but more focused approach that deliberately would look for these observable behaviors associated with learning. To gather the information needed to answer the evaluation/research questions, we identified three studies to conduct in the two galleries. Within two of these studies we used direct methods to focus the data collectors to look for and document nine particular observable behaviors associated with learning.

We informed these studies by the same learning paradigms for which we informed the small science center research: constructivism, experiential, sociocultural, and social-emotional learning. Because half the project team was from the U.S. and less familiar with the German science center's audience, it was especially important to collect detailed information around the sociocultural aspects of the visitor's experience. Experiential and situated learning theories were important for researching in this interactive setting, because the visitor's experience was associated strongly with the context of the science center, its exhibits, and its visitors.

Our initial methodology had data collectors pay particular notice to nine things/behaviors which visitors might show: observing, thinking aloud, trial and error, repeating, explaining discoveries to others, explaining handling to others, being frustrated, being satisfied, and being concentrated. As other visitor behaviors might also prove pertinent, my team utilized several data collection methods, both quantitative and qualitative, including timing and tracking, exit interviews with individuals and groups as they left the gallery, and in-depth play-by-play observations of individual visitor's interactions at a sample of target exhibits, followed by a short, associated interview and a data-collector-completed summary sheet.

The timing and tracking study was primarily quantitative and looked at the path and duration of exhibit stops made by 50 visitors in each gallery, 100 visitors in total. The team conducted 50 exit interviews, 100 exit interviews in total, to gain reactions, recollections, and motivations from a sample of visitors just as they exited each of the galleries. The exit interviews were both quantitative and qualitative, with many questions permitting open-ended responses.

My team and I selected 20 target exhibits, 10 from each gallery, for in-depth study. The methodologies used to investigate these in-depth exhibit interactions were primarily qualitative, with some quantitative components. We alerted data collectors to look for the specific nine behaviors and capture any other behaviors they observed. Most of the data collection was in German. As they watched visitors, data collectors made audio recordings of a play-by-play description of what they were able to see, hear, and feel. We intended this to capture, as far as possible, all the aspects of that visitor's experience, including their expressions, communications, and interactions with the exhibit, other visitors, and museum staff. At the point the visitor appeared to be finished interacting with the exhibit, data collectors approached the visitor and invited them to respond to a short interview. If they agreed, the data collector asked them a series of questions, including spontaneous questions to get clarification and/or understanding of what the data collectors had observed. After these observations and interviews, data collectors filled out a summary sheet. This sheet included those nine behaviors and the degree to which, in their recollection, they had observed the visitor demonstrate. Data collectors transcribed the audio recordings and interviews and those data collectors fluent in both English and German subsequently translated them into English. The team collected these data for at least 25 visitors at each of the 10 target exhibits per gallery, thus a total of 250 observations.

Data analysis permitted us to look for patterns and behaviors across the studies. Other team members analyzed the primarily quantitative data from the timing and tracking and exit interviews. I focused on the analysis of the qualitative data from the in-depth observations of the target exhibits. I looked at behaviors reported in the play-by-play descriptions of visitor's experience, including behaviors we initially did not identify. We all conferred on our respective findings and on report development. Findings from these studies show many instances of visitor behavior characteristic of learning-in-progress. We also were able to distinguish differences across the specific target exhibits as to the form and degree of learning-related behaviors each of these exhibits encouraged.

25.4 Learning Characteristics and Influences on Learning

I learned many lessons along the way over the course of the large science center research project. Perhaps most important was the emergence and refinement of a set of Learning Characteristics and Influences on Learning. During my analysis and coding process of the in-depth target exhibit study data, I was moved to reorganize the original nine behaviors into a more functional grouping. Most of the original nine behaviors remained; however, I reshuffled and/or merged them into five new categories, four of which I labeled "Learning Characteristics," and the fifth labeled "Influences on Learning." Each of the main categories have associated sub-categories derived from observations, which help discriminate among the various ways and conditions under which visitors exhibited these behaviors.

