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SYMPOSIUM

# Cultivating Collaborations: Site Specific Design for Embodied Science Learning

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**Synopsis** Immersion in well-designed outdoor environments can foster the habits of mind that enable critical and authentic scientific questions to take root in students' minds. Here we share two design cases in which careful, collaborative, and intentional design of outdoor learning environments for informal inquiry provide people of all ages with embodied opportunities to learn about the natural world, developing the capacity for understanding ecology and the ability to empathize, problem-solve, and reflect. Embodied learning, as facilitated by and in well-designed outdoor learning environments, leads students to develop new ways of seeing, new scientific questions, new ways to connect with ideas, with others, and new ways of thinking about the natural world. Using examples from our collaborative practises as experiential learning designers, we illustrate how creating the habits of mind critical to creating scientists, science-interested, and science-aware individuals benefits from providing students spaces to engage in embodied learning in nature. We show how public landscapes designed in creative partnerships between educators, scientists, designers, and the public have potential to amplify science learning for all.

## Introduction: the (dis)embodied nature of teaching and learning

Historically, psychologists and other scientists have separated mind from body, to perceive them as peripherally connected but not integral to one another (Descartes 1952,1980; Russell 1990). Schools and universities generally privilege disembodied practises that maintain this mind/body dualism. In this dualistic approach, "[e]xcept as a container for the mind, [the body] has no significance" (Paechter 2006, 123). Recently, cognitive scientists have prompted reconsideration of the mind/body dualism, reminding us that thinking is shaped by and with our bodies and actions (Abrahamson and Lundgren 2014). The study of embodied cognition suggests, "Human cognition is deeply rooted in the body's interactions with its physical environment" (Lindgren and Johnson-Glenberg 2013, 446). Indeed, as Gibbs (2005) cautions, "We must not assume cognition to be purely internal, symbolic, computational, and disembodied, but seek out the gross and detailed ways in which language and thought are inextricably shaped by embodied action" (Gibbs 2005, i). While true across all disciplines, the role of the body in learning may be especially influential in the sciences (Alsop 2005; Liben et al. 2011; Bajak 2014; Kontra et al. 2015; Weisberg and Newcombe 2017). Indeed, "STEM education initiatives may particularly benefit from embodied cognitive practices because STEM disciplines rely on representation systems that require sensory encoding ... and are nevertheless dependent on highly abstract, formalized symbol systems (e.g., those used in ... chemistry). Students need a 'way in' to linking sensory representations with abstractions" (Weisberg and Newcombe 2017). That "way in" requires shifting not only how but also where we teach science.

Examples mount to suggest that "if cognition is embodied and if embodied learning is more efficient for cognitive development, then maybe schools

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should change their style of teaching to promote this kind of learning in students at all ages" (Ionescu and Glava 2015, 10). Though we increasingly see that hands-on, inquiry-driven learning effectively cultivates the critical and creative thinking skills needed for discovery and innovation (National Research Council 2000; Barron and Darling-Hammond 2008; Roberts 2015), mainstream schools and universities prove difficult ships to turn, freighted with policies that oblige teachers to focus on fact delivery and assessment. Traditional science labs seldom provide opportunities for open-ended, active, embodied learning. Instead, accountability measures and pressures of standardized assessment at all levels constrain teaching and learning, hampering imagination and curiosity that deepen into rigorous inquiry. Furthermore, "(e)mbracing the body as an active and meaningful part of the learning process is a . . . daunting ideological and pedagogical hurdle, given our habituated reluctance to consider cognition as embodied" (Blatt-Gross 2015, 138), adding challenges to implementation.

In the design cases described below, which bring together our professional experience in Landscape Architecture (Gill), Curriculum Design (Glazier and Towns), Education (Glazier), and Public Art (Towns), we illustrate the development of learning spaces that invite students to experience science in embodied ways. We build from our argument that creating the habits of curiosity, empathy, inquisitiveness, observation and reflection, habits critical to the development of scientists and science-aware individuals, depends on giving students experiences in the natural world (Schwartz and Martin 2004; Leong et al. 2014).

## Interdisciplinary collaborations: designers are scientists, scientists are designers

Since big freighters—traditional education spaces and methods—prove slow to change despite the demonstrated effectiveness of embodied learning (Singer et al. 2012; Freeman et al. 2014; Kontra et al. 2015), we, as designers, scholars, and educators have boarded exploratory vessels—alternative places of learning like farms, zoos, and museums. In our experience, these sites provide ideal grounds for prototyping alternatives. The challenge of wide-ranging audience expectations and typically small number of staff demand close collaborations to enable the success: staff from disciplines like art, design, science, and education work closely together in these alternative learning sites, bringing with them multi-disciplinary understandings. Referring to science museums, Sue Allen, Learning Research Director at the Exploratorium, writes: "We expect these institutions to provide a hugely diverse visiting public with entertainment, the freedom to choose their own path, follow their personal interests, do their own inquiry, and create their own meanings. Yet at the same time, we want our museums to be respected educational institutions where people can spend an hour and come away having learned some canonical science" (Allen 2004, S18). These seemingly conflicting demands of alternative learning sites depend on sustained interdisciplinary design collaboration.

In our work in and outside the school system, we have found the benefits of carefully designing and building interdisciplinary teams to shape embodied learning outcomes outweigh the challenges. In the design cases below, we show how, when interdisciplinary design teams are established at the outset of the planning process, and come together regularly to define, design, test, evaluate, and revise the design, the process results in flexible, innovative, and effective learning platforms (Fig. 1). The literature suggests—and our experience concurs—that true collaboration exists when partners come to the table early, on equal footing, and with equal interest in the questions and outcomes at hand (Drayton and Falk 2006; Munson et al. 2013). Moreover, in our work with scientists, we have found a necessary symbiosis: as Galatowitsch (1998) explains, "Science and design are complementary ways to generate knowledge (and therefore both are creative endeavors). Scientists solve problems inductively, forming generalized principles from specific observations. Designers use general principles to solve specific problems deductively" (102).

In our experience, the most effective collaborations between designers and scientists include participants from both disciplines who demonstrate capacity to practise deductive and inductive thinking. In essence, both think as scientists and both think as designers in and through this process of creating authentic learning applications. Collaborative, interdisciplinary teams built early, with attention paid to the design practise of establishing empathy for the team and needs of the project lead to powerful design outcomes. These outcomes benefit students (who experience more effective and engaging learning), scientists (who gain tools for communication, and an expanded pipeline of scientists and science interested), and designers (who attain an expanded field for impactful design practise) (Galatowitsch 1998; Munson et al. 2013).

