

Legacies of childhood learning for climate change adaptation

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ABSTRACT

Using archaeological, historical, and ethnographic analysis of Norse and Inuit toys and miniatures, this paper argues that legacies of childhood learning can create limits to climatic change adaptation and provide lessons from the past relevant today. In Medieval Greenland, Norse children played with objects that would have familiarised them with the expected norms and behaviours of farming, household activities, sailing and conflict, but not with hunting, which was a key omission given the fundamental importance of wild resources to successful climatic adaptation in Greenland after the climate shocks of the mid-13th century. The restricted range of toys combined with an instructional form of learning suggests a high degree of path dependence that limited adaptation to climatic change, and we know the Norse settlement ended with the conjunctures of the 15th century that included climatic change. Inuit children, by contrast, learnt highly adapted behaviours and technologies through objects that taught locally tuned hunting skills. Inuit approaches that prioritised unstructured learning time aided the development of creative skills and problem-solving capabilities, and the Inuit successfully navigated the climatic changes of the Little Ice Age in Greenland. This insight from the past has implications for our approaches to childhood learning in the 21st century and the unfolding climate crisis. Innovative approaches to childhood teaching and learning in the context of climate change adaptation could provide effective solutions, on a timescale commensurate with that of projected climate impacts.

1. Introduction

The aim of this paper is to show that learning in the childhood years can create both capacities and limitations for climate change adaptation. We use an historical perspective informed by archaeological evidence of the household economy, resource utilisation, and ecosystem modification to examine path dependencies caused by transmitted knowledge and existing social learning practice in the childhood years. We argue that limited attention to childhood environmental learning can limit lessons that can be learned from history, as it is in these early years' knowledge is transmitted between generations and new information is learned about environment, technologies, and socio-cultural practices (Boyd et al., 2011; Laland and Brown, 2011; Engemann et al., 2020, 2021). This is important because learning is an essential component of

climate change adaptation. *IPCC Assessment Report 6* recognises learning as an important step towards “shared meanings” and “locally appropriate responses” to climate change. Yet, in adaptation research, there remains a limited focus on childhood social learning—particularly over multi-generational timescales—despite the observation that our modes of teaching and learning may be increasingly out of tune with changes in the world around us (Louv, 2010; Leichenko and O'Brien, 2020). In parallel, environmental history and historical ecology literatures of the last five years have emphasised the importance of learning from the past but often without attention to the role of early-age learning in adaptation (Armstrong et al., 2017; Haldon et al., 2018; Ortman, 2019; Smith, 2021; Crumley, 2021). This paper, therefore, attends to this dual gap by evaluating historical evidence of path dependency in social learning strategies over multi-century timescales.

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Recent studies draw attention to the impact that a lack of environmental engagement can have on child health and development, as well as concern that this will limit knowledge of declining biodiversity, climate change impacts, and existing responses to environmental change (Huges et al., 2019; Chawla, 2015; Gill, 2014; Wilson, 2018). E.O. Wilson's (1984) *Biophilia* concept starkly illustrates the human desire to observe and understand the natural world, which is, in turn, a basis for understanding environmental change, including biodiversity loss and climate change. Increasing rates of industrialisation and urbanization, however, have distanced human interaction with nature (Balmford et al., 2002). Such is the extent of this lost connection that many children have lost the language required to describe and understand the natural world (Hughes et al., 2019). As MacFarlane (2016: p. 3) has written, "there [has] been a culling of words concerning nature... The deletions include *acorn*, *adder*, *ash*, *beech*, *bluebell*, *buttercup*, *catkin*, *conker*, *cowslip*... [There is] an alarming acceptance of the idea that children might no longer see the seasons, or that the rural environment might be so unproblematically disposable. The substitutions made in the [Oxford Junior] dictionary – the outdoor and the natural being displaced by the indoor and the virtual – are a small but significant symptom of the simulated life we increasingly live in".

This simulated life, we argue, is a form of niche construction and path dependent behaviour that prevents wider awareness of changes to natural systems. Throughout the Holocene, niche construction behaviours have created environments very different from those that would otherwise exist; cultural environments involving land clearings, cultivated soils, domesticated plants and animals, technologies, and the human knowledge, practice and systems of belief that store and transmit information to future generations (Laland and O'Brien, 2010, 2012; Boivin et al., 2016; Riede et al., 2018, 2019). Constructed niches have been successful in enabling human societies to flourish but if the world view of any society is limited to the niche itself, their ability to understand, let alone adapt, to wider environmental change may be compromised. According to Niche Construction Theory (NCT), the intergenerational transmission of environmental knowledge evolves through the interplay of imitation, combination, and experimentation (Laland and Brown, 2011). This evolutionary understanding of knowledge transmission and learning is developed from standard evolutionary theory but departs in its observation that living things—including humans and their distinct behaviours—"co-construct and coevolve with their environments, in the process changing the structure of the ecosystems" (Laland et al., 2014: 162; Laland and Brown, 2011). The action of ecosystem engineering is articulated as an *extended evolutionary synthesis* that examines the interrelationship between, and ongoing process of, genetic, ecological, and cultural inheritance (Riede et al., 2019). For a farming society, essential generational transfers include genetic material between domesticated species, ecological landscapes shaped by human influences—often over hundreds or thousands of years—and cultural information vital to understanding domesticated plants and animals, subsistence technologies, group routines and behaviour and economic practices (Riede, 2019).

This paper distinguishes two contrasting forms of social learning that underpinned distinct adaptive strategies in response to multi-century climate change. We highlight the contrasting outcomes of cultural adaptations in Medieval Greenland: the Norse of Scandinavian descent and the Inuit (a term we use to refer collectively to pre- or proto-Inuit peoples, previously known in the archaeological record as Thule Inuit, and their modern descendants modern Inuit). In Norse Greenland childhood learning was instructional and focussed on practices and routines operating within their constructed cultural niche, with its emphasis on the farm, domestic animal husbandry and maritime trade (Jackson et al., 2018a). These are characteristics common to other Medieval European societies where children, often from the age of seven, would learn chores, routines, and crafts through observation and replication under the supervision of an adult (Orme, 2003, 2006). In contrast, the Inuit place a greater emphasis on learning-by-discovery and make no division

between nature and culture. The Norse settlement of Greenland came to an end for reasons that remain unclear and debated (Jackson, 2021), but unprecedented climatic change, and the inability of the Norse to respond effectively to the challenges it presented is widely accepted to have played a role (Jackson et al., 2018a; Dugmore et al., 2012; McGovern et al., 1988; Zhao et al., 2022). We argue that the legacies of different approaches to childhood learning were a key factor in determining the end of Norse settlement (and the continued occupation of Greenland by the Inuit). This insight has implications for approaches to childhood learning in the early 21st century and the unfolding climate crisis that will become a major challenge for the current generation of children and generations that follow them.