A full discussion of these Learning Characteristics and Influences of Learning, along with the supporting research literature, is beyond the scope of this chapter. However, to illustrate how others might use this tool in pursuing similar research interests, I offer a brief review of these Learning Characteristics and Influences on Learning and examples of how I applied them in the two research projects applications described above. First, I provide a list of the categories and subcategories that emerged during coding and organizing of findings of the in-depth observation study data collected in Application 2, the large science center research project. Second, I present quick descriptions and explanations for the main categories of Learning Characteristics and Influences of Learning, and follow these descriptions with examples of representative data coded for that Learning Characteristic and/or Influence of Learning. Third, I present a sample of literature used to support and develop these Learning Characteristics and/or Influences of Learning, with particular attention towards their relevance for researching learning in museums.

25.4.1 Learning Characteristics and Influences on Learning Coding Categories with Sub-categories

I have found the following set of *learning characteristic*s and *influences on learning* to be a useful tool toward collecting, sorting, coding, and analyzing data to identify behaviors characteristic of, and associated with, the process of learning at science museum exhibits. Below are the full list of main categories and subcategories I developed during Application 2, the large science center research project:

Learning characteristic—Utilizing executive functioning skills (EFS)

EFS: Attraction to and initial interaction with the exhibit.
EFS: Focusing, concentrating, and paying attention to the exhibit.
EFS: Joint attention-attraction and focusing at the exhibit.

Learning characteristic—Utilizing communication skills

Form of Communication: Utterance at the exhibit.
Form of Communication: Statement at the exhibit.
Form of Communication: Signaling discovery at the exhibit.

Form of Communication: Explaining and/or describing discoveries at the exhibit.
Form of Communication: Directing and strategizing at the exhibit.

Learning characteristic—Utilizing observational skills

Observing: Visitors independently using their senses to gather information through direct interaction with the exhibit.
Observing: Visitors receive guidance to use their senses to discover at the exhibit.
Observing: Visitors informally gathering information through watching and listening at the exhibit.
Observing: Visitors imitating and/or building on the ideas of others at the exhibit.

Learning characteristic—Utilizing critical thinking skills

Critical Thinking Skills: Repeating-comparing-testing at the exhibit.
Critical Thinking Skills: Grasping the concepts at the exhibit.

Influences on learning

Influences on Learning: Affective aspects of visitor experience at the exhibit.
Influences on Learning: Sociocultural aspects of visitor experience at the exhibit.
Influences on Learning: Mechanical and operational aspects of the exhibit.

25.4.2 Quick Descriptions of Main Categories of Learning Characteristics and Influences on Learning, with Examples

Learning characteristic: Utilizing executive functioning skills

Executive functioning skills are the skills people employ to manage situations, such as our attention, emotions, and behavior, to reach goals. Executive functions of the brain interweave social, emotional, and intellectual capacities. The team looked at visitor's highly observable behaviors of attention, focus, and engagement and noted if the attention to something was a solo behavior or was "joint attention" involving additional individuals.

Example *Learning characteristic—Utilizing executive functioning skills (EFS).*

The following is an excerpt of data from Application 2, coded as:
Learning characteristic -Utilizing executive functioning skills.
Subcategory-Focusing, concentrating, and paying attention at this exhibit.

Observation 14, M19, below is an example of a male visitor, estimated to be 19 years old, demonstrating sustained focusing at an exhibit about using your senses. He appears to be thinking carefully as he chooses and interacts among the components. M19's first behavior was to apparently conduct an overview of the exhibit's components, after which he approached and interacted with the hearing component, and moved on to explore the touch component.

Representative data excerpt: Observation 14, M19: M19 arrives at the exhibit and first looks at the different stations. Then he goes to the hearing center and puts on the headphones. Now M19 slowly moves the controller back and forth. M19 listens very carefully and attentively to the sounds. He lets the controller stand completely on the right and looks very concentrated.... Then he again looks at the other theme sections of [the exhibit] and decides for "What feels most comfortable to you?" M19 strokes from left to right across the different surfaces—first with his left and then with his right hand. He performs this movement slowly and deliberately..... {Full duration 6 min 54 secs}.

25.4.2.1 Learning Characteristic: Utilizing Communication Skills

Humans can conduct communication through verbal means and via body language, such as facial expressions and gestures. The team looked for instances of communication in visitors and documented details, both auditory and visible, of those communications.

Example *Learning characteristic—Utilizing communication skills.*

The following is an excerpt of data from Application 2, coded as:
Utilizing communication skills.
Subcategory: Explaining and/or describing discoveries.