## Shifting learning landscapes

Because lived experience influences cognition, the environment where students learn impacts what

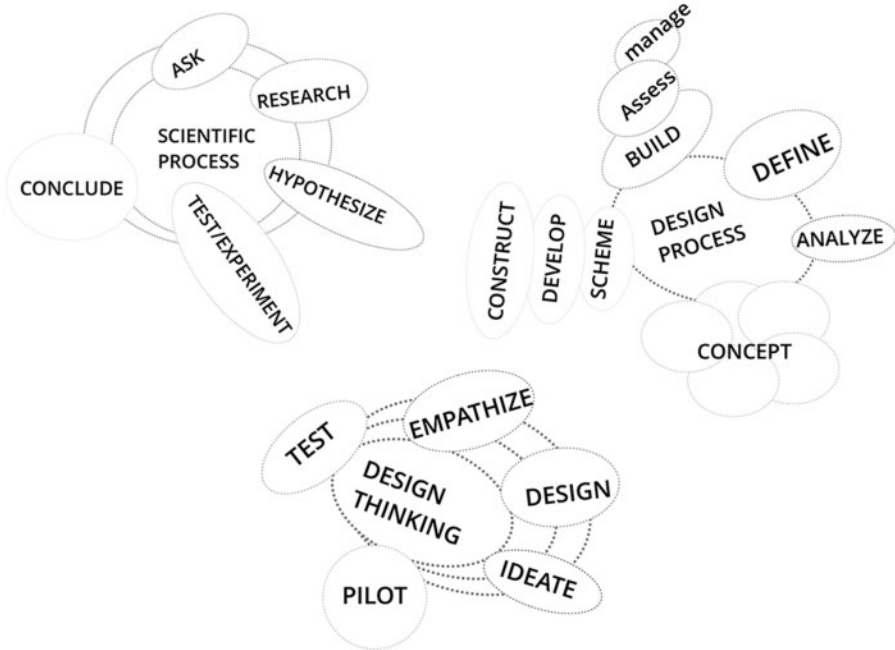


**Fig. 1** The overlap of design thinking, design process, and scientific process: our methodologies for discovery and solution building are similar across disciplines. The typical design process starts with defining a design need, then goes through an analysis, then into concept building, program development, and then schematic, design development, and construction drawings. From this point, the design is built, and the programming and site are managed over time.

learning happens. Full-body experiences, which blend play and experimentation, can help students perceive science more positively. We argue that: "learning environments for math and science can be made more effective if they are designed to tap into bodily know-how that originates both from existing life experience and new learning experiences" (Abrahamson and Lundgren 2014, 11). Furthermore, the field of "embodied cognition has emphasized the role that the body and environment play in cognitive processing" (Weisberg and Newcombe 2017). School and university settings have looked similar for centuries; interdisciplinary collaborations between researchers, scientists, educators, and designers provide compelling opportunities to test new kinds of learning spaces that put embodied learning into practise.

Carefully designed, spaces of informal learning build young people's sense of efficacy, curiosity, and capacity for learning (Allen 2004). Because traditional labs and classrooms seldom have institutional flexibility and space to facilitate these experiences, alternative learning habitats offer needed platforms. Our collaborative work helps us consider: What if we design experiential spaces where body and mind were encouraged to interact? Such habitats for learning and the experiences they can provide are important learning landscapes, particularly for sciences. Actualizing these designs depends on cultivating and managing public and private partnerships. Bringing diverse, interdisciplinary voices—from funders to educators to scientists to designers—together to create and use spaces of natural learning introduces greater opportunity for innovation across disciplines.

Two collaborative design processes we have led—the North Carolina Zoological Park (NC Zoo) *Treehouse* Master Plan and the Durham Public Schools Hub Farm (DPS Hub)—demonstrate the development and use of habitats for fostering inquisitive minds of future scientists and offer insight as to how we can facilitate interdisciplinary collaborations. These sites provide interdisciplinary teams space to prototype immersive learning experiences, and platforms to conduct research on science learning and design effectiveness. We illustrate our reliance on design practise to create habitats and experiences that can build visitors' capacity as independent learners. The design cases illustrate: our process, fruitful and frustrating collaborations and partnerships, and promising practises for authentic science learning and assessment. The design cases further demonstrate that, thoughtfully led, the design process can build the collaborative team even as it builds the design.

**DESIGN CASE 1:** *Adversaries to Team—The NC Zoological Park Treehouse Master Plan*

The North Carolina Zoo (NC Zoo) is a natural habitat zoo that prioritizes the health and well-being of the animals and plants, emphasizing the environmental and educational goals of conservation of species and habitat. This means site-lines are carefully constructed so animals on exhibit seldom see visitors, and have huge spaces to roam. Therefore, visitors may find that, seen from hundreds of yards away in their expansive, natural-appearing enclosures, water buffalo and elephants resemble ants and beetles. At the natural habitat zoo, visitors do not feed, touch, or otherwise play with zoo animals. Insofar as possible, lived experience of the animals mimics their experience in the wild.

## The design question

The team from SolidZebra, led by Betsy Towns as artist and site designer and Katherine Gill as co-site designer and landscape architect, was challenged with how to create embodied biology learning experiences when visitors and animals are separated from one another. Our scope of work called for master planning an exhibit directed at children. At the surface, it appeared to the NC Zoo staff that the principled, conservationist design of exhibits in the zoo opposed the zoo educators' goals of teaching scientific and ecological mindset through close engagement with living exhibits. The research and discovery phase of the design process—involving collaboration between our team of designers and artists, and NC Zoo exhibit designers, scientists, and educators—demonstrated that embodied learning experiences exceed pedagogical outcomes for all visitors compared to content-based interpretives. First, zoo educators, and, somewhat more slowly, zoo horticulturalists, biologists, and veterinarians, came to see that designing embodied learning experiences could substantially impact the environmental, cognitive, and pedagogical outcomes for visitors of all ages, and that we could identify ways to achieve these without impacting zoo exhibit species (Allen 2004; Leong 2014). By engaging all parties equally in the design process from start to finish in periodic full-day design charrettes, we became a cohesive team. The method led to an authentically shared understanding of the value of embodied practise to prepare learners to become inquisitive, empathetic inhabitants of the natural world, and to engage with science material more substantively. "As designers engage in a process of developing an image, representing it, and then testing their ideas, they ... provide a catalyst for change, for achieving an outcome, and, most important, for facilitating a thinking process. In a thoughtful process, the designer takes into account what exists and provides an opportunity for the players to express themselves, to be effective, and to feel empowered. The designer's role is a critical part of the triangle of players who together create a place that goes beyond the narrow and timid to encompass the 'enchantments of childhood'" (Stine 1997, 7). With a team more open to the high-impact practises of embodied learning, the informal spaces of the zoo offered an ideal location to prototype and test learning results more effectively than within traditional schools (e.g., Barron and Darling-Hammond 2008; Roberts 2015). The design process allowed us to turn opponents into collaborators and discover opportunities to create learning experiences that propel the goals of all.