2. Childhood Learning: acquisition of knowledge and skill

In archaeology, less attention has been directed to understanding the experience of children than adult life in general and the experience of men in particular (Crawford et al., 2018; Baxter, 2008; Kamp, 2001). Early proponents of an archaeology of childhood, such as Grete Lillehammer (1989), suggested that the marginalisation of children and other social groups from the archaeological record had neglected important social and cultural processes, including the transmission of knowledge, practices, and traditions from the adult world (see also Crawford et al., 2018). Lillehammer (1989) drew particular attention to the relationship between children, the adult world, and the environment. This provided an early acknowledgement of cultural and environmental setting in the developmental stages of life: how children learn and play; what their health and living conditions were like; and how their world was associated with the adult world (Forte et al., 2023).

Reconstructing the childhood experience has focused particularly on evidence from skeletal remains, bioarchaeology, and material culture (Egan, 1988, 1996, 1998; Park, 1998). This has provided a better understanding of the demographics, the spatial dimensions of childhood and processes of child socialisation into the adult world. Studies of child skeletal remains have revealed important evidence of nutrition and health in prehistoric children, including child survival in early years (up to five) and the impacts of stresses such as malnutrition and disease (Kamp, 2001). Child-rearing practices have also been revealing of the relationship between parents and children, and particularly the roles of mothers, in different cultures. The role of mother and child in hunter-gatherer societies, for example, have different characteristics and spatial dimensions to those in sedentary societies (Coddington et al., 2011; Hurtado et al., 1992). As Whelan et al. (2013) have explained, although food storage in hunter-gatherer societies may have opportunity costs in the active (hunting) season, selective storage of foodstuffs offers additional opportunities for childcare. The categories of cultural transmission (or enculturation), social learning, and work and play have drawn increasing attention over the last two decades, especially in understanding the relationship between childhood learning and socialisation in Arctic and sub-Arctic contexts (Nuttall, 2000; Ingold, 2000; Riede et al., 2018; Walls, 2010, 2012, 2016).

These latter categories associated with social learning and socialisation have been accessible through child material culture, such as toys and clothing, and through ethnographic observations of play and learning (see for example Gulløv, 1997 & Park, 1998). Toys and ethnographic evidence have revealed a gendered division of material cultures, which are strongly associated with socialisation of gender roles in later years (Kamp, 2001; Baxter, 2008). Dolls for girls and miniature hunting equipment among boys are examples of this socialisation process in the traditional societies of Arctic Canada and Greenland (Park et al., 2018). Toys and games are also shown to play a central role in the transmission of knowledge and skills required in later life. Games and toys provide a safe means for children to learn skills, such as archery and other hunting practices (Riede et al., 2018, 2023; Walls, 2012).

The arrival of the Norse to sub-Arctic Greenland introduced a new perception of the environment, new adult-child relationships, and new

forms of learning. Such modes range from informal knowledge and skills to formalised education systems in monastic schools. In ancient Greece and Rome, schooling took place in informal settings or through home tuition (Lancy, 2010). This informal education is epitomised by the Socratic or dialectic method of seeking truth through reasoned dialogue. Between the end of antiquity and the early modern period, monastic settings provided most formal European educational settings. Learning in medieval Europe usually commenced from the age of seven, where household or farm chores were observed and replicated under adult supervision (Lancy, 2010). In contrast with the dialectic education of Greece and Rome, household activities adopted a didactic—or instructional—logic, through presentation and observation or through autodidacticisms such as songs, rhymes and reading. Wealthier families may have sent children to apprenticeships or monastic education where strict rote learning took place (Orme, 2006; Nedkvitne, 2011). Observation and replication would have been key to acquiring skills in a craft or profession, with physical punishment a common didactic tool (Lancy, 2010; Fossier, 2010). Forms of apprenticeship, formal education and informal knowledge transmission have existed for thousands of years and are evidenced in both archaeological and historical records (Derri-court, 2018; Riede et al., 2018). However, the development of literature and psychologically distinct ‘modern’ societies—particularly in Western Europe and North America—is commonly traced to the Early Modern period (Henrich et al., 2010a). Structured learning would have improved the fidelity of knowledge transmission and improved systems of governance, but this could equally have restricted understandings of the natural environment, and its ecologies and rhythms.

This recognition that childhood archaeology provides context about how societies saw themselves, how norms were established in society, and how new forms of knowledge were adopted, offers a more expansive view of societies of the past (Riede et al., 2018, 2023). And with this, a greater understanding of interaction with, perception of and learning about the environment—as it changes.

3. Cultural Chronology in Greenland

The Norse settled Iceland in the late 9th century CE and by the end of the 10th century had pushed further west to colonise southwest Greenland. This land appears to have been unoccupied at the time despite, as later Icelandic written sources note, the Norse finding traces of a pre-existing culture (‘skin-boats and stone implements’ *Íslendingabók*; Grønlie, 2006: 7), one we now know as the Greenlandic Dorset (Park, 2014). The Norse colonisation of Greenland was most probably driven by a pursuit of trade goods (Frei et al., 2015). To exploit the ivory, furs and Arctic exotica of Greenland, permanent settlement was necessary, and the Norse made this possible in two areas of southern Greenland by importing, constructing, and maintaining a cultural niche based on permanently occupied farms and seasonal exploitation of outlying areas to support animal husbandry and for gathering wild resources. This combined utilisation of domesticated and wild, terrestrial, and marine resources had developed in the largely similar ecological settings of northern Scandinavia, applying a generalist strategy to support a resilient subsistence economy. Over the first two centuries of settlement, the Norse economy adjusted to a relatively stable local ecology before adjusting towards an increasingly marine, wild resource base in the 13th century CE (Arneborg et al., 2012). Climatic variability from the late-13th century stressed the application of the Norse farming-hunting economy until it reached its limits in 15th century CE with the final disappearance of Norse settlement (Jackson et al., 2018a). The Norse settlement disappeared at a time of significant political and economic change in Europe following the transition from high status markets associated with ivory, furs, and other elite commodities to high bulk, low value commodities, such as stockfish and trade in standardised cloth (Epstein, 2009; Hayeur-Smith, 2014). Market transitions and the loss of political power in Scandinavia and the transition to the Hanseatic towns of Northern Germany would have isolated the Norse by the end of

the 14th century CE (Imsen, 2010; Nedkvitne, 2018). Political and economic change in the 14th and 15th centuries was in part associated with mass mortality and population decline following the Black Death, which brought about changes to the agrarian economy as labour shortages increased wages while peasant deaths opened available land in Europe and reduced landlord revenues (Benedictow, 2006; Cohn, 2007). This is relevant context as peasant wages created wider demand for low value commodities, shifting the economy and political influence to the low countries, and could have opened new land holdings to Norse Greenlanders in Iceland and Europe.

The Inuit culture developed whale hunting in the Bering Strait region around the end of the first millennium CE, then push eastwards across northern Canada at the same time as the Norse expand their range west across the Atlantic. The Inuit had a diverse suite of Arctic-adapted technology that enabled them to harvest a range of marine and terrestrial resources; they were mobile and spent summers on the move before returning to more permanent housing for the long Arctic winters. The first signs of the Inuit culture in west Greenland, south of Disko Island (and thus in areas settled by the Norse) occur from the late-13th and early-14th centuries CE, although there is little agreement about any potential overlap or interaction of the Norse and Inuit cultures (Gulløv, 1997, 2008). Norse sites were likely abandoned at a time the Inuit culture expanded into the same areas, and we have yet to find unambiguous evidence for any co-habitation (Golding et al. 2011). There is very limited archaeological evidence of Norse artefacts in Inuit sites (or vice versa), and thus limited material evidence for contact and exchange. There are indications of conflict in oral traditions (Nedkvitne, 2018) but corroborating archaeological evidence for this remains elusive (Gulløv, 2008).

