# STEAM by Design

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**Abstract**
We live in a designed world. STEAM by Design presents a transdisciplinary approach to learning that challenges young minds with the task of making a better world. Learning today, like life, is dynamic, connected and engaging. STEAM (Science, Technology, Environment, Engineering, Art, and Math) teaching and learning integrates information in place-based projects accessing everyday technology of virtual field trips, digital interactives, apps, and contemporary art, science and design practices. STEAM by Design develops designing minds. Designing minds work across STEAM fields developing social, cultural, technological, environmental and economical responses to existing and future conditions. Design adds Art and the environment to the STEM equation to contribute site specific, culturally connected, contributions to creative economies. Documented case studies at the elementary, middle and high school level demonstrate the ease of delivering STEAM by Design opportunities and reveal the inherent creativity of students if encouraged. Design cultivates new knowledge, skills and values derived from becoming aware, developing understanding, and testing ideas through making. Designing place-based projects, K-16 students acquire STEAM aptitude and better understand the use of STEM fields in solving contemporary problems. Access to everyday technologies cultivate ways to create, communicate and collaborate. STEAM by Design is supported by the ELearning Designopedia, NEXT.cc, aligned with newly released NEXT Generation Science Standards, North American Association for Environmental Education Standards and Art and Design Standards. STEAM by Design positions designing as world pedagogy that connects students as citizen activists in the communities in which they live and learn.

**Key words**
design; STEAM; creativity; integrated learning; innovation; imagination

## STEAM by Design

The Steam by Design movement mixes art, design and the environment across traditional K-12 subjects (souse & Pilecki, 2013) and intertwines the way artists, designers, and scientists research and integrate complex sets of information.  At Harvard's Artscience Lab, MIT's Center for Arts, Science, and Technology (CAST), and at Ask Nature, an Internet-based biomimicry project that brings knowledge of the natural world to bear on engineering and design problems, missions turn on the successful integration of the arts and sciences.  Refreshing the arts integration efforts of the 60's, with the inclusion of both environmental concerns and design practices, today's integration impacts contemporary K-12 STEM education directly.

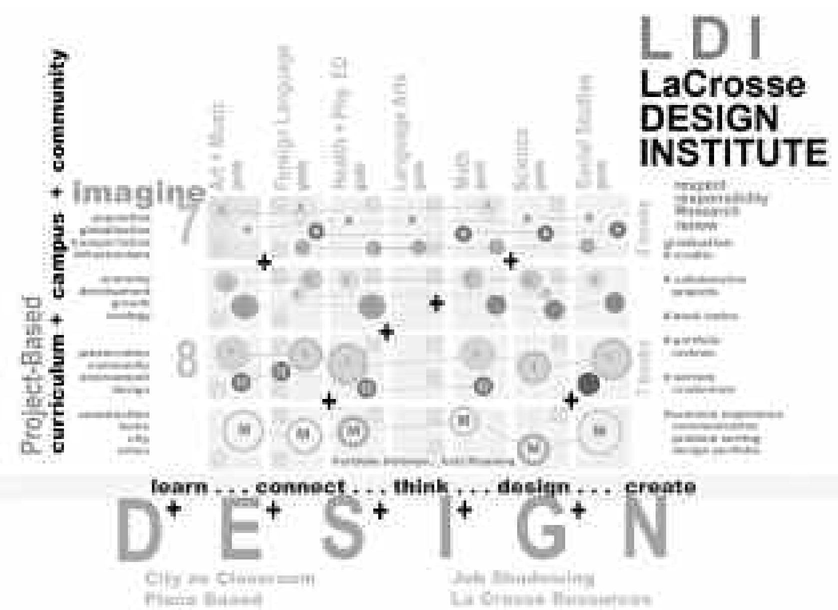


*Figure 1. STEAM by Design Based Learning Integrating Across Subjects.*

Integrating design and technology tools into science education naturally offers students dynamic learning opportunities. Everyday apps and mobile digital platforms make moving between technology, physical making, writing and reflecting fun. The transdisciplinary process utilizing existing and new tools represents real world practices (Standford, 2014). STEAM by Design mixes activities integral to envisioning the unknown with the known, utilizes new technologies, assesses data and probability, and engineers iterative solutions for testing and evaluation. Making connections with science, technology, engineering, environment, art, and math, STEAM by Design encourages student-initiated and selected projects. As a holistic approach, STEAM by Design connects learning about the natural with the constructed world, the social with the cultural, and the economical with the environmental (DeKay, 2011). STEAM teaching now aligns with North American Association for Environmental Education Standards (2006), new National Art Standards (2014) and NEXT Generation Science Standards (2014).

Design and science make use of each other's methodologies. The interplay between the design body of knowledge and the science body of knowledge magnifies results when both inform investigation and propositioning. The processes intertwine when interrelationships and connections between fields influence, disrupt, and inform life systems. While both science and design focus on the convergent study of particulars, they both are also informed by the divergent study of relationships across expanded fields. This dynamic flow opens linear thinking to unexpected innovations. Design offers an ever-evolving set of activities that challenge K-12 students to integrate what they are learning in disciplinary classes into real world transdisciplinary applications. STEAM by Design equips students with the skills to become active participants and contributors (rather than purely consumers and spectators) to discussions, debates, and designs for improving living. STEAM by Design assists schools and students in clarifying goals for the future and in developing responsive institutional and personal missions.

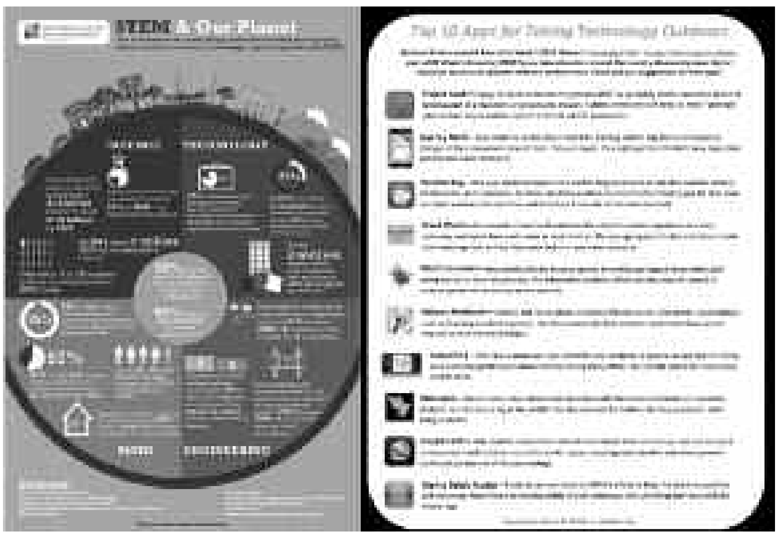

*Figure 2-3. NEEF Stem & Our Planet and Top 10 Apps for taking Learning Outdoors Posters.*

Design-based learning structures a creative, value-driven edge to STEM education aimed at connecting imaginations with a real purpose — finding purpose and fulfilling potential in improving the world. STEAM builds on the inclusion of design by adding the places of the environment, built and natural, to the acronym. STEAM by Design, as a standards-aligned and e-Learning-supported pedagogy, introduces multifaceted design-based opportunities that transform disciplinary-based instruction in separate classrooms into transdisciplinary practices. DBL shifts the primary model of learning about STEM subjects, creating a synthesis that captures students' interests and develops their abilities to contribute purposefully. If the purpose of life is indeed to find and make a life of purpose, individuals are responsible for using learning in newly relevant ways to improve their communities. Learning by design then becomes the vehicle for improving the human condition.