Observation 2.12, F10 below is an example of a female, about 10 years old, communicating what she's done and discovered. As F10 leaves the exhibit, she also appears to explain how this station works, to the next visitor.

Representative data excerpt: Observation 2.12, F10:... F10 places another stone under the microscope and only now discovers the control slides on the microscope... She is visibly surprised by the result the controllers have created... she enthusiastically calls the woman [the group's supervisor?] to her and joyfully points to the big screen. With the same control setting F10 places the white shell (open side to the lens) under the microscope and examines this result with enthusiasm... F10 puts the shell away, stands up and wants to walk away. But then she turns around again and explains to the boy from earlier what he can do there and what function the controls have. Finally, F10 leaves the exhibit. {Full duration: 7 min 15 secs}.

25.4.2.2 Learning Characteristic: Utilizing Observational Skills

Observational learning, or modeling, is learning through observation and imitation. Visitors use their senses of sight, hearing, touch, smell, and taste to gather information. People use these senses to figure out how things work and often do so by watching other people's interactions. Sometimes visitors guide or encourage other visitors to utilize their observation skills. The team gathered observable behaviors of visitors using their senses, noting if they imitated things they observed other visitors do.

Example *Learning characteristic—Utilizing observational skills.*

> The following is an excerpt of data from Application 2, coded as:
> Utilizing observational skills.
> Subcategory: Informal information gathering through watching and listening.

In Observation 5.12, M9, two boys and an adult male, perhaps all related to each other, guide each other in an investigation of the braking mechanism of giant lever designed to lift a heavy ball. All *use their senses to investigate the lever*, they *watch and listen* to each other, and appear to influence each other's attention toward scrutinizing the air brake.

Representative data excerpt: Observation 5.12, M9: M9 comes to the station and pushes the lever down. Another boy (his brother?) comes and pushes the sphere on the other side. Now the other boy goes to M9's side and pushes there, too. After pushing down, M9 lifts the lever [and watches it].... The father now joins in and helps M9 push. Both observe the delayed re-upward movement of the lever.... The father seems to explain something to M9. M9 pushes the lever down again. He lets go and watches the delayed re-up again. M9 then walks away. {Full duration: 0 min 57 secs}.

25.4.2.3 Learning Characteristic: Utilizing Critical Thinking Skills

According to the research literature, *critical thinking* has similarities to the scientific method: determining the issue to be addressed, posing hypotheses, conducting unbiased experiments to test the hypotheses, and drawing conclusions. The process of critical thinking draws on many other skills including focusing, self-control, making connections, communicating, and perspective taking (considering how our solutions affect others). Critical thinking involves meta-cognition, or thinking about thinking, as people reflect, analyze, plan, and evaluate. The team looked for observable behaviors associated with utilizing critical thinking, including experimenting, testing things out, trial and error behaviors, exhibiting curiosity, investigating, repeating actions, making connections between cause and effect, modifying actions, and conducting problem solving. We looked for evidence that visitors were grasping the concept upon which the exhibit focused. Post-observation interviews provided the most informative data towards identifying visitor's conceptual understanding. However, during some observations, comments overheard and/or behaviors noted provide clues concerning visitor's grasping the concept.

25.4.2.4 Learning Characteristic—Utilizing Critical Thinking Skills

The following is an excerpt of data from Application 2, the large science center, coded as:
Utilizing critical thinking skills.
Subcategory: Repeating-comparing-testing at the exhibit.

In Observation 3.23, F6, a young girl is observed to demonstrate *problem solving*. F6 appears to want to get air coming through a hose to blow into a wind tunnel. She tries different hose configurations, and shortly figures out how to locate and arrange a hose that is long enough to work at the wind tunnel.

Representative data excerpt: Observation 3.23, F6: F6 comes to the [Wind Games] exhibit with her grandmother. The air system goes on and she immediately takes the hose away from the flower. With the hose, she goes to the wind tunnel and tries to hold it underneath. But the hose is too short. So she takes the hose away from the cactus [inflatable cactus-shaped-balloon] and connects her hose there instead. She now takes the tube, that was connected to the cactus before, to the wind tunnel. Now the length is sufficient. {Full duration: 2 min 31 secs}.