4. Nature-Culture Ontologies of the Norse and Inuit

A profound cultural gulf between the Norse and Inuit cultures, worldviews, and cosmologies is suggested from Medieval Icelandic and Norwegian written sources and 20th century Inuit ethnographies. Rockman (2003, 2010) has examined the types of knowledge required to colonize the environments unfamiliar to Europeans in the North Atlantic and North America, finding parallels between the fates of colonists who failed to identify, use and sustain local resource systems. On arrival, the Norse would have required knowledge of the location of resources, their seasonal limits, and the social knowledge required to manage changing resources (Rockman, 2003). Collectively, this knowledge, known as landscape learning, combines existing knowledge of how to act with new knowledge to effectively utilise and govern resources (cf. Dugmore et al., 2007).

In the Norse worldview, the socialised human domain was perceived as separate from the untamed environment. The early Icelandic legal codes—the Grágás texts—provide evidence of this separation in a lengthy demarcation of land and property that would be subject to claims and inheritance, taxation and hire or communal use (Dennis et al., 2000). The uninhabited wilderness beyond these domains was, by contrast, not subject to the same legal status. According to the Norse, the *Skræling*, a possible reference to the Inuit, did not belong to “the law of payment for homicide including murder committed in the settlements or under in the northern hunting grounds beneath the North Star” (Arneborg, 1997: 45) because, to the Norse, they did not belong within the socialised human domain (Gulløv, 2008; Gräslund, 2009). This separation is integral to the perception and value of wild and domestic resources and their environments. Cultural landscapes and resources were socially and legally demarcated, with disproportionate cultural capital invested in identity as Norse farmers. This, Dugmore et al. (2012) suggest, would have imposed cultural limits to adaptation, as the Greenlanders identified with a mode of production conducive to the wider Norse diaspora. These diasporic, cultural connections impose specific ontologies on how things were done. Wendrich (2013: 4) explains that while knowledge “is conveyed and acquired through play, observation,

imitation, repetition, and experiment... emphasis on any of these is determined by cultural direction and circumscription, as well as the agency of both master and apprentice". Here, the social context is important to the enculturation of learners and the inspiration to adopt or adapt existing practices.

Unlike the Norse, Inuit hunting societies do not separate social and natural domains and detailed ethnographic research with Arctic cultures has further revealed the absence of a nature-culture division (Brody, 1975, 2001; Ingold, 2000; Nuttall, 2000; Gulløv, 2008). In Arctic cultures, hunters know local environments through a deep social and spiritual connection with animals (Ingold, 2000). Observation and experience of the natural world is essential to understanding the behaviour and distribution of animals, how those change over time, and to provide them with the right death (Collignon, 2012; Ingold, 2000). For animate beings (including humans) to live, reciprocity must be maintained between all life. The rights of the living and non-living things must be respected to maintain the circulation of vital forces between humans and animals, and to contribute towards the regeneration of the lifeworld (Ingold, 2000). Cultural complexes illustrate the orientation of skills towards hunting and foraging activities. Throwing technologies, including harpoons and lances, are key to hunting on water and ice floes, and kayaks are refined and personalised to specifications of each user (Gulløv, 1997; Walls, 2016). Collectively, Inuit techno-complexes and lifeways provided a robust cultural niche for observing subtle environmental changes and applying knowledge required to adjust to such changes (Brody, 2001). There is also a clear emphasis on developing hunting skills and practices from the early stages of childhood during which the use of so-called qualifier toys (functional miniatures) played a vital role (Riede et al., 2018; Park, 2005).

5. Modes of Learning

Many childhood activities are not discernible in the archaeological record, but toys and miniatures have been recovered across numerous contexts, providing evidence of skills acquisition and the transmission of cultural knowledge (Riede et al., 2018; Laland and O'Brien, 2010, 2012; Boyd et al., 2010). Ethnographic evidence of childhood play allows archaeologists to interpret how prehistoric objects were used, and how knowledge and skill were transmitted to children through observation of adult behaviour, mimicry, and experimentation (Park, 1998, 2005, 2018). Collectively, we can understand these activities as socialisation with cultural beliefs and practices, and learning the knowledge and skills required to survive (Ingold, 2000; Nuttall, 2000; Park, 2018; Riede et al., 2018).

Modes of learning influence the nature of cultural transmission and how children come to understand and practice relationships between nature and culture (Ingold, 2000). Different modes of social learning—through observation, experience and being taught (pedagogy)—can therefore influence the degree of conformity and change that is possible within a culture, how this influences their relationship with the environment and their ability to adapt to climatic change (Rockman, 2012; Lewis et al., 2014). Gopnik (2020) makes a useful distinction between pedagogies of exploration and exploitation that can be distinguished in respective Inuit and Norse social learning strategies. While examples of Inuit social learning focus on exploration of local resources, the Norse distinguish between zones of exploitation across the cultural and natural landscape. In other words, Inuit social learning emphasises learned how to learn, whereas the Norse social learning follows a prescribed developmental pathway where knowledge is elicited from progenitors (SI Table 1).

As Blurton Jones and Konner's (1976) hypothesise from study of the !Kung people of southern Africa, "evolution in a hunter-gatherer niche should have meant that there was selection pressure on the human brain such that man became interested in animal behaviour and competent in finding out about it" (p.342). For the !Kung, personal observation is

prioritised over hearsay and interpretation that can be learned ex situ. Blurton Jones and Konner note that value is ascribed to "finding out about animal behaviour *from nature*—from animals themselves and their tracks" (1976: 347). Such learning strategies hold a resemblance with Inuit communities in Greenland and Canada, where ethnographic evidence of childhood socialisation and learning emphasise passive exploration of technology, nature, and kinship (SI A1 & SI Table 1). In such cases, exploration of animal behaviour and the wider environment are essential if children are to master the complex association between changing environmental conditions, animal behaviour and the use of hunting technologies.

The Norse Greenlanders hunted throughout the 500-year settlement of Greenland, supplementing the farming economy through the hunting of marine mammals. Children learned within the cultural landscapes they transported from Scandinavia in the 10th century (Jackson et al., 2018a). Supplementary Information Section A.1 provides a detailed comparison of Norse and Inuit social learning, but the most striking differences are associated with the learning environment, pedagogy, and stages of social development (see SI Table 1). Historical and archaeological evidence from Iceland suggest children would have learned largely about farming within farming environments. Stages of childhood development are also legally demarcated in Iceland law codes and both formal and informal education would have remained within a social hierarchy.