Researchers at Stanford's School of Education reports that design-based learning widens possibilities for learning science. Developing and delivering design-based activities can increase motivation for working and make students feel proud of their achievements. It can build confidence in students as lifelong thinkers, designers, and doers (Barron et al. 1998). It cultivates a dynamic and interactive learning environment encouraging active engagement in the construction of knowledge, in contrast to directed learning about science from textbooks and lectures (Doppelt et al. 2008). Overall, research supports encouraging evidence that such inquiry-based learning increases students' science content knowledge and engagement. Working on design challenges, students transfer knowledge into multiple tasks, learn through collaboration and doing, and develop positive attitudes towards science (Doppelt et al. 2008, Fortus et al. 2004, Fortus et al. 2005, Puntambekar & Kolodner 2005, Mamlok et al. 2001).

**STEAM and Environmental Education**

The environment, both built and natural, connects the world at large with the world of imagination. As governments globally rethink relationships between the built and natural worlds in response to climate change and a globalizing economy, educational leaders must recognize environmental education as a priority across the curriculum. With David Orr, they must understand that "All education is environmental education." As jobs increasingly rely on technology and integrated STEM skills, all students need opportunities to develop mathematical, scientific and creative capacities.

Environmental education, approached from the perspective of Buckminster Fuller's Design Science site, bridges the study of the built and natural environments with engineering practices. For Fuller, Design Science "the effective application of the principles of science to the conscious design of our total environment in order to help make the Earth's finite resources meet the needs of all of humanity without disrupting the ecological processes of the planet." (https://bfi.org/design-science/primer/environmental-design-science-primer0 This approach moves traditional engineering to a more relational field that dynamically responds to change. Design science is a problem-solving approach that entails a rigorous, systematic study of the deliberate ordering of the components in our universe (Buckminster Fuller Institute, 2015). With North American Association for Environmental Education Standards established in 2006, schools can align their teaching across several subjects with objectives that activate design thinking. For example, the NAAEE standards require learners "to design environmental investigations to answer particular questions — often their own questions." In the process, students engage in design-based processes, including the selection of modes of inquiry appropriate to their questions and appropriate systems of measurement and observation. Like engineers, they evaluate data and evidence for accuracy and relevance, and they present data in a variety of formats including charts, tables, graphs, maps, and flow charts.

All students, in every subject, need to be asking questions and interpreting information. Learning about the earth, physical and life science, are sets of Science Standards. Studying humans and their societies is cultural, ethnographic and anthropological research of the humanities. The third category of standards aligns with designers conducting site analysis and environmental research as well as the development of ethical responsibility. Standard IV, Personal and Civic Responsibility make the same contribution to character development that design does. In keeping with the notion that all education is environmental education, the National Environmental Education standards include guidelines for the study of Earth as a physical system and as a living environment. Standards addressing the study of the environment and society, including skills for analyzing environmental issues, developing citizenship, and personal and civic responsibility align with the work of designers conducting site analysis and environmental research as well as the development of ethical responsibility.

Standards guiding instruction in personal and civic responsibility make a contribution to character development that is similar to the contribution made by the design field, where individuals are required to use their knowledge and expertise in responsible ways. We want [students] to be able to pursue independent inquiry in whatever subject, in whatever discipline, whether it's in school or not. We want to get them excited about learning. Teacher (Morgan, et. al, 2007, p.ii). It is a bit like your lesson where you teach yourself by doing things.... It's a bit like teaching yourself to work individually. Student (Morgan, et, al., 2007, p. ii).

I. Questioning Analysis and Interpretation Skills
II. 2.1 The Earth As a Physical System
    2.2 The Earth As a Living Environment
    2.3 Humans and Their Societies
    2.4 Environment and Society
III. 3.1 Skills for Analyzing and Investigating Environmental Issues
    3.2 Decision-making and Citizenship Skills
IV Personal and Civic Responsibility

**STEAM and Arts and Science Integration**

Providing a philosophical foundation for learning that is life long, arts education provides students opportunities to develop unique ways of knowing and interpreting the world. New National Core Arts Education Standards promote achievement in the arts through guidelines that emphasize creating, responding, and connecting (NAEA, 2014), activities that designers do daily. The arts, like design, remain a medium for ideation, or the conceptualization, study, and exchange of ideas. The arts are a collection of skills and thought processes that transcend all areas of human thought (Sousa & Polecki, 2013, p. 17) including design and science. Elliot Eisner's (2002) classic 'Ten Lessons the Arts Teach' echo STEM competencies and design aptitudes:

- Perception of relationships (identifying patterns)
- Attention to nuance (looking closely)
- Perspective of multiple solutions and multiple answers (iterative process)
- Ability to shift goals (resiliency)
- Permission to make decisions in the absence of rules (invention)
- Use of imagination as source for content (innovation)
- Acceptance of operating within restraints (controlled variables)
- Ability to see the world from a visual perspective

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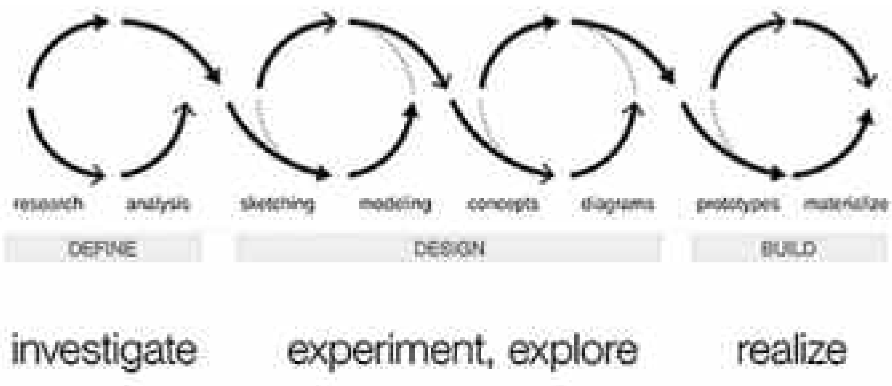


*Figure 5. The iterative design process, the evolution, conceptualization, and testing of ideas reflect engineering practices (Design Process, NEXT.cc, 2012).*



*"The value of art and design to innovation is clear: Artists and designers humanize technology, making it understandable and capable of bringing about societal change. The tools and methods of a studio-based education offer new models for creative problem solving, flexible thinking and risk-taking needed in today's complex and dynamic world." (RISD Stem to STEAM 2012).*

*Arts-based learning has emerged as an experiential and interdisciplinary approach to STEM education that is increasingly seen to offer a distinctive new set of tools to advance creativity and engagement among STEM learners (Seifter, 2014).*


***Figure 6. STEAM by Design aligns with NGSS Cross Cutting Concepts; NEXT.cc 2015.***

### STEAM and NEXT Generation Science Standards

STEAM by Design gains further momentum as new states adopt NEXT Generation Science Standards (NGSS). Completed in 2013, the NGSS include engineering design in the K-12 science curriculum, significantly shifting science instruction toward alignment with design teaching and learning. The new Engineering, Technology, and Applications of Science (ETS) standards emerge from the belief that students should not only learn how scientific knowledge is developed and acquired, but they must also learn how science is utilized, "in particular through the engineering design process." (Henning, 2015) While science investigates that which is, design explores that which could be. This alignment opens the classroom to design- based learning.