25.4.3 Influences on Learning (Affective Aspects, Sociocultural Aspects, and Operational and Mechanical)

The *influences on learning, affective aspects, and sociocultural aspects,* draws on the research indicating the interrelatedness among the cognitive, sociocultural, and affective, emotional aspects of the human learning experience. Observational data relevant to these aspects includes *facial expressions, body language, vocalizations,* and *interactions (both with the exhibit elements and with other people).*

The following is an example from Application 2, with data coded as:
Influences on Learning.
Subcategory: Affective aspects of visitor experience at the exhibit.

Observation 1, M6, is an example of how different emotions can be demonstrated during an exhibit interaction at the interactive about moving air [Wind Games}. When parachutes get tangled, support comes from M6's grandmother. M6 subsequently displays happiness as he carries on with other investigations. He also asks his grandfather to witness his activity.

Representative data excerpt: Observation 1, M6:... M6 now has discovered the wind tunnel. He is looking for something to put in. He discovers the parachutes and sets them up. He blows two parachutes upwards until they get twisted into each other. They do not fly upwards. M6 takes them out and wants to disentangle them. He does not make it. His grandmother helps him. M6 starts playing with the hose and the flower [inflatable] figure… The grandmother gives him a parachute again. M6 takes the parachute and puts it into the wind tunnel. He lets it fly. He is happy and calls his grandpa to have a look… {Full duration: 6 min 20 s}.

25.4.4 Sample of Literature for Recognizing Behaviors Characteristic of, and Influences on, Learning

25.4.4.1 Learning Characteristic: Utilizing Executive Functioning Skills

Brunner summed up the critical connection between motivation and learning by stating, "motives for learning must be... based as much as possible upon the arousal of interest in what there is to be learned" (Brunner, 1960, 1977, p. 80). Duncan et al. (2007) examined what skills or knowledge children acquired early in life matter most to children's later success when they entered school. These researchers concluded that three skills were related strongly to later success in reading and math, including the less obvious one of "attention skills." They found that the more penetrating our attention, the richer and deeper our learning (Duncan et al., 2007). Motivation is key to paying attention and research has shown that supportive environments such as science centers and museums can rekindle the natural motivation and desire to learn. In conjunction with the 1995 American Association of Museums conference convened to establish a research agenda to investigate learning in museums, Csikszentmihalyi and Hermanson (1995) wrote an influential paper on "intrinsic motivation" as it relates to what drives people to want to learn in museums. Csikszentmihalyi and Hermanson connect what psychologists and other researchers know about what motivates learning with learning experiences in the contexts and cultures of science museums. They include ideas of curiosity and interest, and "The Flow Experience" (Csikszentmihalyi & Hermanson, 1995, p. 69; Csikszentmihalyi, 1990). In the formal school environment, Gregory and Kaufeldt (2015) investigate student motivation as informed by research from neuroscience and psychology, citing researchers such as Ryan and Deci, Maslow, Glasser, and Bandura. Gregory and Kaufeldt propose strategies to improve student motivation, and advance ideas such as first hand experiences, choice and self-directedness, and group flow (Gregory & Kaufeldt, 2015). Ryan and Deci's research on intrinsic motivation, highlight people's inherent psychological needs of competence, self-determination and relatedness (Deci & Ryan, 1985; Ryan & Deci, 2000). The museum literature show researchers and practitioners in the museum community are making connections to these inherent psychological needs to address issues around motivation and a sense of belonging, for both visitors and staff (Allen & Crowley, 2014; Dohn, 2011; Gutwill, 2016; Price & Applebaum, 2022).

Focus and self-control involve many executive functions of the brain, including paying attention, remembering the rules, and inhibiting one's initial response to achieve a larger goal. These functions connect significantly to our ability to learn (Diamond, 2013; Jensen, 1998; Rueda et al., 2005; Sylwester, 1995). Zelazo, in a 2016 report for the U.S. Department of Education, explains most current researchers generally agree that human executive functions are characterized by a specific set of regulatory skills including cognitive flexibility, which involves thinking about things in other ways; working memory, which involves keeping things in mind; and inhibitory control, which involves the ability to suppress attention from distraction (Zelazo et al., 2016). All of these functions are applicable to the museum experience, but attention is a visible behavior, which can be observed and documented in visitors.