5.1. Norse Social Learning

In Norse Greenland, evidence of children's games and objects of play are largely identifiable within communal living spaces, suggesting play took place indoors, especially during the cold, harsh winter months where few activities could take place outdoors (Jackson et al., 2018a; McGovern, 1980). This said, evidence of outdoor play—such as that with animal bones—is unlikely to either survive in situ or be located within indoor archaeological contexts.

The King's Mirror, written in Norway in the 13th century, is an Old Norse didactic text structured as a dialogue between father and son. The text provides lessons on the Norwegian kingdom and its four orders of men: 'the merchants and their interests; the king and his retainers; the church and the clergy and the peasantry' (Larson, 1917: 6). The dialogue structure of this text, which bears similarities with Snorri's *Edda* and *Barlaams saga*, serves as a device for enhancing the delivery of information to the reader (Eriksen, 2014). We argue that the intellectual function of the text mirrors the western model of learning observed at the time, a point also made by Eriksen (2014). When *The King's Mirror* was written, theories of education and learning were spreading in European monasteries, universities, and cathedral schools (Nedkvitne, 2009). However, the account recorded in this Norwegian text is unlikely to reflect knowledge beyond a select elite group in Norse society. As Eriksen (2014) explains, the dialogue in the *King's Mirror* reflects the narrative structure, which draws an unequal balance between the son, who requests knowledge, and the father, who holds knowledge, and sanctions or provides it to his son. In the description of Greenland, the father explains the rationale for settling new environments, the wealth of the lands, and natural resources. He notes new species, as well as the limits of the land for farming and the continuation of the Norse lifestyle. Notably, the text also refers to key topographic features essential to maritime navigation and the importance of sustaining a good livelihood and economic base (Larson, 1917).

In addition to parents, priests played an important educational role in Scandinavian society. Nedkvitne's (2009) examination of ecclesiastical and lay knowledge of Medieval Scandinavia, notes a change in the role of parish priests as educators in Norway and Iceland. For the lay society, religion provided norms and values, whilst laws and codes of honour maintained public interests (Nedkvitne, 2009). The Medieval Icelandic legal codes—the *Grágás* law codes—dedicate significant attention to the observation holy days and religious duties and

responsibilities.

Unlike Inuit cultures, children in Norse society were not considered socially whole until the age of 16 – the legal age of adults according to the *Grágás* law codes. Historical and archaeological evidence indicates that from the age of 12, children would have participated in animal rearing activities (Dennis et al., 1980) and it is likely children made important contributions to farming while men hunted (Gardela, 2019). Isotope analyses support this, suggesting that children remained within the farms because they consumed less marine food than adult men (Naumann, 2012). This indicates that childhood play and education would have happened in the farm environment and within the constructed cultural niche space.

Runic inscriptions provide the only direct written evidence from Norse Greenland, and, though limited, they offer an important insight into identity, writing culture and religious devotion as well as learning (Imer, 2017; Gräslund, 2009). The “Narsaq stick”—has been interpreted as a learning stick for practice runes (Væbek, 1992), and we can infer a didactic style of learning developed through dialogue and reinforced through the study of runes, a process starting in the home and perhaps moving onto a religious centre of learning in adolescence (Nedkvitne, 2009; see also Orme, 2003, 2006).

5.2. Inuit Social Learning

The forms of structured didactic learning central to Western pedagogy differ from social learning in Inuit societies from the late 19th and early 20th centuries (Park, 2005, 2018). Rather than teaching by instruction and questioning, traditional Inuit societies embrace experimental forms of learning, where children are encouraged (tacitly) to observe and imitate the behaviours of elders (Honigsmann and Honigsmann, 1953; Park, 2005). This encourages active experimentation with adult activities in early childhood. Many early 20th century ethnographic observations noted the correspondence between childhood play activities and adult activities; activities such as playhouses, where children construct the layout of summer houses or build winter snow houses mirror, in miniature, adult activities (e.g., Jenness, 1922). These examples of semi-supervised learning allowed children to observe, imitate and experiment with both technologies and local environments.

Games and imitated play activities such as dog sleds and imaginary hunting would have provided children with important skills for later life. As Jenness (1922: 219) observed, children would set “up rows of stones and turf, *injukhuit*, as for a caribou drive” and they would dig “shallow pits, *tallut*, from which they launched their shafts at imaginary deer”. Children would use miniature bow-and-arrows in activities that imitated hunting strategies for caribou and seal hunting games would involve miniature harpoons, toy kayaks and stone layouts, where children would arrange in the shape of kayaks and imitate the skills required to hunt seals on the open water (Walls, 2010, 2012). These games provided a basis with which to learn and socialise with hunting practices in Inuit society, and an important stage in the development of hunting strategy and knowledge of animal behaviours (Riede et al., 2018). For example, the representation of a seal beneath a blowhole and knowledge of the harpoon technology required to retrieve the catch (see Parks, 2005 for discussion) and “small ivory carvings of animals and birds, with which they play by the hour, arranging them for various plays and hunts” (Hawkes, 1916: 113). Ethnographic observations in Kalaallit have demonstrated the importance of situated learning and apprenticeship in the construction and on-going refinement of kayak technologies to suit the demands of marine environment and to suit the size and shape of hunters as they hunt seals (Walls, 2016).

Activities in traditional Inuit society were highly gendered, dividing food preparation and the production of clothing from hunting activities. Observed gendered activities include playing with dolls and cooking meat on small lamps providing girls with knowledge of childcare and cooking (Jenness, 1922; Boas, 1888). In an account from 1888, Boas

observed a selection of play activities involving “play with toy sledges, kayaks, boats, bows and arrows, and dolls. The last are made in the same way by all tribes, a wooden body being clothed with scraps of deerskin cut in the same way as the clothing of men” (p.571). Young girls would have carried out this activity, practicing their skills at making parka jackets. Carefully tailored clothing is essential to life in Arctic and sub-Arctic conditions (Gilligan, 2010), and knowledge of how to source and produce wind- and water-proof clothing would have been an indispensable skill to transfer between generations (Boyd et al., 2011).

Inuit society considers children socially whole from birth (Park, 2018). The naming of children is thought to deliver the skills of previous generations directly to new generations. Hence, a child given the name of an experienced hunter who had passed, would be expected to become a good hunter (Nuttall 2001). However, Nuttall’s (2001) observations suggested that, while children were said to have adopted the skills of their namesake, they learn through situated practices (i.e., didactic interaction) in a ‘lengthy apprenticeship’ with elder members of the community. This formed an ongoing process of enskilment as the child graduated from play and imitation to situated learning and the practical refinement of environmental skills (Nuttall, 2001; Berkes and Armitage, 2010; Riede et al., 2018).

5.3. Space, Culture, and the Learning Environment

Research in developmental psychology notes the importance of ‘unstructured time’ for developing creative skills and problem-solving capabilities (Russ and Fiorelli, 2010; Riede et al., 2018). The amount of unsupervised childhood learning time is likely a key difference between Norse and Inuit cultures. During the long winter months, childhood activities in Norse Greenland were probably structured to include the legal and moral guidance of the social and ecclesiastical elite, as well as games and object play (Nedkvitne, 2009; Vésteinsson, 2009). In contrast, the Inuit culture, with their view of children as socially whole, would have allowed space for both structured, didactic learning and experimentation with objects and the local environment (Gulløv, 2008). Thus, Inuit children are likely to have had more time to explore the environment and experiment. Miniatures and objects of play conform to central characteristics of each culture, but as we will see, the conformity of Norse objects of play appear partial, focussed on farming and cultural environments, whereas objects and play of Inuit children represent a more complete subset of adult activities adapted to local environments.