NGSS Crosscutting concepts, one of three dimensions of the NGSS, facilitate interdisciplinary connections and provide students intellectual tools that enrich opportunities for introspection, interaction, and disruptive innovation. As overarching scientific themes that emerge across all scientific disciplines, the crosscutting concepts also bring to light the knowledge, language, and skills that are shared by the arts and sciences, suggesting new opportunities for promoting innovative thinking through trans-disciplinary learning and arts/science integration. (Figure 6)

- Patterns: nature patterns to urban patterns
- Cause and effect
- Scale, proportion, and quantity
- Systems and systems models
- Energy and matter
- Structure and function
- Stability and change

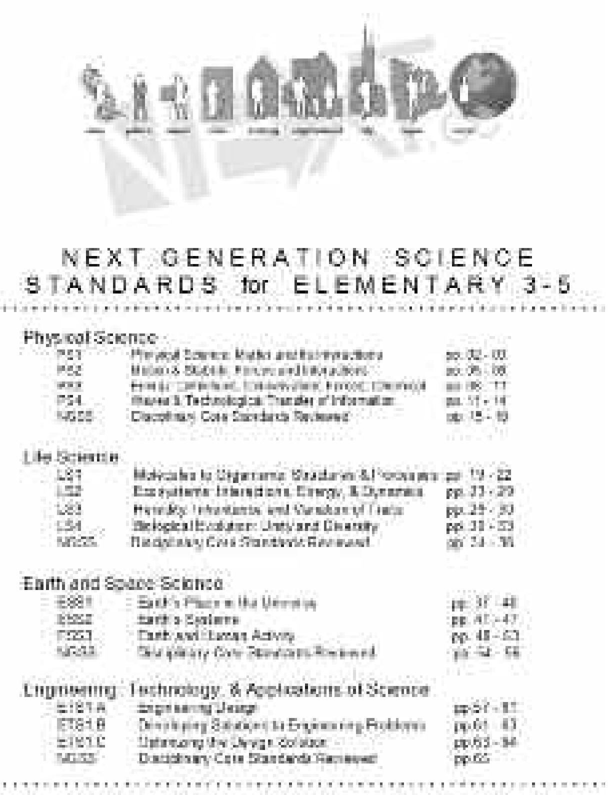


*Figure 7. NGSS standards for 3-5 (NEXT.cc 2015).*

In fact, science education has been facilitating reform for decades. Science for All Americans Benchmarks, AAAS, (1989); a site unifying principles in National Science Education Standards (1996) and NGSS 'cross-cutting concepts' in National Science Teacher's Association's Science Anchors (2010) engage design with engineering's iterative testing and discovery of how the world works. Today, NGSS Crosscutting Concepts promote the interdisciplinary and transdisciplinary development of core concepts as students look for systemic patterns, cause and effect, as well as stability and change in the dynamic ecosystem that is our world (NGSS Framework, 2012). The NGSS now combines the disciplinary core ideas in physical, life, and earth and space science with scientific and engineering practices, embedding design concepts, architecture (built environment) and environmental education in K-12 science instruction.

Education standards are changing. Concurrent ideas about humanizing the ubiquitous use of technology, response to cultural, environmental and economic change, and the creation of new spaces, systems, and environments in preparation for a better future are objectives of STEAM by Design as promoted by the e-learning Designopedia, NEXT.cc The following four examples of documented

*Figure 8. Prototypical Asphalt Playground for Letting Off Steam instead of Creative, Nature and Active Play.*

workshops- elementary, middle school and high school provide case studies researching STEAM by Design teaching and learning. Or. The following examples explore STEAM by Design teaching and learning as carried out in four workshops at the elementary, middle school, and high school levels.

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### Case Study Nature Play Project

The Challenge

- Reimagine a playground
- Empathize with and provide for multiple age users
- Brainstorm new types of play
- Engage natural light, air, water and habitat systems on school grounds
- Use technology (Sound App) to analyze and respond to site
- Introduce natural habitats in outdoor areas
- Collaborate and communicate design proposals

In this workshop, a 4th grade class from a Milwaukee Charter School was challenged to initiate studies to transform their asphalt playground into a nature play area. (Figure 8)

These dual conditions, nature, and play, started an investigation into five topics: Who played there? What types of play did the asphalt offer? What new kinds of activities would they like to have? What settings would provide best for those types of play? Could nature be introduced, and, if, so, where? Combining place-based, outdoor education with an e-learning platform, children accessed NEXT.cc's Word Mapping, Site Analysis, Design Thinking, Play, and Outdoor Play Journeys to initiate questions and brainstorm ideas. (Figure 9)

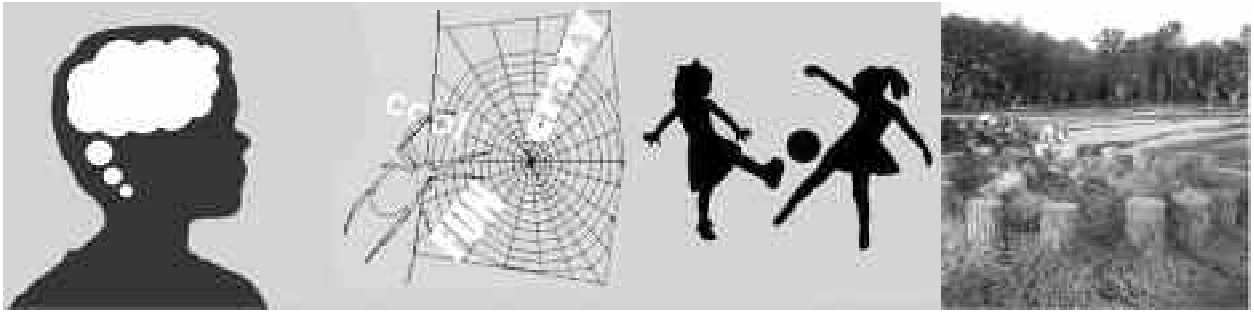

*Figure 9. E-Learning support: Design Thinking, Word Mapping, Play and Outdoor Classroom Journeys.*


*Figure 10. Students brainstorming/word lists of senses, nature, games, activity, etc.*

*Figure 11. Studying Light and Time with a Mobile App.*

Next, students were asked what kind of nature would they like to see in their playground. Beginning with grass, flowers, and trees, students quickly expanded to birds, flowers, squirrels, rabbits, butterflies and insects. (Figure 10)

Students then looked at their playground to learn the site, itself. They located where they came in and out; they placed a north arrow to understand the positioning of the playground and to determine where it was sunny and shady. They learned to tell time by the movement of the sun and the shadow cast by the clock tower. (Figure 11)

Looking at aerial views (or plans) and perspectives (people views), they analyzed their playground. They discovered that they knew where it was windy, noisy and wet. They completed analysis diagrams and then placed their ideas onto the site plan drawing (Figure 12) and into the site perspective (Figure 13). As they collaged ideas onto a photograph of their schoolyard. (Figure 14) The audible energy filled the room. They were quite excited to transform their playground.

Armed with pen and paper, the class again walked the playground to test if their analysis and placement of ideas was accurate and responsive. Students physically located the area drain and determined it to be the lowest part of the site. They also looked at two building facades facing