Vygotsky (1938/1978) recommends that experts support learning by creating a "scaffold" between what they know and what the learner knows and understands. He labeled this space between the knowledge levels of expert and learner as the Zone of Proximal Development (ZPD). This scaffold enables achieving a higher level of understanding of a given concept or learning goal (Crain, 1992; Vygotsky, 1938/1978; Wertsch, 1995a, 1995b). Ash (2003) examined the detailed content of family dialogue and the co-construction of knowledge taking place among the group members of different ages. Her research of family conversations at several science centers were considered through a Vygotskian ZPD perspective (Ash, 2003). *Joint attention*, especially between parents or other caregivers and children, is a powerful means of supporting learning and development (Pan et al., 2005; Rogoff & Gardener, 1984; Rollins & Snow, 1998; Snow & Beal, 2006; Wertsch et al., 1984). Pursuits such as working together on an activity or problem, or interacting around an exhibit, can provide a setting for focused conversation and/or engagement. Joint attention is commonly observed in research studies conducted in science museum settings (Callanan et al., 2017; Fenichel & Schweingruber, 2010; Gutwill & Humphry, 2005; Patrick, 2014; Patrick & Moorman, 2021; Tunnicliffe, 1998).

25.4.4.2 Learning Characteristic: Utilizing Communication Skills

Rittle-Johnson et al., (2007) investigate the transfer of knowledge. Researchers found that having a listener, even one who does not respond, helped children's problem solving and their ability to transfer learning to a new situation (Rittle-Johnson et al., 2007). Adults can provide what Hart and Risley (1995) labeled as "extra talk." Hart and Risley's studies showed adults posing questions such as *What if?*; *Remember?;* and *What do you think?*, highly correlate with their children's performance on IQ tests at three years of age and achievement tests in third grade (Hart & Risley, 1995; Sulzer-Azaroff, 1997).

In 2002, Allen studied in-depth learning through documenting visitor conversations, or "learning-talk," at an exhibition on frogs at the Exploratorium science center.

For this study, she defined learning as, "an interpretive act of meaning-making, a process rather than an outcome, and a joint activity of a group rather than being attributable to one of the people only" (Allen, 2002, p. 262). In her analysis of conversations, she distinguished five overall categories for talk: perceptual (identifying, naming, pointing out feature, quoting a label), conceptual (simple inferences, statements, interpretations), connecting (connections with exhibit and personal experience), strategic (how to use and manipulate the exhibit), and affective (Allen, 2002; Fenichel & Schweingruber, 2010, pp. 69–74). Allen concludes that tracking visitor conversations is worth the considerable effort it takes by bringing "the researcher into the heart of the learning 'action' of the museum visit, and emphasizing learning as process rather than merely outcome" (Allen, 2002, p. 301).

Parents and other caregiver's looks and gestures help children direct their attention to what these adults think is important. *Pointing*, for example, one of the most familiar of gestures, is a signal to children and from children. Children begin to *point* around eight months of age or later, an important milestone in the development of communication skills and a first step into language. Children communicate feelings through expressions and tones even before language can do so, and learn language through the filter of feelings (Fernald, 1993; Galinsky, 2010; Goldin-Meadow, 2007; Kuhl, 2010). Borun et al. (1996) and Borun and Dritsas (1997) explored how conversations among families in science museums can influence the learning process. They found alterations in exhibits made a difference in terms of supporting learning and encouraged development of "family-friendly exhibits" (Borun & Dritsas, 1997; Borun et al., 1996).

25.4.4.3 Learning Characteristic: Utilizing Observational Skills

We observe by making use of our senses to learn about the world (Bransford, et al., 2000; Wolfe, 2001). Meltzoff (2009) identified three channels for learning and development: individual discovery, trial and error, and observational learning. Observational learning often is associated with imitation. Meltzoff points out that imitation is faster than individual discovery and trial and error (Meltzoff et al., 2009). Modeling, learning through observation and imitation, is a powerful tool for childhood learning. In some cultures, modeling has been the traditional, fundamental way to teach children (Bauer & Pathman, 2008; Falk & Dierking, 2000; Rogoff & Lave, 1984). Bauer and Pathman (2004) posits learning is physical; therefore, we must remember the properties of objects in order to communicate their relationships. The researchers found that memories are preserved better under some circumstances than others and that direct experience is more likely to promote memory than passive observation. Beginning in infancy, children learn best through direct experience (Bauer & Pathman, 2008; Bauer et. al., 2004). Additionally, Kolb's work around learning puts experience at the center of learning and development (Kolb, 1984). Kolb's ideas help connect theory to practice in science museums and many of the behaviors he discussed in his theory of experiential learning we can observe as visitors of all ages interact with exhibits.