6. Materials and Methods

To identify toys and miniatures associated with Norse and Inuit childhood learning and play, we have systematically interrogated excavation reports and other publications on material finds. We propose that these objects played a key role in the high-fidelity transmission of technical and ecological knowledge (Riede et al., 2018; Mesoudi, 2018). Written sources and ethnographic records contextualise these finds by analogy or description (cf. Wylie, 1985) and help us to understand the use of these objects, and their roles in socialisation and learning. Ethnographic records from the late 19th and early 20th century provide rich insights into the traditions of Inuit communities and observations of child rearing, object play, and environmental learning (Park, 1998, 2005). Medieval written sources also provide further information about the activities associated with child play and learning in Norse society (Raffield, 2019; Nedkvitne, 2009).

A significant proportion of site excavations, and thus material finds, in Greenland date from the beginning of the 20th century and are reported in *Meddelelser om Grønland*—renamed *Man and Society* in 1979. We carried out an archival search of excavations recorded in *Meddelelser om Grønland* between 1880 and 2010. Few of these sources are digitised and therefore do not feature in *Web of Science* and *Scopus* citation databases, so analysis has been limited to physical copies at the National Museum of Denmark and National Library of Scotland. We obtained

further evidence of Greenlandic child material cultures from a broader review of publications available online between 1979 and 2023. For this step of analysis, publications were downloaded into NVIVO for keyword searches matching (and including variations of) ‘child*’, ‘toy*’ or ‘miniature*’. Publications identifying child material culture are listed in [SI Table 2](#) & [SI Table 3](#).

With the exception of runic inscriptions, no direct written evidence survives from the Greenland Norse, so we rely on written sources from the contemporaneous Norse communities of Medieval Iceland and Norway to interpret childhood activities and their place in society. Multiple accounts of children and childhood activities exist in the *Sagas of the Icelanders* (Raffield, 2019), *The Kings Mirror* (Eriksen, 2014) and the *Grágás* legal texts (Dennis et al., 1980, 2000). Furthermore, the *Bishop’s Saga*, for example, describes biblical and ecumenical learning in church schools (Nedkvitne, 2009).

Childhood objects from Inuit sites are relatively abundant and have been subject to extensive reviews because of a combination of well-preserved material finds and analogous ethnographic evidence from the late 19th and early 20th centuries. Park (1998, 2005) has documented play objects across Northeast Canada and West Greenland to compare the relative abundance of children’s toys and miniatures and full-sized adult finds. Multiple site reports classify object typologies (i.e., transportation, household utensils) allowing comparison across this region. By comparing the relative abundance of artefacts associated with childhood and adulthood, it is possible to trace the transmission of technologies and skills between generations (Park, 2018). We adopt Park’s (1998, 2005) methodology and apply it to Gulløv’s (1997) material finds from Godthab district. We selected the sites of Illorpaat, Itissaalik and Kangeq because of the proximity of Inuit sites to Norse settlement areas (see [SI Table 4](#) and [SI Table 5](#) for object inventory;

Gulløv, 2004, 2008).

The potential of studying child material culture in the past (and present) must be tempered with acknowledgement of the lacunae and uncertainty of material analysis. Examining any artefact is an interpretive, relational process associated social and practical use of the object by people, past or present (Hannan and Longair, 2017; Lucas, 2010). Triangulation of object, texts and ethnographic observations therefore provide a representation of social practice of play and object significance through the cross-referencing of material and textual information (Lucas, 2005, 2019). This is very much true also for the study of childhoods past (Baxter, 2005, 2008). In the hands of children, any object may become a toy (Crawford, 2009) and our inferences based on the material record are inherently limited. Yet, we consider the investment made, by adults, into the making of play objects significant vis-à-vis the intergenerational transmission of salient cultural knowledge. An analysis and discussion of object finds from Norse sites, and a selected Inuit site, in Greenland is provided in [Supplementary Information](#) Section A.3.

Discussion: From Learning to Adaptation

Communities in the high latitudes are highly adapted to weather, seasonal and inter-annual changes in resource availability (Ford et al., 2015; Brody, 2001). When these cultures experience unprecedented change, however, adaptive strategies can become mismatched with prevailing environmental conditions (Laland and Brown, 2006). The ability to adapt is potentially constrained by both physical and cultural limits (Moser and Ekstrom, 2010; Dugmore et al., 2012; Dow et al., 2013). These include the physical constraints of the local environment, the ability to identify new resources and to adjust norms and behaviours that are essential to cultural identity (Rockman, 2003; Dugmore et al., 2007). [Figure 1](#) illustrates the contrast we have inferred from evidence