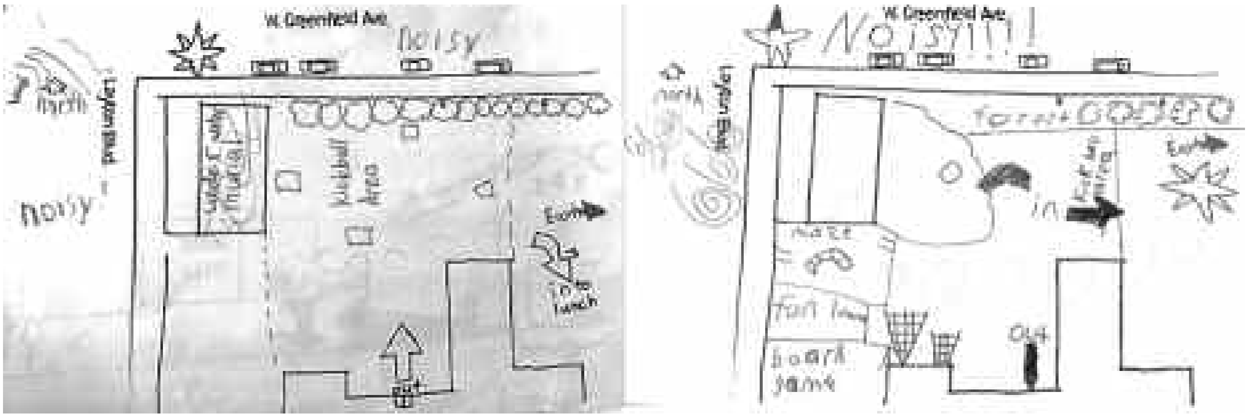


*Figure 12. Site Programming Examples.*

*Figure 13. Envisioning Transformation with Nature using Collage.*

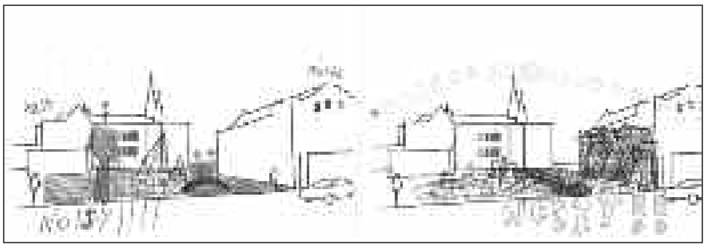

*Figure 14. Experiential Vignettes.*

*Figure 15. Testing Ideas on the Site.*

*Figure 16. Using Free Apps to Visualize Research Findings.*

the playground as opportunities for a mural and a planted area. They noted where the playground was in sun and shade and which areas were suited for different age play depending on daily recess times.

Using a sound app, students confirmed the street they thought was the busiest and the noisiest. It was indeed the road to the north, whereas the street to the west was quieter being buffered by some buildings and trees. (Figure 16) This led to their reflecting on what could be used to buffer the noise from this street. Some mentioned trees. Others suggested hills.

Coming back inside the students were eager to get to work. In three self-selected teams the students (Team Green, Team Fun, and Team Active), the students spent forty-five minutes building their dream playgrounds. They exchanged ideas rapid fire and worked collaboratively as they contributed ideas. (Figure 17) The transition from individual ideas to group synthesis moved easily in the energy of generating a real model that would visualize three dimensionally what might be possible.

The team models (Figure 18) reveal that the students took into account much that they had learned and filled their empty playground with interactive play, games, gardening areas as well as nature habitats. They buffered the noise of

*Figure 17. Collaborating in teams to build out ideas on the existing playground.*

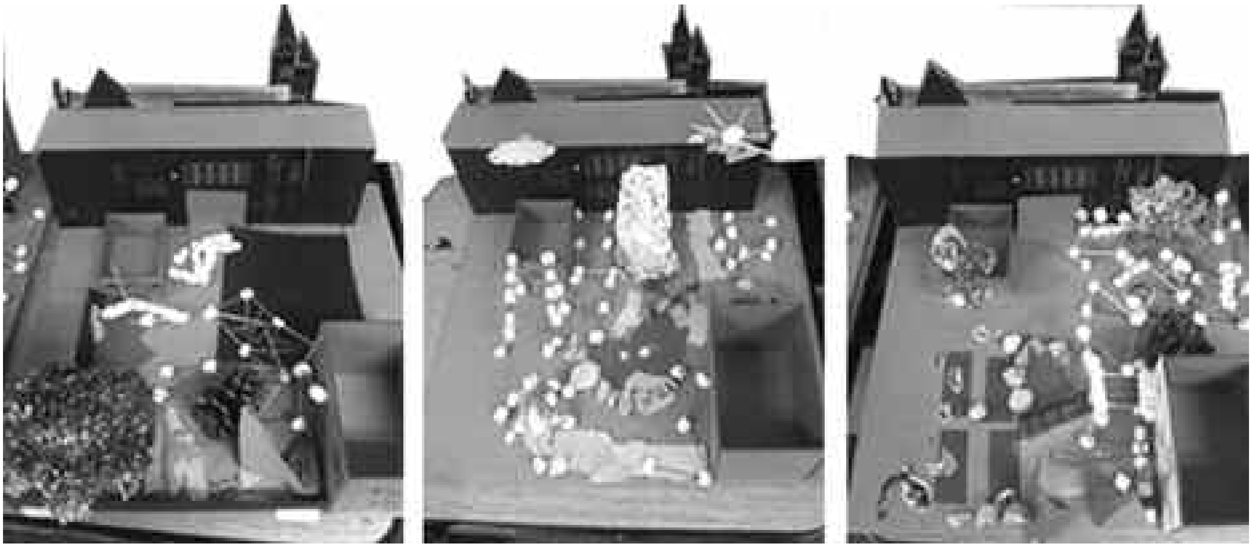

*Figure 18. Team Models of Nature Play Classrooms.*



the street, created a water habitat in the low areas, used murals to identify the school, and envisioned areas to run, jump, climb and play while allowing for quiet areas to read, play board games, and have dress up and imaginary time. The school is now considering fund-raising to improve their play areas.

The two-hour workshop exposed students to design thinking, design research, and the design process as a response to both physical realities and imagined possibilities. It provided a variety of activities to stimulate and motivate focused attention. It challenged students as they worked individually and collaboratively. The workshop offered a range of writing, drawing, mapping and modeling opportunities. Students worked with college art education and design students and with professional architects as role models. Students were introduced to both design-based processes and science and technology research techniques. The workshop introduced a natural mix of science, technology, engineering, environment, art, and math instruction for the school in a feasible and desirable project that was engaging and fun! The School is currently considering fund raising to improve the playground.

**Green School Workshop**
**The Challenge**

- Reimagine their school
- Observe, analyze and design with nature patterns
- Brainstorm renewable area demonstrations
- Engage natural light, air, water and habitat systems on school grounds
- Understand movement of sun and orientation north, south, east or west
- Introduce Outdoor Classrooms
- Design and prototype Earth Day Pavilions for school grounds
- Collaborate and communicate on Design Proposals

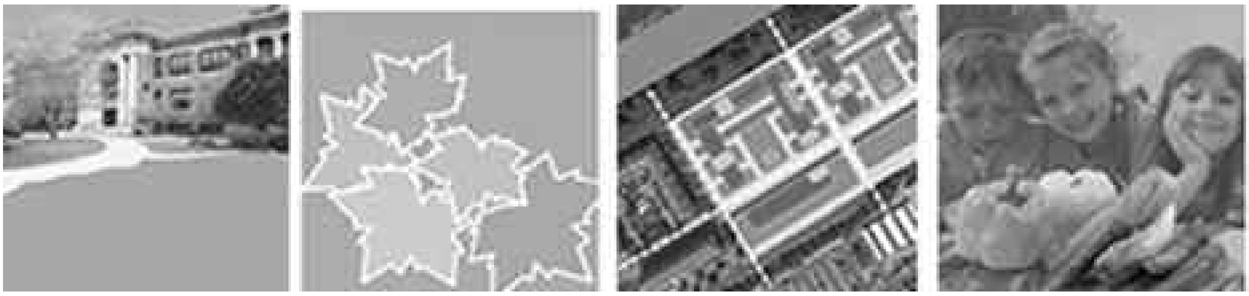

*Figure 19. E-Learning support: Green Schools, Nature Patterns, Site Programming, School Gardens, Pavilions.*