## Design strategy emerges

Based on the areas of agreement discovered in stakeholder workshops, the design team (Towns and Gill) made two decisions that shaped the design of the Master Plan: rather than designing animal encounters involving the zoo wildlife collection, the exhibit would create spaces apart from the zoo animal habitats for "parallel encounters" with familiar species that visitors could transfer to their observation and reflection on the zoo animal exhibits. Animal encounters in the design focused on pet species (dogs, rabbits), indigenous species abundant on the property (squirrels, ants, owls, black snakes), and species with history of domesticity (goats). The choices avoided bringing visitors into contact with exotic collections, while engaging the expertise of zoologists, conservationists, and horticulturalists in creating relevant parallel experiences; together we considered how scientific content could become 'hands-on' engagement.

## Defining the exhibit

At this point, we proposed that the NC Zoo Master Plan focus on three strategies to achieve the conservation education mission: (1) Creating play opportunities that duplicate and repeat behaviors that visitors watch animals do in their own habitats (empathy building); (2) Designing spaces for imaginative independent play (creativity and curiosity); and (3) Establishing pivot points between the visitors' inner and outer selves, giving them opportunities to reflect on physical engagements to take with them the traditional 'look but don't touch' exhibits of the rest of the zoo.

Following Discovery phase, the exhibit emerged around these strategies. A preliminary concept, *The Treehouse*, created immersions in each strategic practise. For example, to build empathy through parallel experiences, we created sequences of exhibits around climbing, home building, and food-gathering. The dramatic centerpiece is a large treehouse in the deciduous forest (Fig. 2). Each iteration of the design process brought scientists, educators, and designers together to critique and evaluate the accuracy and effectiveness of the ways that designers had put visitors into motion in relation to zoo ecology. Optimally, zoo visitors would emerge from the experience with an increased alertness to qualities of locomotion (especially adaptations that enable mammal survival in treetop habitat), with a sense of species interactions (squirrels and oak interdependence), and practise/warm-up in observing wildlife (embodying squirrel feeding, climbing, and nesting behaviors), all concepts with transferability to exhibits throughout the zoo (Fig. 3).

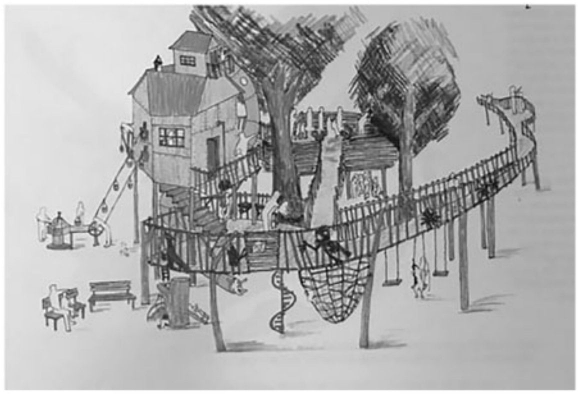

**Fig. 2** Illustration by the designers showing the main treehouse: webs, log-balance, and tunnel scramble draw young people into the canopy and challenge them to move through space in ways that engage their whole bodies in the treetops in the kinds of movements they see squirrels achieve in the adjacent trees. These climbing experiences lead visitors to nest building materials like those squirrels employ in the highest level of the trees, and to acorn gathering and stashing points throughout the entire treehouse exhibit. Feeders encourage the native squirrels to platforms in the canopy, and viewing stations give visitors practise at the kind of observation "work" they will do with the zoo exhibit animals throughout the park.

## Implications

The Master Plan relies on meaningful engagement with plant and animal species tolerant of human interactions to create openness to learning about animals and plants in the zoo exhibits. Experiences that engage biomechanics, movement, interaction, manipulation, and many senses and modes of cognition offer potential to reach many different developmental levels and learning styles and capacities. In parallel, repeating play experiences creates capacities necessary for observing and reading that take prominence at zoo-interpretive exhibits (Fig. 4). When designs like this work effectively, we see an elevation of the kinds of questions visitors take time to develop (Bell et al. 2009). At the traditional zoo with caged animals, children might ask their parents: "Why is the lemur looping the same path again and again?" as the children experiment with their own loops on trails. At the natural habitat zoo, they might wonder: "Why can't I see the lemur?" At the natural play enhanced zoo, children might consider, as they climb structures and observe animals climb: "Why do lemurs have long front legs? Why do goats have four legs that are the same? and why do we climb on two legs?" It's not unusual for visitors to try out or mimic other ways of climbing to mimic those of the animals they see (Falk et al. 2008).

## Commentary

In the NC Zoo Master Plan process, bringing the diverse perspectives of designers, scientists, and educators together made it possible to design playful, open-ended, embodied engagement that led to question-finding and problem solving, which build science-learning skills (Ellsworth 2004). Designing for open-ended and learner-driven play requires the institution and the educator to release some degree of control over specific content delivered. The designer forfeits some control in collaboration with the users: "Designing for open-ended play means taking a risk .... As a designer you do not know at the start of the project what the outcome will be. You have some assumptions, but these assumptions can turn out to be wrong" (de Valk et al. 2013, 98). Thus, the process corresponds with the experiences we shape for learners—it takes as its starting point open-ended play, examines judgments and embraces risk, experiment, and prototyping as strategies to reveal and exceed assumptions and limitations, and creates a climate for reflection, critique, and adaptation. Designing spaces for "knowledge in the making" (Ellsworth 2004) requires a process of "design in the making" and has given us routes to new ways of thinking about design, teaching, and learning. Working with designers can introduce scholars in all fields to new tools, methods, and places of learning that can increase the reach and impact of their pedagogy and research. The collaborative Master Plan design process at the NC Zoo, which involved staff Scientists, Educators, and Curators and Gill and Towns as Facilitators and Designers, led the Zoo to consider new strategies for embodied learning throughout their exhibit design.