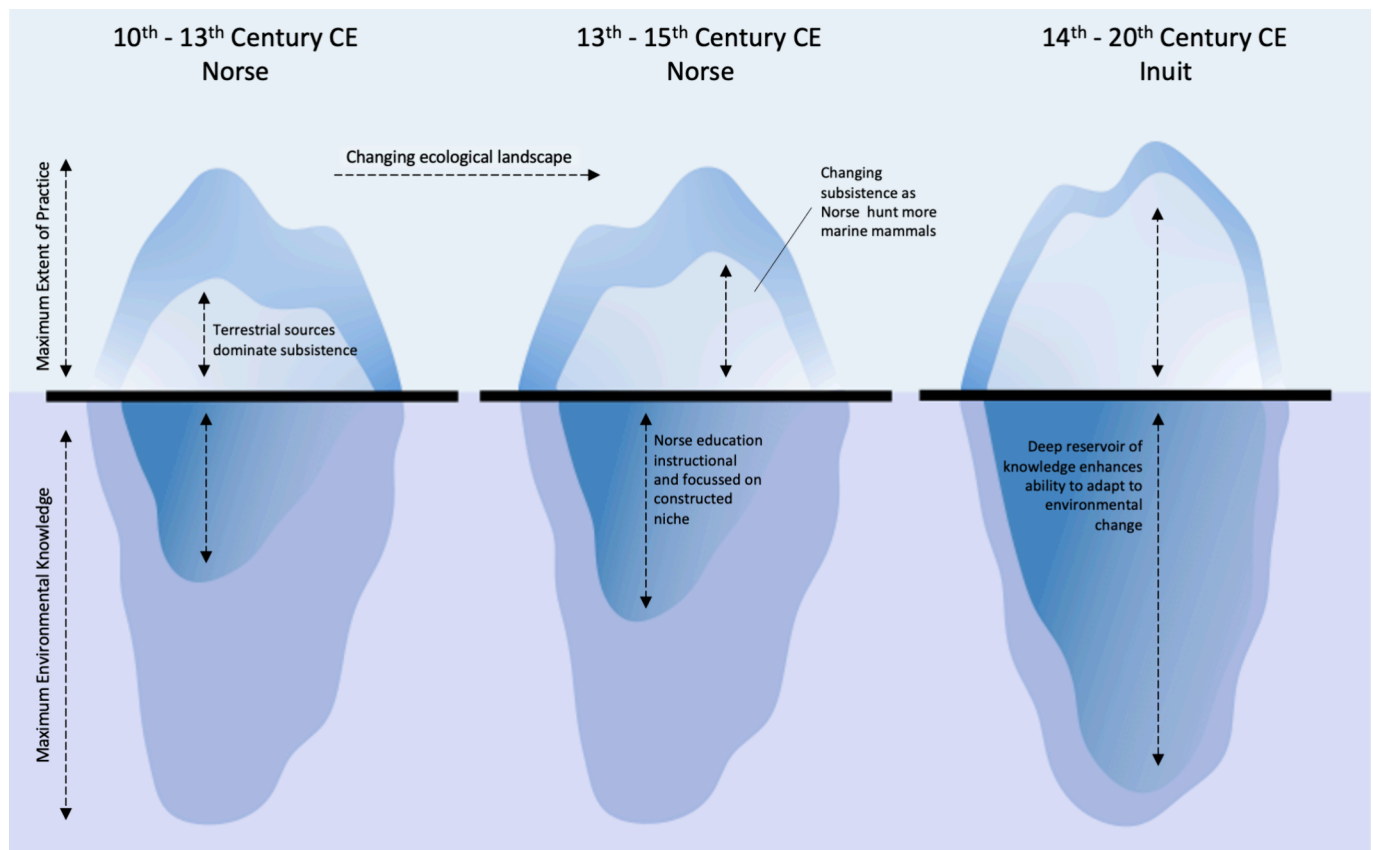


Fig. 1. Availability of terrestrial and marine resources. ‘Icebergs’ represent practical evidence of hunting, demonstrating the high adaptive capacity among Norse and Inuit cultures. However, knowledge of the marine ecosystem would have been more restricted for the Norse owing to more limited intergenerational transmission of knowledge and technological know-how, and no evidence of cultural exchange of ideas with Inuit communities.

of Norse and the Inuit adaptive strategies. Both practiced hunting, here conceived as the solid outline of the iceberg. The zooarchaeological record shows that the Norse were selective in their exploitation of marine mammals – the ringed seal is noticeable for its limited occurrence (Ogilvie et al., 2009). The Inuit, by comparison, harvested a wide range of wild resources representing a marine balanced subset of available animals. Underpinning practice is knowledge—ice below the surface—and we argue that the combination of an immersive experience of nature—as opposed to the constructed niche—coupled with childhood experimentation through play. The deeper reservoir of knowledge—visualised in Figure 1 as ice below the water—positioned the Inuit better to cope with unprecedented changes. Similar practices but without the knowledge required to practice efficient hunting of marine mammals is therefore visualised in Figure 1 to show that evidence of a broad resource strategy is the tip of the iceberg.

Central to path dependency is what Boyd et al. (2011) identify as the interplay between intergenerational knowledge transmission and social learning. To increase the fidelity of information transmission between generations, children learn cultural behaviours through play and experimentation with toys and miniatures that reflect adult practices (Laland and O'Brien, 2010; Parks, 2018). This must be balanced with selective learning to allow the incremental improvement of existing adaptive strategies over time. Social learning can take a range of forms that allow new selective strategies as well as existing cultural adaptations to accumulate, but the accumulation of cultural expertise must be balanced with exploratory learning of object and landscape affordances, where changes to resource location and timing of resource availability are identified and utilised (Hoppitt and Laland, 2013; Rockman, 2003, 2010).

For contemporary generations faced with the challenge of adapting to current and future climatic change, the institutional memory of past decisions—over short and medium timescales—will have a significant influence on the efficacy of future adaptations (Jackson et al., 2018a; Walsh et al., 2023). What children learn about their local environments, how to understand environmental changes, and how different human activities will influence the availability and distribution of resources, will have a significant bearing on their capacities to identify and respond to change. Without resorting to historicism, focusing on examples of social learning and the transmission of cultural knowledge can inform the efficacy of different adaptive strategies in different geographical and cultural contexts (Hulme, 2011).

In the formative pre-adult years humans develop cultural understanding and acquire the knowledge and skills required to survive in later life. In the middle stages of childhood, children prime their physical and cognitive abilities through activities such as games and object play (Riede et al. 2018). During this period, knowledge of the cultural niche, including its traditions, practices, beliefs and technological know-how are developed and refined (Zeder, 2016; Gamble, 2007; Hoppitt and Laland, 2013). Social learning, as IPCC Assessment Report 6 (2022: 95) references (with medium confidence), is essential to developing “shared understanding” and “locally appropriate responses” to climate change. But while the latest assessment report recognises the need for “innovation, adjustment and learning” (IPCC, 2022: 106), there remain few if any assessments of social learning in a dynamic and changing environment.

6.1. Learning in a Dynamic Environment

The dynamic terrestrial and marine environments of the circumpolar north require significant adaptive capacity among Arctic peoples, such as the capacity to observe and identify of local changes to the biophysical environment and adopt new technologies and practices required to utilise seasonally abundant resources (Ford et al., 2015). Dietary records suggest that the Norse utilised a range of terrestrial and marine resources, suggesting high levels of adaptive capacity (Jackson et al., 2018a). But Norse miniatures and toys seem to reflect only a

subset of adult activities, including farming, sailing and conflict, with little evidence of childhood play to prepare skills in harvesting wild resources in general and hunting marine mammals and caribou or fishing (SI SI Table 3). This notable omission seems to highlight a difference between identity and adaptive strategies, imposing cultural limits on the scale of adaptation to changing resource systems in Greenland.

Inuit material culture was refined to adapt to seasonal extremes of the Arctic and resource availability. Miniatures helped children learn how to use Arctic adapted technologies, experiment, and develop skills required to make clothing, household objects, boats, throwing weapons, and other hunting equipment. Archaeological and ethnographic evidence show that childhood play covered the full range of adult activities in circumstances where creativity and problem solving could flourish (SI Table 4 and SI Table 5). Inuit, games and play with miniatures provided a “simulative environment to practice and develop sub-sets of hunting skills” (Walls, 2012: 175). Adults would have provided rules for games allowing different hunting scenarios to be explored within the safety of the home base. As Walls (2012, 2016) explains, the didactic nature of games and sports would have refined technical abilities, transmitted local ecological knowledge, and built social relationships between future hunters. These situated learning practices would provide vital skills required in the active environment once children had reached adolescence (Nuttall, 2000; Ingold, 2000).