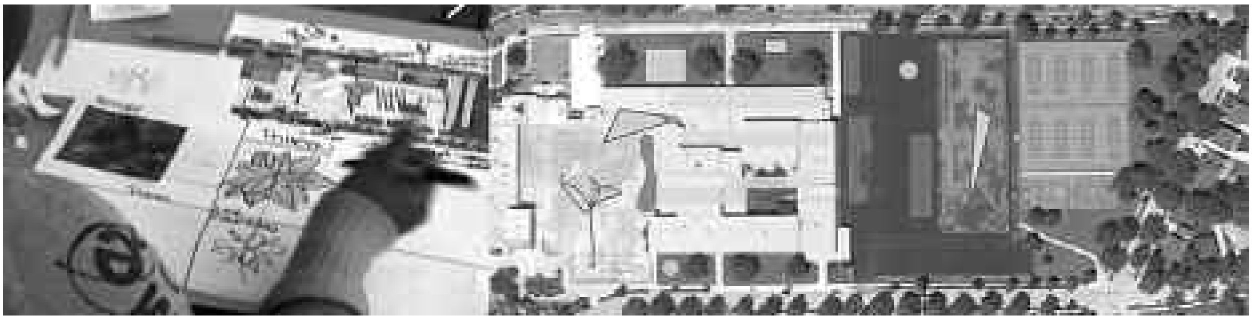

*Figure 20. Students Drawn and Digitally Create seamlessly in One Workshop.*



*Figure 21. Students learn new digital visualization programs and start teaching other students and teacher.*

*Figure 22. Students self-select materials to construct Earth Day Pavilions.*

The National Environmental Education Foundation's (NEEF) research shows that almost 100% of young children believe that the earth is worthy of caretaking (NEEF, 2010). STEAM by Design charges academic learning with environmental connections, digital fluency, and transdisciplinary activities. In this two hour Green Your School Workshop with thirty ESL students from an inner city, Milwaukee middle school, students, without art instruction, rapidly took to drawing, imagining and making. Students inhabited a letter with things important to them in their life; they chose flowers, birds, trees, friends, family, music, sports, etc. They then chose a nature picture, sketched it, analyzed its form and pattern, and diagrammed its geometry before designing an object, space, or environment. To move from recording a nature pattern to using it as a design element is an early step toward Biopilia, or 'love of all things living'.

Using diagrams of their school, students placed cut paper solar panels, wind turbines, outdoor classrooms, water gardens and urban agriculture plots based on site drainage, use, function and movement of the sun and winter winds. (Figure 19) Others chose to learn new digital skills (Google Scribble Maps) to digitally map changes to their school and began to teach other classmates how to use the free and friendly technology.

(Figure 20) Students brainstormed and prototyped diverse 'Earth Day' structures to be built on their school campuses to introduce new sustainable practices. (Figure 21,22,23) If similar art and design activities were allowed for two hours per week, students would have the opportunity to explore and communicate changes in their schools, school communities, and cities. They would be encouraged to be engaged and active citizens.

*Figure 23. Students draw nature patterns and Green their school with renewable energy sources and an Earth Day Pavilion for an outdoor classroom.*

*Figure 24. E-Learning Resources: Green Cities, Green Homes, Streets, Building Types, Skyscrapers.*

**Green Cities Workshop**
**The Challenge**

- What makes a city?
- What makes a green city?
- Role Play of Civic positions
- Coordinate systems of earth, air, water, food, and energy with built environment
- Design cities that analyze and respond to site
- Introduce ideas about healthy cities
- Collaborate and communicate on Design Proposals

In Green City Workshops, forty 6th-grade girls from Chicago Public School formed self- selected teams to build green cities. E-Learning Resources were shared online and throughout the three hour workshop. (Figure 24) Placing the compass for the north arrow, and starting with a single house, girls established their home on a landscape close to a river. The basic needs of providing for a shelter, warmth, water and food sprouted farming fields, barns for animals, solar panels and water wells. Girls experienced strategies for orienting, ventilating, hydrating, vegetating, insulating, optimizing, materializing single family homes. Finding the overlapping needs of house placement in relationship to the land, opened imagination to why things are placed where and how buildings can be more responsive to location. Connecting the homes led to the activity of roads and path building. (Figure 19)

*Figure 25. Girls locate their single family homes on the rural landscape.*

Next girls were asked to define the roles of the Mayor, Health and Well-being Counselor (water, energy, food issues), Parks and Recreation, Business and Commercial, Education, Housing and Transportation Directors as they developed Main Streets, or small towns. Girls from each of the six communities 'traveled' to Mayor meetings, Transportation Conferences, Business Development Conferences, etc. to brainstorm ideas about their responsibilities in contributing to urban design and planning. Girls, in new 'professional' groups, worked with professional female mentors from the City of Chicago, The School of the Art Institute, and the Chicago Chapter AIA to brainstorm strategies and acquire necessary building materials. (Figure 26)

*Figure 26. Girls attend civic mentoring brainstorming sessions with local professionals.*

*Figure 27. Teams present their cities, noting successes and challenges.*

With the new charge to coordinate different approaches and systems of development, girls collaborated vigorously to contribute ideas from their disciplines, choosing what to place where and how best to create a healthy city. As cities were developing, mentors delivered 'new residents' with housing needs, business requests for Class A, B and C office buildings of companies wanting to establish themselves in the city, new schools or commercial buildings. Girls began to introduce greenhouses and vertical farming locations to feed their growing populations. As the girls moved 'down the river' to establish roads, bridges, and airports, they replaced forested areas but found areas within their growing cities to replant them. Growing cities increased demands on the river as a water source; girls responded with green roofs, a variety of porous green public space and water filtrating wetlands within their cities. At the end of the third hour, the teams presented their cities, introduced first by their mayors, followed by the directors sharing their challenges and contributions.

The experience was an overpowering success. Shy girls were empowered as leaders. 6th graders became civic agents of change. Friends became collaborators working to create a successful city together. The sheer fun of exploring building at the urban scale overpowered the complexity of decisions to be made. The activity became the energy and the motivator creating a contagious and participatory learning environment. Students became powerful activists in introducing green infrastructure to their cities. They became aware of different types of buildings and the parts that the activities inside the buildings lend to city life. The underlying mission of the all of the cities was healthy living. This premise developed critical thinking in the girls as they considered what to place where and how to create adjacencies of urban needs. The students, their teachers and the mentors were all very proud of what was accomplished in the workshop. The ecopolises were display as part of the Chicago Biennial 'Outside Design' Exhibit. (Figure 27)

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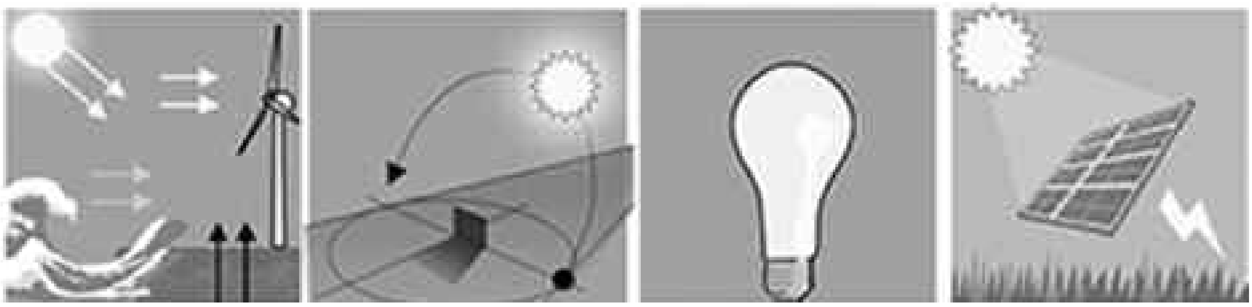

*Figure 28. E-Learning Resources for the CPL, DD, NEXT.cc HIVE Funded Energy Hack.*



Education, to affect environmental and social issues, needs to develop expertise in future generations and equip them to be active participants in deciding urban issues (Brown, Cook, & Gabel, 1978). These competencies, called, 'eco-literacy', demonstrate a personal affinity with the earth through outdoor activities (ELF, 2008). Noting a three-decade interrupt of advocacy for environmental stewardship, urbanization of the world from the 1950's self-sufficient agrarian populations to the current linear nonrenewable fossil fuel-driven metabolism of the mega-cities makes the charge for design-based learning an emergency situation. Children have inherited political and economic structures, and they have inherited an even greater responsibility to evaluate the possibility of living better on earth in the future.