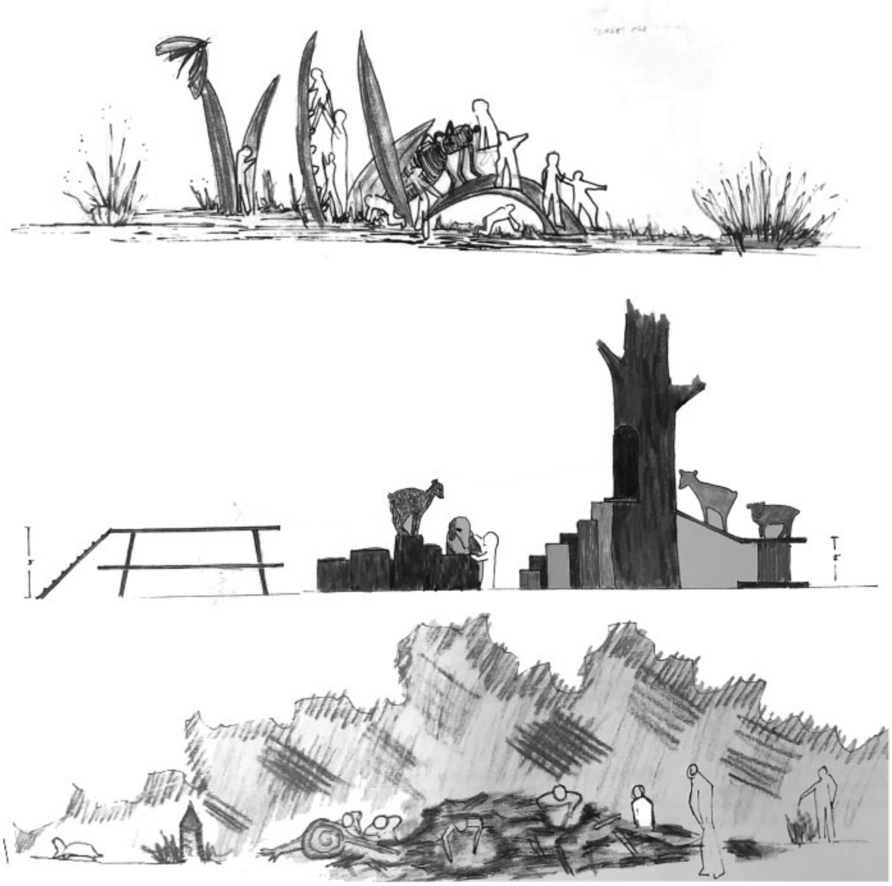

**Fig. 3** The designers' sketches show climbing-experiences throughout the exhibit that parallel behaviors of the animals located there. A goat treehouse designed with rustic materials and same saturated color points as the children's treehouse lets visitors see how kid goats and kid humans climb in similar and different ways; dog and squirrel obstacle courses build on this integrative thinking through engaging repetition; oversized blades of grass and replicas of native ants invite visitors to climb in and explore.

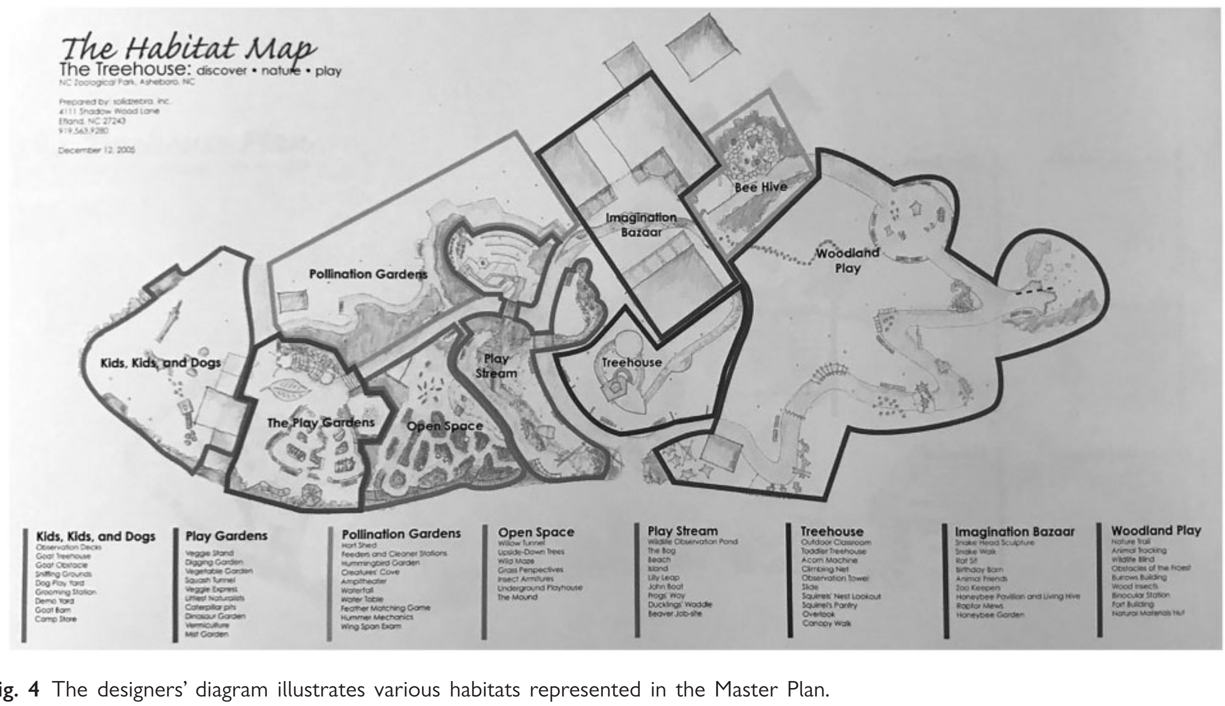


**Fig. 4** The designers' diagram illustrates various habitats represented in the Master Plan.

**DESIGN CASE 2:** *Cultivating Embodied Learning by Engaging Community Partners, Scientists, Administration, Teachers, Volunteers, and Students in adapting Fallow Lands into Environments where Students Delight in Learning Outdoors.*

The Durham Public Schools Hub farm is a 32-acre outdoor learning lab initiated in 2011 by a small group of stakeholders interested in creating opportunities for all 32,000 district students to engage in outdoor, project-based health, and science learning. As landscape architect and founding project developer, Katherine Gill helped develop creative strategies for collaborations and to facilitate a strategic plan and design for how the school system could put this fallow site to work for experiential learning. The engaged team that led the initiative included a committed member of the district's Board of Education; the district Director of Career and Technical Education, and leaders and scientists from educational non-profits in the community. A driving design question was: How might the design of the Hub Farm complement and extend science learning that happens inside school walls? (Fig. 5)

From a design perspective, the Hub Farm differs from typical landscape architecture projects where designers are hired to create a design from concept to construction, and complete the project before it is used. The Hub Farm is unique: it is an environment where design emerges as students and teachers engage in this space and where outcomes evolve based on visitors' own questions, lives, and experiences on the site. The design concept for the Hub Farm is to provide an open-ended experience for all types of learners, providing a framework and the structure for the exploration of multiple learning outcomes.