25.4.4.4 Learning Characteristic: Utilizing Critical Thinking Skills

Galinsky (2010) defines the core of critical thinking as "the ongoing search for valid and reliable knowledge to guide our beliefs and actions" (Galinsky, 2010, p. 204). In Galinsky's view, critical thinking skills can be placed among the higher-order skills among executive functions of the brain, and involve things such as reflection, metacognition or, thinking about our own thinking. Zelazo et al.'s (2016) definition of reflection closely aligns with Galinsky's (2010) definition of critical thinking. Zelazo et al. define reflection as "To pause, consider the options, and put things into context prior to responding" (p. 141). Definitions of critical thinking have and continue to vary over time. Research of this term reveals differences according to when the definition was presented, the disciplines from which it emerged, and the geographic regions where the definitions arose. In 2007, the Journal of Museum Education presented a full issue that offered a variety of perspectives around the idea of critical thinking and if, and how, it ought to relate to museum education (Herz, 2007). More recently, this conversation is taking place around art and history museums (Hubard, 2011; Martinko & Luke, 2018). Use of the actual term "critical thinking" is less is evident in the emerging literature from informal and formal science education, although ideas around cognition, learning, new technologies that support critical thinking, programs and exhibits that encourage making informed decisions, crossing borders between school science and everyday science, and critically reflecting on ethical museum research practices, are still very much in the current literature (Gutwill & Allen, 2010; Knipfer & Wessel, 2011; Lee et al., 2020; McManimon, 2020; Fenichel & Schweingruber, 2010; Spitzer & Fraser, 2020).

Kuhn (2010) discusses scientific thinking development in children. She explains young children have a natural curiosity that can be supported by encouraging their observations, questions and ideas (Kuhn, 2010). There is a growing body of research that looks in particular at parent's and caregiver's role in supporting children's scientific thinking in museums. Callanan and Oakes (1992) found that parents played a strong role in promoting children's scientific reasoning in everyday activities. Using video recordings of conversations at Children's Discovery Museum in San Jose, she concluded that children were engaged more in the exhibit if they explored it with parents rather than alone. In a later study Callanan et al. (2017) found that parents varied in their sense-making talk and in connection to the nature of the exhibit. Moreover, parental engagement was predictive of children's engaged conceptual talk (Callanan & Oakes, 1992; Callanan et al., 2017). Other researchers have found parent's support promoted their children's scientific thinking, in that this support helped children focus on the evidence, gather new evidence, and interpret the evidence (Ellenbogen et al., 2004; Gelman, et al., 1991; Gutwill & Allen, 2010;). Pattison and Dierking (2019), in collaboration with science museums, have researched and described science-related interest development in young children from low income families. They found important variations across families related to parental expressions, involvement, and approaches to re-engaging children's interest (Pattison & Dierking, 2019). To develop parental support, the Providence Children's Museum and Brown University, conducted research to identify ways to encourage parental interaction with their children by increasing caregiver's understanding about how play connects with learning (Letourneau et al. 2017). This research included studies in which caregivers were invited to observe their children at play in the museum. The caregiver's activity sheet focused them to look for specific behaviors. This sheet also incorporated explanations of those behaviors in terms of children's learning. For example, the behavior of *repeating over and over* was explained on the activity sheet as "Kids are exploring cause and effect and practicing new skills" (Letourneau et al., 2017, p. 95).