In a systems approach, adding eco-literacy as a new literacy to schools brings traditional subjects in connection to the larger earth, air, and energy cycles. Previously isolated subjects in classrooms then spill out onto the schoolyard and cross over into the school community to ground children's imaginations in the climate, topography, and landscape of the places where they live and learn. STEAM by Design provides opportunities for students to interact with complex systems and critical decision-making in the environments in which they learn.

### Energy Hack CPS Students
### The Challenge

Does a STEAM by a design-based approach to teaching complex energy systems result in greater student comprehension and extended engagement with conserving energy and using renewable energy sources than traditional instructional methods?

Chicago Public Library You Media, Chicago Architecture Foundation Discover Design, and NEXT.cc ELearning Designopeida (Figure 28) teamed on a HIVE Energy Hack Grant to conduct a series of design workshops that would introduce energy and energy hacking to Chicago Public School teens. The researchers used a STEAM by Design approach to learning about energy, changes in energy practice, and best energy practices. The researchers had three specific goals:

1. Explore STEAM by Design in the study of energy through a design-based approach.
2. Examine whether the framework of STEAM by Design learning could help students think and engage deeply about the topic.
3. Investigate implementation of STEAM by Design methods in an after school workshop setting in a library teen center.

By creating a learning experience where students attempt an energy hack on a library space, researchers hypothesized that students could gain a more functional and working understanding of conventional energy systems and opportunities for mindful energy use than students learning from directed instruction. We combined aspects of research investigation, modeling, and career engagement with design-based learning to create a series of sixteen fun and intense 90-minute workshops over an eight-week period. This methodology primed with e-Learning, both with the NEXT.cc Designopedia and with Chicago Architecture Foundation's Discover Design, extended with real life modeling and ending with design and modeling of propositions at three different scales was tested over students from different schools and with multiple attention spans and learning techniques.

This research worked with eight high school students from different schools over 16 consecutive Tuesday and Thursday 90-minute workshop sessions. The researchers conducted an informal verbal survey of initial energy knowledge. Questions were asked about how the students got energy, retained energy and used energy. Students were asked where energy for their homes came from. Workshops were videotaped and observed, with the researchers maintaining research logs. Workshops began with directed presentations during which students would arrive, unpack, sit down, settle and focus. Worksheets of

*Figure 29. Energy Hack WK I Building a Solar Chart (NEXT.cc & Chicago HIVE, CPL You Media & CAF Discovery Design, 2015).*

*Figure 30. Energy Hack WK I Movement of the Sun(NEXT.cc & Chicago HIVE, CPL You Media & CAF Discovery Design, 2015).*

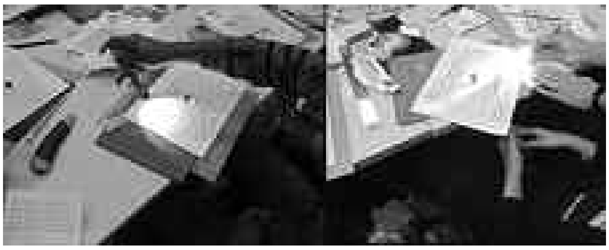

*Figure 31. Energy Hack WK I Movement of the Sun(NEXT.cc & Chicago HIVE, CPL You Media & CAF Discovery Design, 2015).*

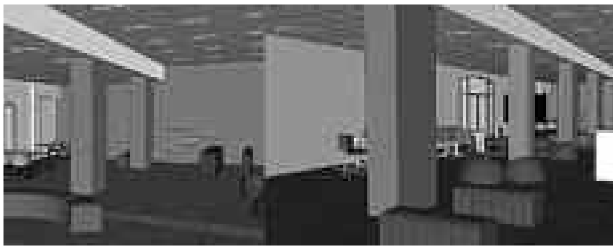

*Figure 32. Energy Hack WK I  Movement of the Sun(NEXT.cc & Chicago HIVE, CPL You Media & CAF Discovery Design, 2015) SketchUP Model of Library Space.*



different complexity were completed weekly to combine listening and note taking skills and reinforce concepts and vocabulary through repetition and documented research.

In Week 1 workshops, students studied the science of natural light, its seasonal altitude and azimuth using quickly constructed house models and a solar chart. (Figure 29) Also, students observed the color and heat of light between candles and incandescent, solar beads, fluorescent and LED lights.  They also studied absorption, refraction, reflection, and transmission with prisms, different surfaces, and materials. (Figure 30) In evaluating the library space, they concluded that it was so dark due to the absorptive colors of the floor and walls and height of the ceiling lights. They also noted that there was only general lighting and not accent or task lighting.

Students completed a SketchUp model of the library space. (Figure 32) To test unobstructed sunlight coming o the space, the students physically measured (in strides) the street width in front of the library and visually estimated the height of the building across the street to add to the model. They tested for sunlight from the morning, noon and afternoon sunlight on the library space. Some students needed more support for modeling the light. The researchers noted an initial difference in ability between students' concentration on research and their project explorations, but observed strong group-level collaboration within the group and across sub groups.

Week II students used handheld photometers to measure light levels around the space, outside, and during a lighting lab tour of a local architectural firm. They learned about lamp types, lighting strategies and color rendition of lamps from practicing lighting designers and interior architects. (Figure 33)

They completed take-home worksheets locating types of bulbs: incandescent/compact fluorescent, and LED; placement of bulbs: recessed/surface mounted/scone/desk lamp/table lamp, and hours lights were on. Students were asked to read light bulb boxes and compare bulb lumens, wattage and life span. Students did energy calculations, Watts of energy used = watts per bulb x time and compared energy savings of  different bulbs.

Week III students talked about the types of energy sources they already knew. Most students could mention coal, oil, and natural gas. Researching renewable energy sources online, they found solar, wind, nuclear and hydrological options. One student started research biking a stationary bike as an option. Students built and tested solar kits inside and wind vane technologies outside and online. (Figures 35, 36)

*Figure 33. Energy Hack WK II Visit to SOM Lighting LAB (NEXT.cc & Chicago HIVE, CPL You Media & CAF Discovery Design, 2015).*

*Figure 35. Energy Hack WK III Solar Activation(NEXT.cc & Chicago HIVE, CPL You Media & CAF Discovery Design, 2015).*

*Figure 38. Energy Hack WK IV (NEXT.cc & Chicago HIVE, CPL You Media & CAF Discovery Design, 2015).*

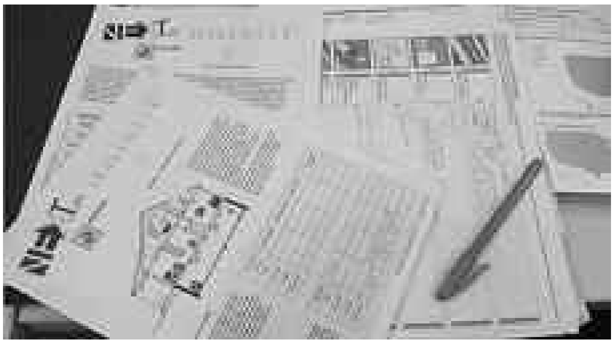

*Figure 34. Energy Hack WKIII Home Light and Energy Assessments (NEXT.cc & Chicago HIVE, CPL You Media & CAF Discovery Design, 2015).*

*Figure 36. Energy Hack WK III Energy Producing Wind Vanes(NEXT.cc & Chicago HIVE, CPL You Media & CAF Discovery Design, 2015).*

*Figure 39. Energy Hack WK IV (NEXT.cc & Chicago HIVE, CPL You Media & CAF Discovery Design, 2015).*

*Figure 40. Energy Hack Wk V (NEXT.cc & Chicago HIVE, CPL You Media & CAF Discovery Design, 2015).*

*Figure 41. Energy Hack Wk V (NEXT.cc & Chicago HIVE, CPL You Media & CAF Discovery Design, 2015).*



Students brainstormed what was needed to improve the library space in terms of personal comfort and use and took decibel readings of the noise in the space and checked the space with ultraviolet, hand held, monitors for temperature differentials and infiltration along door and window openings. (Figure 38) They were surprised to find no leakage, even on a windy day. Students were lent the photometers and ultraviolet testers to study their own homes and were surprised to find many drafty areas.