With very little money, a completely overgrown site, and limited leadership from the highest levels of the administration, it was critical to begin the design process by focusing on the strengths inherent in the site and the people who would use it. In other words, the collaborations became the project, and the activation of those partnerships became critical to the Hub Farm growing into a vibrant learning lab. At the beginning of the design process at the Hub, we identified the type of collaborations and partners in the community with expertise in providing programming and curriculum for students but that were limited in their ability to reach students within the school system. The Hub Farm site is comprised of a diversity of Piedmont forest types and unusual volcanic granite rock formations. The hydrology includes stormwater from neighboring roads, parking lots, and rooflines that flow into a perennial stream, wetlands, and two agricultural ponds. Given these site features, we were immediately able to inhabit, experience, and bring to life the natural history of NC geology, ecology, climate change, and land use history through partnerships with organizations in the area that are doing related research and seek to provide outreach assistance to the community: NC State University's Soil Sciences Department; UNC College of Education, Durham County Soil and Water Conservation, NC State Agricultural Extension Water Quality experts, and many others (Fig. 6).

The Hub Farm acts as the lab to pilot and assess embodied teaching and learning outcomes from which further programming across the district and state can develop. It is the hub from which spokes emerge, reaching across schools and organizations (Fig. 7). For example, through a collaboration with the Durham County Public Health Department, the Hub Farm implemented an innovative teaching approach which we named *Seed to Belly*. The collaboration between the Hub Farm, the schools, and the Health Department nutritionists enabled children to experience full cycles of the food system and nutrition processes firsthand (Fig. 8). Providing embodied learning opportunities for K-12 students at the hub farm is paramount. However, what happens when students step back into traditional school contexts? How can embodied science learning in this context stretch back to schools? To that end, we partnered with Jocelyn Glazier, faculty in the School of Education at the University of North Carolina, who works with K-12 teachers across multiple disciplines. Recognizing the impact of experiential learning on students, Jocelyn wondered how to better support teacher training in this pedagogy. How, for example, would science teachers teach authentically if they themselves experienced only disembodied science learning?

## Design strategy

An ongoing summer partnership with the UNC Masters in Education (MEDX) program and the Hub Farm works to support experiential teacher learning about science through implementation of the design process. The design process during these summers consists of: (1) Framing a project for teachers and students to implement that would integrate science learning in the design-build process; (2) Introducing the general steps within the design process; (3) Reminding teachers and students to expect the ambiguity of many possible solutions, and that working through this ambiguity was part of the design challenge. Engaging in the process provides the next set of questions, answers, and challenges.

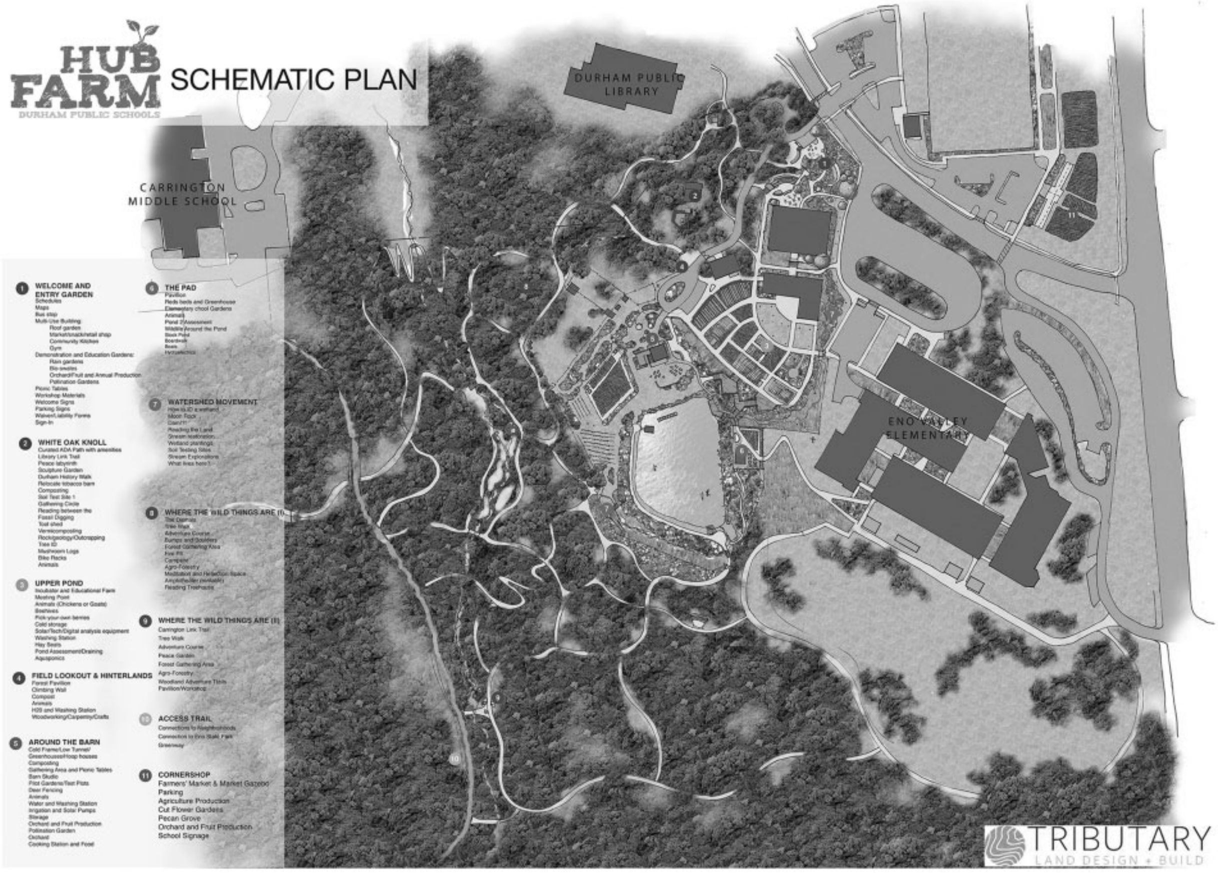


**Fig. 5** The Hub Farm Master Plan plays off the natural habitats of the site to afford various exploration and science-based learning opportunities. The Master Plan also references the types of partnerships, collaborations, and student-run citizen-science initiatives that may be incorporated into the overall program.

Teachers and students familiar with the scientific process found key correlations with the design process.