6.2. Climatic Change and Adaptation

In a North Atlantic context, the Norse subsistence system based on animal husbandry and the harvest of wild resources was hugely successful, enabling hunting or fishing to make up short falls in production from domesticated animals, balancing the utilisation of terrestrial and marine resources, and providing the scope for trade (Jackson et al. 2018a). However, the settlement of Greenland saw this system pushed to its limits (Dugmore et al. 2009). Whilst animal husbandry is viable in favoured areas of southern Greenland, hunting of marine mammals and caribou is critical, both for subsistence and the trade goods required for overseas exchange and the import of key resources such as iron, timber, and cereals (Dugmore et al. 2007, 2012). The climatic changes of the mid-13th century demanded adaptation, and this challenge was met through a substantive increase in the utilisation of seals – as evidenced in both bone refuse assemblages and the isotopic composition of human remains (Arneborg et al., 1999, 2012; Dugmore et al. 2012). Given the critical importance of sealing for their survival especially from the 13th century onwards, the lack of toys—and apparently play as well—related to seal hunting, is striking. Figure 2 visualises the relative conformity of Norse toys along the ecological gradient from the east to west North Atlantic. Though objects associated with cereal cultivation are not found in childhood material culture in the west North Atlantic, weapons, boats and domestic livestock remain prominent. There is no evidence that the Norse were proficient with highly adaptive Inuit hunting technologies, such as kayaks and harpoons, and emphasis remains on cultural economic landscapes that are identifiable across the rest Viking world.

The Norse approach to childhood learning developed a long familiarity with the constructed niche but a limited representation of the wider marine and terrestrial ecosystems of Greenland. Available evidence also appears to suggest it was not directed toward promoting innovative responses to variable environment. The Inuit, by contrast, appear to have both taught children how to live in the whole of the Greenland environment, and trained them how to be continually aware and able to learn through dynamic environmental change. When it came to unstable climatic conditions, the Norse were at a double disadvantage while the Inuit were pre-adapted in a way to identify and respond to change.

Climatic challenges and the conjunctures of the mid-15th century drove the Greenlandic Norse communities outside of their safe and just operating space. The increasing lack of a just access to resources is

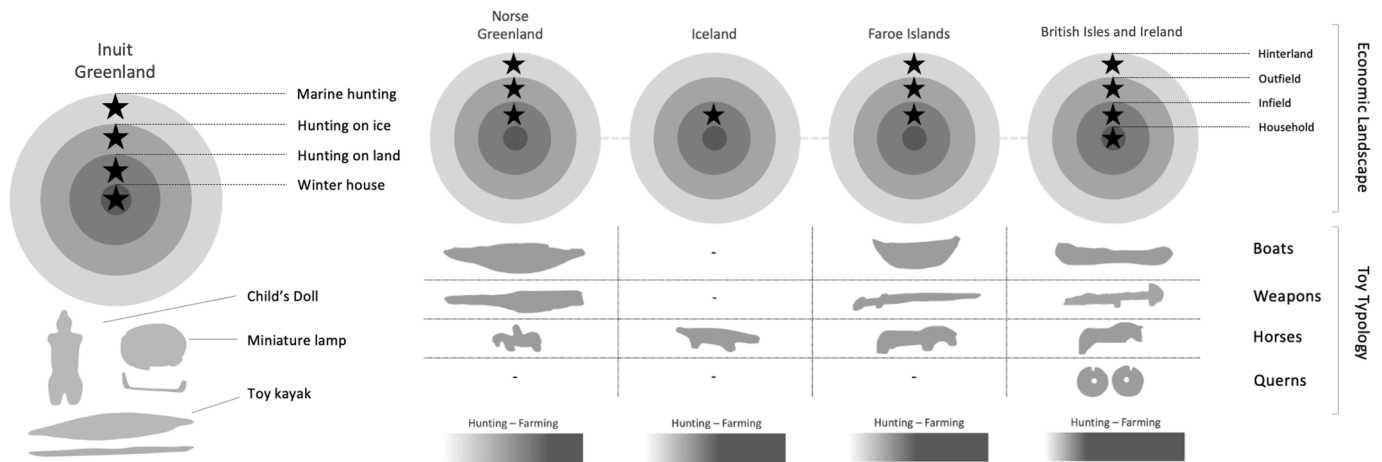


Fig. 2. A conceptual model to illustrate gradients of ecological difference across the North Atlantic islands and the mismatch between Norse toy typologies and the balance of farming and hunting needed to survive (summarised in the bottom row). After the climate shocks of the 13th century CE hunting became ever more important in the Western North Atlantic and this was an activity for which childhood prepared the Inuit well.

evidenced by the increasing divergence in elite and commoner capacities to keep cattle and acquire their meat. The decreasing overall safety of Greenland Norse society is, in turn, evidenced by the successive decline and collapse of their settlements that culminated in their complete abandonment or depopulation. These changes put traditional animal husbandry in Greenland under ever-greater pressure, so that effective climatic change adaptation required alternative approaches. We have no evidence for cultural exchange between the Norse and Inuit—the Norse did not adopt any of the Inuit hunting methods, such as the winter hunting of ringed seals through blow holes in the sea ice—something that arguably could have aided their survival (Gulløv, 2008). Norse toys and miniatures from Greenland are like those recovered from other sites across Scandinavia and the North Atlantic islands, delivering cultural solutions that were not fine-tuned to Arctic wild resource systems. Although adjustments were made to object materials, such as the substitution of whalebone, driftwood, antler and baleen for iron, the object shapes and symbolic importance was not substituted, there is little evidence that technologies were adjusted, or new technologies and skills adopted.

We have no evidence that the Norse used skin boats, despite the need for imported timber to construct their traditional clinker-built boats. Greenland's wood supply, limited to birch trees, willow shrubs and driftwood, was only suitable for small-scale repairs to boats, and not the construction of traditional Scandinavian ocean-going craft. In addition, Scandinavian boat building utilised iron rivets, which would have been in scarce supply given a lack of iron deposits in Greenland. Already in the 12th century, an Icelandic source notes:

Ásmundra kastanrazi came from Krosseyjar in Greenland and 13 men together on a ship that was nailed with wooden nails only. It was also tied with cords. He arrived in Breidafjörður in Iceland
Flateyjarbók IV, ed. by Sigurdur Nordal, 1945

The key point being that wooden boat construction endured (indicating social conservatism), but the lack of iron produced a local adaptation of construction techniques. This indicates crucial limitation to adaptation—and potential barriers to meeting environmental challenges.

Thus, we argue that the Norse cultural axis, during critical phases of childhood learning was towards farmsteads and the constructed niche, whereas the crucial early years of learning and innovation of Inuit was orientated to the whole environment. We have provided evidence that Norse social learning reflected a hierarchical social structure and age-segregated didactic structures to the intergenerational exchange of knowledge. This learning hierarchy and sanctioning of knowledge likely

reinforced cultural norms and the worldview of Norse children, where the modus operandi of hunting was to support the farming economy. This would have had critical implications for innovation and adaptation. In contrast, the Inuit approach to early years learning was of a whole-of-person immersion in learning from childhood and adulthood. We argue this encouraged flexibility, questioning and innovation. Ultimately, the end of Norse Greenland probably reflects a combination of limits to cultural adaptation, compounding vulnerabilities and conjunctures (e.g., Dugmore et al 2012). Didactic childhood learning that reinforced a farm-based identity, failed to emphasise the harvest and use of wild resources, or nurture creativity and problem solving, could have been a key factor in the entrenchment of maladaptive path dependency, and inhibited climatic change adaptation.