Week IV students concentrated on US energy and smart grids. None knew how many energy grids there were in the United States or what main components were needed to bring energy into their homes. Students used NEXT.cc's Smart Grid Journey to learn the parts, map the three grids and put the parts of the delivery of energy to the home in order. They collaborated on measuring the windows in the space, brainstorming energy hacks, and fabricating physical and digital prototype models. (Figures 38, 39) They then turned their attention with their new knowledge of light, light behavior, and program needs, to model ideas.

Week V students met with the Library Building Manager and the company that had recently retrofitted the lights throughout the library. (Figure 41) Students were amazed to learn that the library was not heated! The thick walls, heat from the lights, masses of books on shelves and heat from library clients, kept the building warm. Students critiqued the teen space as not being lit well and often cold. The Building Manager pointed out the addition of electrical wall units to the teen space as the recent energy saving measure was to install more energy efficient lights that gave off less heat and lasted longer. Students were able to see the energy audit company demonstrate testing that they had done with inexpensive photometers, temperature and humidity thermometers, and infrared heat differential laser recorders. They worked actively on a group model of the entire room, prototypes of energy hacks at the front windows, and completed a full scale mock up.

In the outtake survey, 75% of the students reported knowing very little about careers in energy. After meeting and working with professional architects, lighting designers, and engineers, over 50% of the students felt like they knew very well the diversity of careers in energy; the rest

*Figure 42. Energy Hack WK V Multiple scale assimilations of lighter colored surfaces, sound absorbing walls, window seats lit by solar activated light scoop. (NEXT.cc & Chicago HIVE, CPL You Media & CAF Discover Design, 2015).*

felt that their understanding was open and growing. At the beginning of the workshop, half of the students admitted to barely knowing about design research; at the end, 75% of the students felt they knew the role of design as 'half a pro' and the others as 'very well.' Before Week I's Workshop, half of the students did not know the difference in basic types of light bulbs while 75% did not know how to compare bulb types regarding energy efficiency. At the end, 100% knew the different light bulbs in the residential market and how to compare energy efficiency when buying bulbs. In the beginning, 75% of students did not know about footcandles, or lumens, or the use of a photometer to read light levels for general, task or accent lighting. By the last workshop, 75% knew how to use light meters very well and the other 25% almost 'half a pro.' In the beginning, 70% had never thought about the electrical grid. After the eLearning support and worksheet, 80% knew about electrical grids very well, including their components en route from energy production to the home. A third of the students reported that measuring of the window areas and library space was difficult. Another mentioned learning all of the new stuff was a bit troublesome because they admitted not knowing anything about energy before.' In conclusion, students reported that the extended workshops were fun. Some wrote that they would like to do it all over again. Others wrote that it was very educational. One student commented, "A great way to show the importance and option to live within our means.' The students, from different schools, formed friendships and a collaborative learning environment. One student reported, "It was a fun and caring environment.' Unlike the earlier single short session two-four hour workshops, the extended schedule of workshops allowed for deeper learning, awareness extensions, reflection and curiosity development, and testing of propositions at multiple scales. Here are six recommendations:

1. Present challenges as involving relevant fields of information. Support weekly challenges with physical materials and E-Learning research.
2. Engage in priming activities students can practice and apply outside of school to build generalization and application.
3. Moderate regular group reflection to encourage students to examine broadly ideas and issues.
4. Allow teams to study components of the challenge and present findings to build a holistic understanding of the problem and design solutions.
5. Support workshops with practicing scientists, engineers, artists and designers to validate student learning and share career possibilities.
6. Have students celebrate final presentation with reflection on the process.

Students engaged in active STEAM by Design experiences become highly motivated by the challenge and — through extensive research, group work, and discussion — become more deeply involved in complex issues and the need to test proposed solutions. The variety of physical and digital prototyping give students chances to work individually or in groups through various mediums. The weekly sessions build memory as well as knowledge. The emotional connection of building memory of experience strengthens and deepens learning. The extended time also gave workshops participants to meet with and interact with diverse professionals working in the field of energy and design. These opportunities expanded assessment to include knowledge about behavior with activism for and responsibility to implement changes in energy use for the students. These experiences deepened learning for all.

STEAM by Design integrates information about the environment, energy and energy use for rethinking energy consumption at home and for completing an energy hack in a public library teen space. This study presented students with a complex challenge, requiring student identification of and engagement with the knowledge and skills necessary to successfully solve the problem or address the challenge. Students were introduced and used the design process of discovery (observation and reflection of current conditions and knowledge, research, documentation, experimentation, data analysis, testing, evaluation and proposition at a range of scales) to improve conditions. "Priming" exercises with everyday technologies introduced energy use of people and buildings simultaneously; students accessed Energy and Buildings Like Bodies Journeys to assimilate human energy use for living with buildings' energy use for providing support for living comfortably. They took visual notes in energy journals choosing and discussing energy symbols and types of energy. They completed worksheets theoretically internalizing knowledge to a greater degree through active engagement and experimentation in learning about energy politically, socially, culturally, environmentally and technologically, rather than receiving the information through traditional lecture or presentations.

**STEAM E-Learning with a DESIGNopedia**

Support for art and design-based learning receives support from new national K-12 standards, including Next Generation Science Standards (NGSS), National Core Arts Standards, and North American Association for Environmental Education Standards. As the new standards stimulate research and curriculum development across disciplines, new learning opportunities arise in the form of an ever-increasing number of standards-aligned curriculum resources, including interactive simulations and modeling

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*Figure 43. E-Learning Tools, Languages, Discovery and Design Journeys of NEXT.cc Designopedia.*

software. Students of all ages can now access resources for formal, art and designed-based instruction across disciplines as well as for informal, self-directed learning. Outstanding examples include projects in biology, robotics, and engineering design. The Learning, Research, and Design Center at the University of Pittsburg, Phet Interactive Simulations, the University of Colorado at Boulder, and the Learn Genetics Resources at the University of Utah, are innovative resources integrating research with technology, arts, and design-based learning.

STEAM by Design supported with E-Learning emulates the entrepreneurial mindset and stimulates the individual's ability to turn ideas into action (World Economic Forum, 2009). The Enquiring Minds Report (Morgan, et. al., 2007) explains how students' ideas, interests, and experiences can inform the content, processes, and outcomes of teaching and learning in schools. The student selected approach aligns design not only as an individual practice but also as a team effort as students contribute diverse interests to work together simultaneously learning from each other in a design studio culture. STEAM by Design draws upon the active learning methodologies of design education and tests new ideas on a foundation of learned knowledge. It leads to processes that result in creativity, innovation, and continued growth and exploration of the world (Zhao, 2012).

Creativity and innovation matter in today's global economy. President Obama announced ConnectED, an initiative to create access to professional e-Learning opportunities for teachers and students. NEXT.cc's online e-Learning activities, research links, and access to everyday digital tools are valuable and needed as a ConnectED creativity and innovation resource that blurs learning, work, play, and fun with global citizenship. According to Eileen Pollack, "Last year, the President's Council of Advisers on Science and Technology issued an urgent plea for substantial reform if we are to meet the demand for one million more STEM professionals than the United States is currently on track to produce in the next decade" (New York Times, 2013). With STEM jobs on the increase and not enough students to answer the need, curriculum that expands and diversifies a STEAM -literate and STEAM ready population can be achieved through development of design opportunities for students.