Over the last 5 years, depending on the environmental, practical, and curricular needs of the space, MEDX teachers have created curriculum kits on water quality of ponds on site; built learning spaces along a path that connects the public library next door to the Hub Farm; and built gates and bridges that protect animals, and subtly invite or dissuade students from entering the farm. Each of these examples of spaces built by teachers offers poignant snapshots of embodied learning: a teacher knee deep in water who discovers how to measure the angle needed to support an 8′ wide bridge; the teachers' sense of accomplishment and satisfaction at seeing the gate they built from downed limbs; the shared smile of teacher and student discovering not one but seven different invertebrates in the bucket of water they pulled out of the pond together (Fig. 9). These outcomes were anticipated and surprising all at once. They were framed for the teachers with enough ambiguity to enable them to engage in necessary risk taking, initiative, and play. By following the design process, the teachers could engage in rigorous, hands-on learning while changing the landscape to support the learning of the next visitors to the Hub. Too often, teachers and students alike are invited into outdoor learning spaces that are closed-ended, exhibits that tell rather than show, that are hands-off rather than hands-on, that establish set questions and answers rather than opportunities to explore. When outdoor spaces are designed to enable authentic engagement with materials and opportunities to literally and figuratively fall into learning, scientific inquiry can blossom. The boundaries of spaces like the Hub Farm stretch to meet the questions and curiosities of those who visit.

## Commentary

The Hub Farm enables open-ended opportunities for learning with varied outcomes that pivot the learner in new directions. The purposeful design concept of the farm leads to multiple experiences that lead in

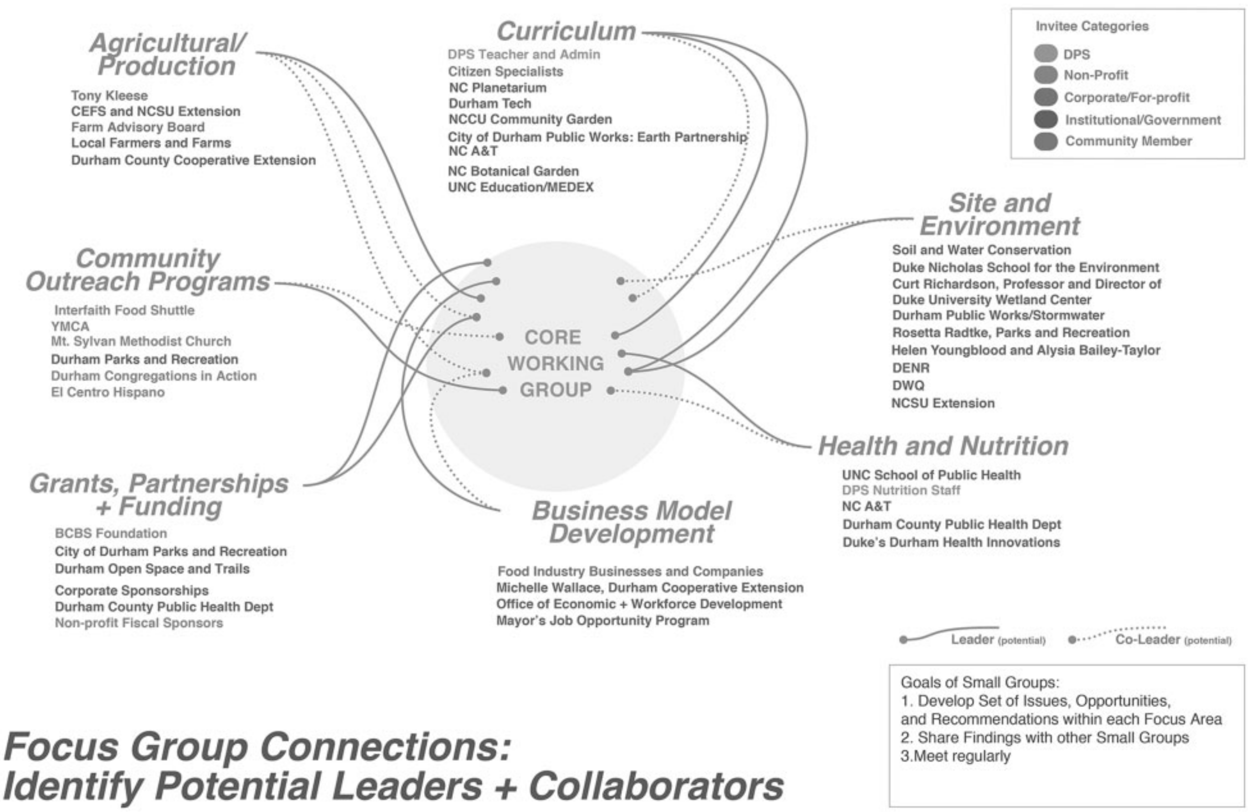


**Fig. 6** A diagram of the potential partnership relationships across key programming goals and site features.

turn to a series of next challenges. Each season brings a new and different problem that demands authentic problem solving. The farm strips away the traditional boundaries of teaching and learning behind the walls of a classroom opening up new challenges for how to integrate learning at the Hub Farm with the learning that happens in the classroom. For teachers, the farm provides the critical space for teacher growth. Teacher trainings taught by scientists and professional experts in fields of science that not only bring scientific research into the hands of teachers but also tie-in the required learning materials of the classroom become very powerful tools that would lead to better integration from the Hub Farm back to the classroom. Teachers' experience of embodied learning allows them to imagine new possibilities for their classrooms. They are in turn able to create and develop inquiry-based and embodied experiences for their students. This experience cultivates autonomy, giving both teachers and learners a sense of authority, efficacy, and the opportunity to solve problems rather than having the right answers in mind. In essence, the teachers become scientists so that they can lead their K-12 students in becoming the same.

## Discussion

As described, learning is as much physical as mental. "Embodied exploration and learning are inextricably intertwined" (Hirsch-Pasek and Golinkoff 2008). The habitats we present here reflect experiential spaces in which mind and body are invited to interact, providing important learning landscapes, particularly for science learning. As illustrated, these habitats provide opportunities for learning that is exploratory and open-ended. In order to build the desire and capacity for learning about science, we have to offer visitors experiences in well-constructed spaces like those above, that demonstrate to them pleasure, freedom, and autonomy to build their comfort in engaging in learning. Similarly, for learners of all ages to understand the relevance of the questions they consider in these spaces, they need exposure, guidance, and shared experiences with scientists, who, though they may be asking questions of a much higher level, are nonetheless, inquiring and learning in very similar ways to younger students. Scientists, who are willing to come to the table to work with designers and educators, can show us all the motivating environments that drive them into scientific inquiry.