7. Concluding Remarks

Toys and miniatures can operate as primers for technologies that children are required to master in later life and help children familiarise themselves with adult culture and the local environment (Riede et al., 2018; Nowell et al., 2020). Peer play amongst children is more likely to promote innovation later in life. Qualifier toys and peer play can promote exploration and adaptation as well as promote normative and conservative forms of socialisation. In Medieval Greenland, Norse toys were similar to those found on farms in Scandinavian homelands but the scales of niche construction and reliance on harvesting wild resources were very different as wild resources formed the majority of the Greenlanders' diet from the mid 13th century onwards. Meanwhile, children played with Viking ships, toy weapons, miniature farm animals, miniature household utensils, and bones that could represent rule-based games. These objects would have familiarised Norse children with the constructed niche and expected norms and behaviours of farming, household activities, warfare, and feuding. Noticeably absent are toys associated with hunting and wild animals, which is a key omission given the fundamental importance of harvesting wild resources to successful climatic adaptation in Greenland—especially after the climate shocks of the mid-13th century. The fact that large scale hunting of selected marine mammals occurred over multi-century timescales is evidenced in archaeological records. How hunting was learned and adapted to changing conditions is lost in the mists of time, but what is clear are differences in the way childhood learning occurred in Norse and Inuit cultures. The restricted range of toys and miniatures combined with an instructional didactic style of teaching suggests a high degree of path dependence limiting the capacity of Norse children and young adults to innovate and adapt behaviours suited to the changing ecologies of sub-

Arctic Greenland.

The Inuit, by contrast, transmitted highly adapted behaviours and technologies about local resource use to their children using miniatures and toys that taught hunting skills, and to how to experimentally yet safely adjust technologies to suit user demands and the local characteristics of the environment. This techno-complex was highly refined for hunting marine mammals in open water and in sea-ice. It utilised materials found within the fjords of southwest Greenland, including driftwood and sealskins for kayaks, caribou hide for winter parkas, and animal bone for harpoon points and lances. Child material culture conforms closely to the full range of this techno-complex and would have allowed children to practice hunting and develop skills before engaging with the active environment. Inuit approaches that prioritised unstructured learning time, would have aided the development of crucial creative skills and problem-solving capabilities.

Although the Norse had refined a subsistence strategy based on animal husbandry and the harvest of wild resources that successfully underpinned initial settlement from mainland Scandinavia to Greenland, this strategy had inherent limits, which were in turn reinforced by their normative approach to childhood learning. Whilst their approach to provisioning allowed them to adjust for shortfalls in production from domestic animals by hunting more, we lack evidence of childhood instruction in hunting and there is no archaeological evidence that the Norse adopted Inuit technologies or adaptive strategies, or that they invented their own. It appears that the Norse continued to transmit cultural information between generations that prioritised norms of farming, sailing and conflict (Jackson et al., 2018a; Raffield, 2019). This package of strategies was eminently suitable for areas where domesticated animal husbandry was possible, farming produced the mainstay of subsistence, and timber and iron were available for Viking shipbuilding, but it was inadequate for survival at the margins of agriculture, when climate conditions were variable. We argue here that childhood learning by the Greenland Norse would have done little to promote innovation and equip young adults with the flexible, hunting-orientated, locally embedded strategies necessary to respond to the radically changing climate of the later Medieval period when both animal husbandry in Greenland and contact with Europe became increasingly problematic. In contrast, the Inuit were well placed to do so.

This completed historical experiment has implications for our approaches to childhood learning in the early 21st century and the unfolding climate crisis that has become a major challenge for the current generation of children. The next generation will be poorly served by past approaches to the management and utilisation of natural resources. Innovative approaches to childhood teaching and learning are needed for effective climate change adaptation, especially when our temporal perspectives for adaptation look towards the long term (cf. Lyon et al. 2022).

7.1. From Cultural Niche to Climate Niche

The ability to learn in new environments goes beyond knowledge of different geographical limitations. Adapting to new climates will require an understanding of the long-term impacts of climate change on local resource systems and the limits and barriers to climate change adaptation by local cultures (Moser and Ekstrom, 2010). Xu et al. (2020), show that since 6000 BCE humans have occupied a narrow average temperature range between 11°C and 15°C. Without major reductions in greenhouse gases, this narrow climate envelope is likely to be exceeded, resulting in the need for unprecedented climatic change adaptation by several billion people (Xu et al., 2020; Lyon et al., 2022; Kemp et al., 2022). Major efforts are required to mitigate further contribution to global warming; however, adaptations within our cumulative knowledge as a species have the potential to inform strategic decision-making in the future (Jackson et al., 2022a, b) and this is assuming an ever-greater importance.

Considering lessons from across multiple cultural niches has the

potential to make us think differently and forge a closer connection with our environments, our assumptions of how they should look, and how these environments will change in the future. Henrich (2020) has drawn attention to the Western Educated Industrialised Rich and Democratic (WEIRD) assumptions of how people perceive their environments and, in turn, how they observe and adapt to environmental change. WEIRD societies make analytical observations of the environment that zoom into pre-given reductionist associations. By contrast, non-WEIRD societies perceive their environments in a more holistic way, where associations are made across entire landscapes (Henrich et al., 2010a, b). Lessons from traditional societies and alternative ways of seeing and learning about environmental change have the potential to contribute successful adaptive strategies to overcome the long-term consequences of climatic and environmental change (Barnes et al., 2013; Gómez-Baggethun et al., 2013).

The archaeological record can provide key data about the toys and miniatures that inform childhood learning, with the continuing challenges of how best to recognise toys for what they are and how to understand the ways children played and learned strategies that informed adaptation to social and environmental change. Meeting these challenges and developing better understandings of the past will provide an unique opportunity to understand how, over multi-generational time-scales, children learn about the environment and create both opportunities and limits for climate change adaptation. The archaeological and historical record provide an essential reference for understanding our attitudes to environment and climate. Insights from the past have implications for our approaches to childhood learning in the 21st century, continuing adult education, and the unfolding climate crisis. Learning strategies and education systems that connect children with the environment and provide multiple viewpoints and flexibility to deal with the challenges of unprecedented change could build greater adaptive capacity. Contemporary climate change education at its best could encompass formal knowledge of climate science, informal connection with the natural environment, and semi-formal engagement through museums (Rousell and Cutter-Mackenzie-Knowles, 2020). Cultural history museums are uniquely placed to connect the present crisis with the long history of different cultural approaches to the challenge of climate change and their successes and failures (Jackson et al., 2018b). Innovative approaches to childhood teaching and learning in the context of climate change adaptation could provide effective solutions on time-scales commensurate with that of projected climate change impacts.

CRediT authorship contribution statement

Rowan Jackson: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing, Visualization. **Andrew Dugmore:** Supervision, Conceptualization, Methodology, Project administration, Writing – original draft, Writing – review & editing, Visualization. **Felix Riede:** Supervision, Conceptualization, Methodology, Project administration, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Rowan Jackson reports financial support was provided by The University of Edinburgh.

Data Availability

Data is included in the Supplementary Information

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.gloenvcha.2024.102878>.

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