25.4.4.5 Influence on Learning: Affective Aspects

Over the past three decades, research has paid increasing attention to the emotional and affective content of learning. This literature has emerged from a cross-section of fields seeking to better understand learning and brain-body connections with that process. We can enhance learning, in general, by the motivational and memorable nature of settings such as science museums (Crowley, 2002; Csikszentmihalyi & Hermanson, 1995). Paris and Ash (2000) emphasize the vital aspect of the affective domain in the science museum experience and the importance of further researching connections between enjoyment and learning. Recent advances in neuroscience highlight links between emotion, social functioning, and decision making that influence our understanding of affect in education and learning (Davidson et al., 2020; Elias, 1997; Golman, 1995; Immordino-Yang, 2016; Immordino-Yang & Damasio, 2007; Posey, 2019; Sprenger, 2020). Research shows that play is associated with learning. In 2017, the Lego Foundation published a white paper that pulled together a great deal of the research to date on children's play as a learning mode. They identified several characteristics of playful learning, including that it is socially interactive, iterative, joyful, meaningful, and actively engaging (Zosh et al., 2017). Moreover, Hirsh-Pasek and Hadani (2020) discuss the power of playful learning and conclude that skills and content are taught best in playful ways. They posit that playful learning advances the six critical skills of collaboration, communication, content, critical thinking, creative innovation, and confidence (Hirsh-Pasek & Hadani, 2020). Additionally, the Lego Foundation collaborated with the Harvard's Project Zero to design a pedagogy of play, which offers playful learning has three distinct overlapping categories: choice, wonder, and delight. Playful learning includes both subjective and objective dimensions with indicators representing psychological states as well as behaviors that are observable (Project Zero, Harvard University, 2016).

25.4.4.6 Influence on Learning: Sociocultural Aspects

Socially constructed learning is an important feature of museum learning models. In museum settings, people learn together as they share ideas and perspectives (Fienberg & Leinhardt, 2002; Schauble et al., 1998). Research findings suggest spontaneous conversation makes a difference in younger children's learning. Higher levels of parent mediation while examining dinosaur fossils in a museum were associated with children being able to identify more fossils than they could before these conversations. The researchers posit that authentic objects available in museums and the associated conversations around them, are likely more memorable due to their high-interest place-based setting (Crowley & Jacobs, 2002). Leinhardt and Knutson (2004) looked at learning as it connects to museum conversations and concluded conversations are critical to the learning that takes place in the museum (Leinhardt & Knutson, 2004). Moreover, Rogoff (1984) posits, "Cognitive activity is socially defined, interpreted, and supported. People, usually in conjunction with each other and always guided by social norms, set goals, negotiate appropriate means to reach the goals, and assist each other in implementing the means and resetting the goals as activities evolve." (Rogoff, 1984, p. 4). This behavior often is observable in the social interactions around museum exhibitions.

25.4.4.7 Influence on Learning: Mechanical and Operational Aspects

We can find one of the influences for learning in museums in exhibit design. Various aspects of exhibit design either enhance or inhibit learning behaviors. Museum researchers continue to study what aspects of exhibits to improve to increase the potential of learning. Gutwill and Humphry (2005) worked on identifying characteristics of exhibits that will extend the time visitors engage with exhibits. These included, (a) being immediately approachable hence supporting initial engagement, (b) have interactive elements that encourage prolonged exploration, and (c) that the presentation supports social groups through inclusion of multiple components, which are accessible for different developmental levels and interests. Moreover, visitor research and evaluation can inform improvement of exhibit design to enhance learning. An example of this research is that of Perry (2012), who conducted research on a way to improve the learning potential of an exhibit relating to colored shadows. She identified a need to signal visitors to look toward the source of the light. Changing this signage proved to be a highly effective way to increase visitor's conceptual understanding of mixing colored light (Perry, 2012).

25.5 Importance to Research

As the question "Is learning taking place in informal science settings?" is often asked, I believe the approach I developed toward investigating this question has value for the field. I will continue to refine what at this point I might call a theoretical framework for the *Learning Characteristics and Influences on Learning* (Camp, 2001). This framework and approach still are evolving and thus far has been helpful for two research ventures in informal science settings. However, I will be happy to see it evolve further.

Different realms of research examine many of the behaviors that take place in informal learning settings. Fields such as psychology, neuroscience, cognitive development, formal education, literacy development, sociology, anthropology, organizational development, and beyond all have something to offer. Although the findings come through seemingly disparate research paths, such as how the brain works, language development, and how humans interact and influence each other, they all relate to human learning.