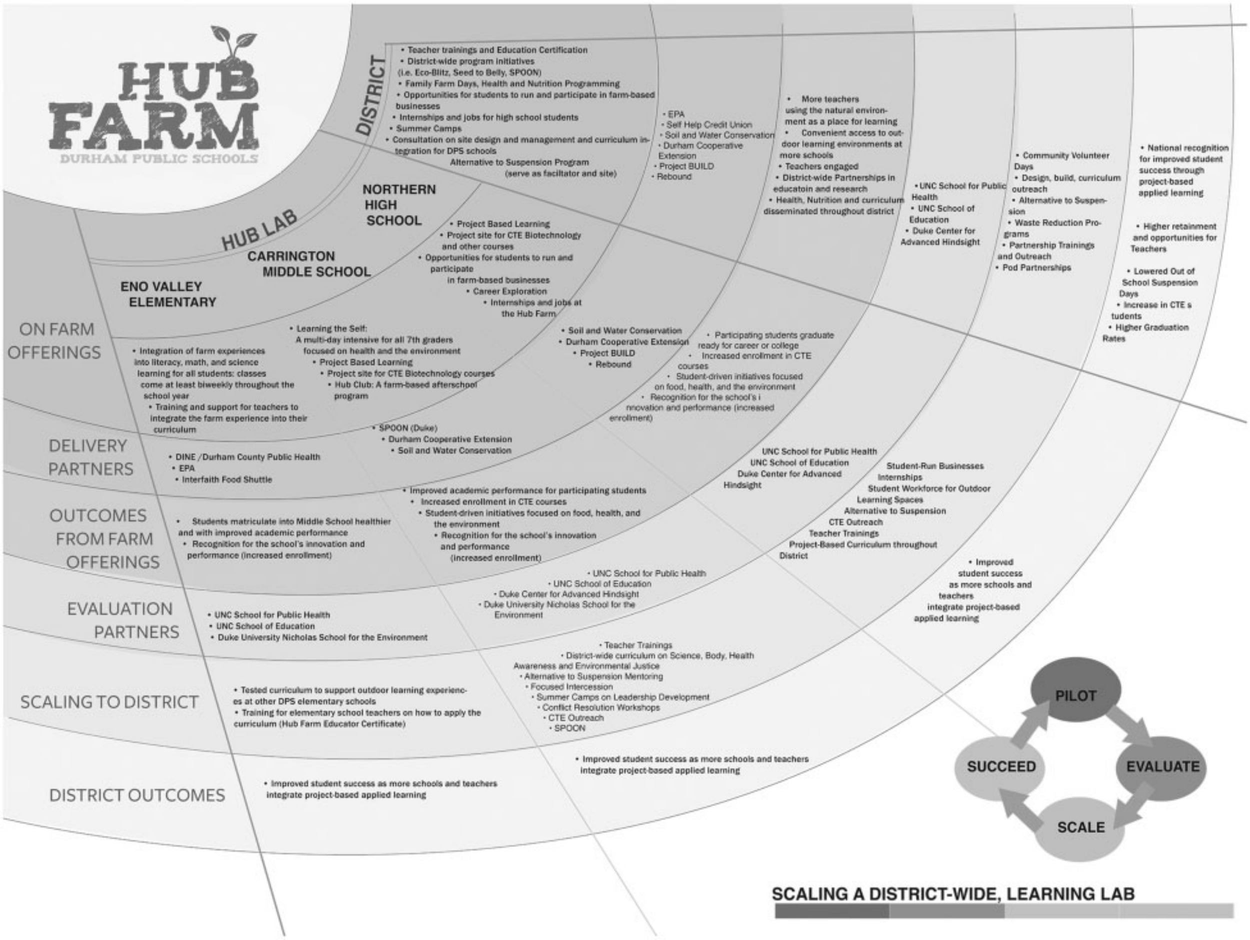


**Fig. 7** Diagram showing scalable objectives tied to institutional partnerships with higher education.

**Fig. 8** Food production becomes an embodied experience for students as they learn first-hand the role of soil, sun, water, and the ecological processes embedded in the food system while also learning to plant, harvest, prepare, and eat a fresh salad.

**Fig. 9** UNC Masters in Education teachers busy in their new environment. It is hard to tell students from teachers in this embodied learning scene!

## Conclusion and future directions

The careful design of outdoor learning environments, whether on farms, school grounds, museums, or zoos, plays a critical role in affording habits of mind that allow critical science thinking and learning to take root in students of all ages. These intentionally open-ended designs provide entry into authentic means of exploration, removing constraints of traditional school contexts. These sites also provide the learner the tools to discover interest and complexity and to locate the questions that plant the seeds for becoming scientists, artists, innovators, and educators. Effective design and partnerships play a critical role in taking this to capacity and applying it, making it useful, effective, and real. It also tasks designers to "do" design that meets educational and ecological imperatives and demonstrates models for collaboration and partnering with broad entities.

Our projects, involving design, implementation, and programming, have led us to the phase of careful assessment of the effectiveness of our work. What are indications of learning efficacy in these contexts? How do we know what science, what discoveries, visitors make in these landscapes? In these spaces, we seek to "measure" outcomes in ways that move beyond the traditional test. For example, we can observe students' engagement with materials over time. As we observe students "muck around" in one of the ponds on the Hub Farm site, we can attend to how they engage with the water, with the mud, with one another. What sort of sense making are they engaging in? How are they talking about what they observe? How do they collaborate with one another? The freedom from traditional assessments and evaluation enables visitors to take risks with the materials, to play with outcomes that may seem implausible on the surface. In these spaces, they can make discoveries that venture beyond those we ourselves can imagine. The outcomes are not necessarily pre-determined. Indeed, here's where scientific discoveries can happen.

Future assessment models may be qualitative and quantitative and can assess both process, outcome, conceptual understanding, and can drive the next set of questions to be explored. Visual mapping, behavior mapping, and conversation mapping (Beeken and Janzen 1978; Marcus 1990; Malone and Tranter 2003; Moore and Cosco 2010) can provide qualitative insight into spatial, temporal, and communication outcomes. With behavior mapping, we can gather data on how long someone spends within a particular exploration mode, in what areas, and with what diversity of spatial materials with which they are engaging. Conversation mapping can track the types of questions that are asked and gauge the complexity and relative interest in the subject, not to mention visitors' understanding of the phenomenon being examined. Such evaluations can show how well students are working together and collaborating to solve a problem. Such mapping may also reveal how well diverse groups come together across gender, race, and age, by mapping the physical patterns in learning based on where students choose to be or who they choose to be with. Then evaluations can be made about the type of thinking and learning that occurs in each space.