The future is transdisciplinary, so interdisciplinary connections between and across discrete subjects are necessary for schools today. Other countries are shifting from teaching traditional subjects to teaching 'topics' (Dolasia, 2015). Teachers must cultivate opportunities for student-selected integration of topics for innovation. Acknowledging that information is accessible and constantly under construction, students need to have opportunities to construct knowledge pertinent to projects and be encouraged to pursue making, tinkering and testing while still in school. Standard academic foundations must now serve as 'kick-starters' for real world practices. According to Martinez and Stager (2013), "creation is the heart of creativity and is only meaningful when grounded in action - it's not a feeling, a mindset, or an outcome" (p.

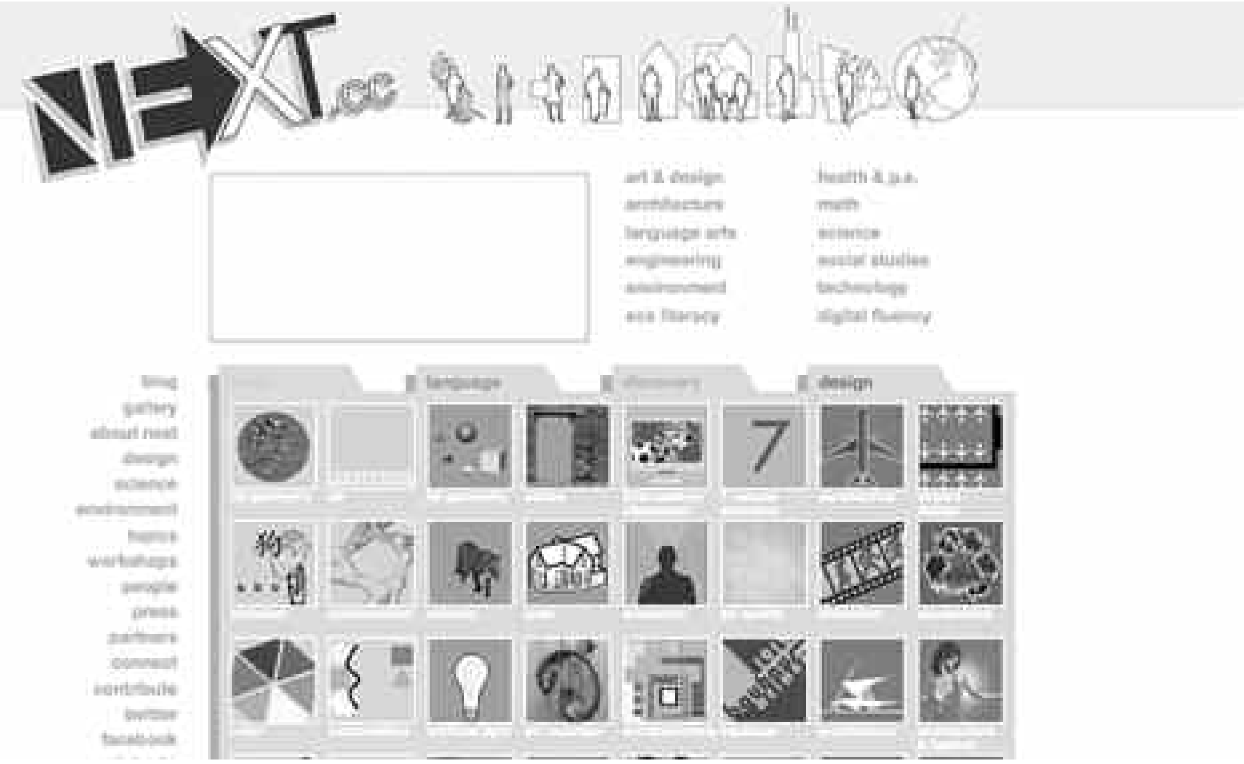


*Figure 44. NEXT.cc E-Learning Designopedia: Choose Scales, Subjects & Topics.*

80). These sentiments resonate back to Dewey's work in Experience & Education when he writes that if an experience arouses curiosity, strengthens initiative, and sets up desires and purposes that are sufficiently intense to carry a person over dead places in the future, continuity works in a very different way. Every experience is a moving force (p. 38).

In this growing network of innovative leaders in arts and design-based learning, NEXT.cc, a Designopedia that develops ethical imagination and environmental stewardship, takes its place as a leading proponent of STEAM by Design, particularly as it provides opportunities for students to develop design knowledge and skills about environmental stewardship. It links K-12 students with college students and careers in contemporary art, science, environment and design practices. It shares access to digital tools, learning videos, museum interactives and virtual field trips exploring tropics transdisciplinarily.

NEXT.cc, founded as an educational non profit in 2007, introduces online transdisciplinary activities for students and teachers to informally investigate ways of knowing about the world that are topically connected to contemporary ways of exploring the world. Design thinking, research, process, and making activities connect easily to other knowledge fields collaborating and sharing knowledge to inform solutions to situations that need improvement. Introduced to, and modified by, teachers in over one hundred professional development workshops, over 90% of teachers surveyed responded that this way of reaching learners was important. The majority of responders did not introduce design in art or science classes prior to the workshop. Workshops sparked a new and greater interest in learning in general. In every instance, students explored ideas using physical and digital tools. Workshops with elementary, middle school, and high school students instantly engaged learners, some without arts instruction, others not interested in science or mathematics, to new modes of learning not encountered before. Post workshop, students reported enjoying the opportunity to use new tools and simultaneous tools to imagine new ways of interacting with objects, media, space and environments; they also reported that they felt more connected with careers that continued the type of work they had encountered in the workshop. E-Learning supports informal STEAM interests of students, pedagogy of teachers, and transformational changes in learning. As other countries shift effective teaching from the delivery of instruction to the building of an education system and curriculum around the potential of the learner (Bolstad & Gilbert, 2012), NEXT.cc's Designopeida supports twenty-

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first century technology accessed informal learning in STEAM-related contexts for students and teachers.

NEXT.cc hits the twenty-first century learning sweet spot! (Wasserman, 2012). It is brilliant scaffolding for design-based learning. NEXT.cc delivers content in context embedded in templates and tools. It is at the right level between abstract concept and concrete instantiation. It builds both subject matter mastery and meta-cognitive skills. It reifies domain knowledge transparently as generative engagement. Seamlessly, it inculcates habits of attentive observation, heuristic discovery, and self-reflection. It speaks epistemological authority with a light, non-pedantic voice. Beyond all that, NEXT.cc is intrinsically motivating, which is the fancy term for FUN! (Wasserman, 2012).

STEAM by Design E-Learning uses everyday digital technology to connect formal learning with informal learning, blurring boundaries and investing in lifelong learning mindsets. The blurring of boundaries shifts the teaching of disciplines to the teaching of 'topics'. NEXT.cc assists school districts in connecting disciplines in design-based projects conceptually framed in topics. By linking scales of design affected by topics, students are introduced to systems thinking and relational thinking.

Students and teachers report that using online resources helps to expand design opportunities and build informed decision- making; it allows the student to process, rethink, and redesign with new information over time (Escuela Verde, 2014). STEAM by Design creates contexts for focused attention and extends concentration through initiation to the execution of ideas. Repeated as a process in response to different issues, design exercises and expands minds as skills and experience scaffold. Building focus, selecting strategies and objectives, and realizing ideas build expertise. Let STEAM by Design capture the imagination of our schools with new ways of knowing, learning and making.

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