This raises the notion that perhaps these paths are not so separate and in some instances, they converge and/or cross. Many chunks of qualitative data from informal education settings often present multiple and sometimes concurrent examples of behaviors associated with learning. To illustrate, the following is a brief excerpt of data between a boy, about four and a half years old, and a parent at a wildlife center:

Observation: Family moves into the raptor exhibit and immediately locates the bird up on a branch. Mom reads the signage aloud about the turkey vulture.

Mom: "Do you think the turkey vulture is watching those squirrels outside of his habitat?".

M4: "Yeah, I bet he wants to eat them."

This short exchange illustrates several things related to learning. One, the mother's question is an example of "extra talk" where her query extends the conversation, increasing the learning potential (Allen, 2002; Hart & Risley, 1995; Pan et al., 2000; Snow & Beal, 2006). Two, the response from the child suggests he is utilizing his critical thinking skills and is making connections around what he is observing and his prior knowledge (Callanan & Oakes, 1992; Callanan et al., 2017). Three, this child is using his executive functioning skills as he pays attention to what is going on (Diamond, 2013; Ruedea, 2005; Zelazo et al., 2003, 2016). Four, both participants are using their observation skills and having a direct experience with the objects in their setting. This data is an example of "joint attention" for this child and his mother around an exhibit and a situation where the interaction of people involved together around an activity, conversation, problem, can affect or change the dynamic of the learning and communication experience (Rogoff & Gardener, 1999; Rollins & Snow, 1998; Pan et al., 2005; Snow & Beal, 2006; Tunnicliffe, 1998). Finally, this experience is socially constructed. Thus, the sociocultural aspects of the situation, such as their relationship and the culture and context of the setting they are in, are influencing this experience (Fenichel & Schweingruber, 2010; Rogoff, 1999).

As this data example illustrates, drawing a simple inference from what we observe to evidence for learning is part of the challenge of researching in informal settings. Perhaps informal science research is not alone facing this challenge to understand the association between behaviors and learning. As I read the literature relating to how we learn, my perception is that theories about learning increasingly are migrating and cross-pollinating across fields. Could this mean that researchers are moving from the silos of their specific discipline and genre toward seeking a more comprehensive or inclusive way to research human behavior, interactions, and development? Engeström (2016), well known for his work around activity theory, or cultural historical activity theory (CHAT), points out the Learning Sciences are increasingly looking at learning outside of formal learning environments. Engeström posits that the *process* of learning has not received proper attention in recent years. He submits that an expanded view about learning is necessary (Engeström, 2016).

The process of looking inward and increasing our understanding of informal science learning remains important. Non-formal science organizations certainly have their unique opportunities to excite and stimulate the public toward science. As the Oppenheimer quote indicates, museums were and continue to be eager to hold onto their differences and distance themselves from the pressures traditionally associated with formal education. It has been an important goal and one they have achieved in many ways. Museums have attracted not only science geeks, but also science-shy visitors, into the world of science centers. However, by doing so they also have run the risk of becoming distanced from the positions and roles in our society held by the more establishment formal education institutions often characterized as "hallowed halls" of learning.

These insights motivate me to keep drawing from a range of disciplines to identify and document observable behaviors characteristic of the learning process. We can find relevance, intellectual merit, and, perhaps, inspiration from research studies emanating from other fields that hold an interest in the learning process. Connecting to the literature from other fields, such as cognitive development, neuroscience, sociology, and more, provides a fresh set of lenses through which to view our own informal science research (Falk, 2009; Falk & Dierking, 2000, 2019; National Research Council, 2009; Wertsch et al., 1995a, 1995b).

However, I propose that it does not need to be an either-or situation. Designing an approach toward recognizing evidence *that learning is taking place* in these informal settings—however challenging—is a meaningful step toward verifying the value and efficacy of informal science institutions, and an important quest toward solidifying and making more credible their role within society's greater educational infrastructure.

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Correction to: How People Learn in Informal Science Environments

Patricia G. Patrick

Correction to:
P. G. Patrick (ed.), *How People Learn in Informal Science Environments*, https://doi.org/10.1007/978-3-031-13291-9

This book was inadvertently published with the incorrect book title with question mark at the end, which has now been amended throughout the book and cover. The book has been updated with the changes.

The updated version of the book can be found at
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