Interdisciplinary collaboration in the design and assessment of outdoor learning landscapes enables us to offer students of all ages rich, complex, and educative possibilities. Places of outdoor learning offer critical opportunities to build understanding at multiple levels: visitors of all ages can find new ways to engage with the natural world, leading to increased comfort and enjoyment or emerging inquisitiveness and substantive new learning; designers gain opportunities to shape spaces that will be animated by the engagement of diverse leaders and learners, resulting in a continually evolving creative learning space; educators immersed in new ways of learning in landscapes like the NC Zoo and the Hub Farm can take this same learning to their own K-12 students; research scientists experience a place to examine their own questions of science in collaboration with citizen scientists and opportunities to test their powers of communication and contribute to a more educated populace.

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## References

Allen S. 2004. Designs for learning: studying science museum exhibits that do more than entertain. Sci Educ 88:S17–33.

Alsop S. 2005. Beyond Cartesian dualism: encountering affect in the teaching and learning of science. The Netherlands, Dordrecht: Kluwer Academic.

Abrahamson D, Lundgren R. 2014. Embodiment and embodied design. In: Sawyer RK, editor. The Cambridge handbook of the learning sciences. 2nd ed. Cambridge (UK): Cambridge University Press. p. 358–76.

Bajak A. 2014. Lectures aren't just boring, they're Ineffective, too, study finds. Science (http://www.sciencemag.org/news/2014/05/lectures-arent-just-boring-theyre-ineffective-too-study-finds).

Barron B, Darling-Hammond L. 2008. Teaching for meaningful learning: a review of research on inquiry-based and cooperative learning. Powerful Learning: what we know about teaching for understanding. San Francisco (CA): Jossey-Bass.

Beeken D, Janzen H. 1978. Behavioral mapping of student activity in open-area and traditional schools. Am Educ Res J 15: 507–17.

Bell P, Lewenstein B, Shouse, A, Feder A., editors. 2009. Learning science in informal environments: people, places, and pursuits. Washington (DC): National Academies Press.

Blatt-Gross C. 2015. Review of moving ideas: multimodality and embodied learning in communities and schools. JoLLE 11:138.

de Valk L, Bekker T, Eggen B. 2013. Leaving room for improvisation: towards a design approach for open-ended play. In 12th International Conference on Interaction Design and Children, New York. p. 92–101.

Descartes R. 1980. Discourse on method and meditations on first philosophy, DA Cress, trans. Indianapolis (IN): Hackett Publishing Co.

Descartes R. 1952. Descartes' philosophical writings, selected and translated by NK Smith. London: Macmillan.

Drayton B, Falk J. 2006. Dimensions that shape teacher–scientist collaboration for teacher enhancement. Sci Educ 90:734–61.

Ellsworth E. 2004. Places of learning: media, architecture, pedagogy. New York (NY): Routledge.

Falk JH, Randol S, Dierking LD. 2008. The Informal Science Education Landscape: A Preliminary Investigation. Washington (DC): Center for Advancement of Informal Science Education.

Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP. 2014. Active learning increases student performance in science, engineering, and mathematics. Proc Natl Acad Sci U S A 111:8410–15.

Galatowitsch S. 1998. Ecological design for environmental problem solving. Landscape J 17:99–107.

Gibbs R. 2005. Embodiment and cognitive science. UK: Cambridge University Press.

Hirsh-Pasek K, Golinkoff RM. 2008. Why Play = Learning. In: Tremblay RE, Barr RG, Peters RDeV, Boivin M, editors. Encyclopedia on Early Childhood Development [online]. Montreal, Quebec: Centre of Excellence for Early Childhood Development. p. 1–7.

Ionescu T, Glava A. 2015. Embodied learning: connecting psychology, education, and the world. Studia Ubb Psychol - Paed LX: 5–17.

Kontra C, Lyons D, Fischer S, Beilock S. 2015. Physical experience enhances science learning. Psychol Sci (doi:10.1177/0956797615569355).

Leong LYC, Fischer R, McClure J. 2014. Are nature lovers more innovative? The relationship between connectedness with nature and cognitive styles. J Environ Psychol 40:57–63.

Liben L, Kastens KA, Christensen AE. 2011. Spatial foundations of science education: the illustrative case of instruction on introductory geological concepts. Cogn Instr 29:45–87.

Lindgren R, Johnson-Glenberg M. 2013. Emboldened by embodiment: six precepts for research on embodied learning and mixed reality. Educ Res 42:445.

Malone K, Tranter P. 2003. Children's environmental learning and the use, design and management of school grounds. Child Youth Environ 13 (http://www.colorado.edu/journals/cye/13_2/Malone_Tranter/ChildrensEnvLearning.htm, accessed February 12, 2013).

Marcus CC. 1990. From the pragmatic to the spiritual. In: Altman I, Christensen K, editors. Environment and behavior studies: emergence of intellectual traditions. New York: Plenum Press. p. 111–40.

Moore R, Cosco N. 2010. Using behaviour mapping to investigate healthy outdoor environments for children and families: conceptual framework, procedures and application. In: Thompson CW, Aspinall P, Bell S, editors. Innovative approaches to researching landscape and health. London: Routledge (http://www.naturalearning.org/sites/default/files/OpenSpace2_Moore_Cosco2010Full.pdf)

Munson B, Martz M, Shimek S. 2013. Scientists' and teachers' perspectives about collaboration. J Coll Sci Teach 43:30–35.

National Research Council. 2000. Inquiry and the National Science Education Standards: a guide for teaching and learning. Washington (DC): The National Academies Press.

Paechter C. 2006. Reconceptualizing the gendered body: learning and constructing masculinities and femininities in school. Gend Educ 18:121–35.

Roberts J. 2015. Experiential education in the college context: what it is, how it works, and why it matters. Abingdon: Routledge.

Russell B. 1990. The problems of philosophy. Indianapolis (IN): Hackett Pub. Co.

Schwartz DL, Martin T. 2004. Inventing to prepare for future learning: the hidden efficiency of encouraging original student production in statistics instruction. Cogn Instr 22:129–84.

Singer SR, Nielsen NR, Schweingruber HA. 2012. Discipline-based education research: understanding and improving learning in undergraduate science and engineering. Washington (DC): National Academies Press.

Stine S. 1997. Landscapes for learning: creating outdoor environments for children and youth. Indianapolis (IN): Wiley Press.

van Uum M, Verhoeff R, Peeters M. 2016. Inquiry-based science education: towards a pedagogical framework for primary school teachers. Int J Sci Educ 38:450–69.

Weisberg SM, Newcombe NS. 2017. Embodied cognition and STEM learning: overview of a topical collection in CR: pI. Cogn Res 2:38 (doi: 10.1186/s41235-017-0071-6).