

The Wheel Garden: Project-Based Learning for Cross Curriculum Education

Sherry S. Herron, Douglas Magomo, and Paula Gossard

Abstract—In this article, we discuss project-based learning in the context of a wheel garden as an instructional tool in science and mathematics education. A wheel garden provides multiple opportunities to teach across the curriculum, to integrate disciplines, and to promote community involvement. Grounded in the theoretical framework of constructivism, the wheel garden provides a multi-disciplined educational tool that provides a hands-on, non-traditional arena for learning. We will examine some of the cultural, art, science, and mathematics connections made with this project.

Keywords—Art education, cross-curriculum instruction, multicultural education, project-based learning, school gardens, task-based learning.

I. INTRODUCTION

WE describe a wheel garden project initiated on the campus of a comprehensive southeastern university and another at an urban high school in a neighboring city. The wheel garden, an adaptation of the Native American Medicine Wheel, is constructed of stones positioned in a circular pattern and divided into sections. The development and later maintenance of a wheel garden are both examples of project-based learning. Project-based learning has been defined as an individual or group activity that proceeds over a period of time, resulting in a product, presentation, or performance [1]. The wheel garden presents itself as an instructional tool in core subject areas, vocational programs, and technology programs. It also provides an excellent opportunity to integrate the arts into all curriculum activities. Undergraduate and graduate students in science and mathematics education continue to develop and refine curriculum materials and activities correlated to state and national standards for elementary, middle, and high school grade levels.

II. PROJECT-BASED LEARNING

Unlike *problem-based learning* where a problem is specified by the instructor and students work over a period of time to develop solutions to this problem, students exert a great deal of control in *project-based learning* [1]. The project

may or may not address a specific problem, but aims to provide understanding of various problems at every stage of its development. The project's final product is the union of these solved problems. In the project described, students come away from planning, constructing, and planting a wheel garden with not only the knowledge of various concepts required for successful results, but experience in applying their knowledge as well. As with many projects, the wheel garden also provides students the opportunity to understand the interconnectedness of art, science, and society.

Students involved in project-based learning develop intrinsic motivation [1]. When intrinsically motivated, students engage in an activity "for its own sake, for the enjoyment it provides, the learning it permits, or the feelings of accomplishment it evokes" [1], [2]. When intrinsically motivated, students tend to employ strategies that demand more effort, process information more deeply, and use more logical information-gathering and decision-making strategies than students who are extrinsically oriented. Relevant curricula and contextualized, real-world learning promotes motivation [1]. School practices that stress "learning, task mastery, and effort" rather than relative performance and competition promote motivation to learn [3]. Constructing and cultivating a wheel garden gives learning meaning, makes learning authentic and relevant, demands effort, and requires a long-term commitment, all of which are qualities that promote learning [4]. From a theoretical perspective, project-based learning is an ideal way to approach education.

III. SCHOOL GARDENS FOR PROJECT-BASED LEARNING

Internationally, school garden projects tie into the goals of UNESCO's Man and the Biosphere Programme aimed at reducing biodiversity loss, improving livelihoods, and enhancing social, economic and cultural conditions for environmental sustainability [5]. In the United States, organizations such as 4-H Clubs [6], Roots & Shoots [7] Project Wild [8] the National Gardening Association [9], The National Wildlife Federation: Schoolyard Habitats Program [10] and the National Science Teachers Association [11] all promote school garden projects. Many varieties of school gardens have been described at conferences of the National Science Teachers Association: vegetable, flower, butterfly, rain, reclamation, and rock gardens [12], [13], [14], [15], also see [16]. Garden projects are aligned with the U.S. *National Science Education Standards* [4]: 1. Teachers of science plan an inquiry-based science program for their students, 2. guide and facilitate learning, and 3. design and manage learning environments that provide students with the time, space, and

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resources needed for learning science. Results of research conducted in environment-based programs shows that these high school students developed more critical thinking skills than their peers enrolled in classroom-based environmental science courses taught in a traditional manner [17].

Numerous resources are available to guide educators interested in promoting school gardens. The popular book *How to Grow More Vegetables (and fruits, nuts, berries, grains, and other crops) than you ever thought possible on less land than you can imagine* by John Jeavons is now in its 6th edition [18]. Born out of Ecology Action in California over thirty years ago, this group continues to “rediscover the original principles behind the highly effective, resource-conserving, and sustainable 4,000-year-old Chinese biointensive way of farming. One to two millennia ago, cultures in Latin America, Europe, and other parts of Asia developed similar approaches” [18]. Bob Bergland, former U.S. Secretary of Agriculture has stated, “The Jeavons approach has done more to solve poverty and misery than anything else we’ve done” [18]. In his book, Jeavons covers everything from conversions to bed preparation to backyard ecosystems.

The National Gardening Association’s *Guide to Kids’ Gardening* was written for elementary school teachers [9]. Not only are the nuts and bolts of gardening included, but ways to incorporate art, music, and drama are described as well. The Colorado State University Denver County Cooperative Extension Master Gardener website includes a “Children and Gardens” section with links to school gardens [19]. Clearly, the implementation of garden projects in schools is not new. However, the use of a wheel garden to encompass learning goals across the curriculum is new. Indeed, a wheel garden lends itself to making more connections within the sciences and mathematics than with a traditional rectangular garden.

IV. WHEEL GARDEN STRUCTURE AND MEANINGS

The wheel garden is an adaptation of the Native American Medicine Wheel, stone structures built for various spiritual and ceremonial purposes. Medicine wheels were constructed of stones positioned in a circular pattern that often looked like a wagon wheel lying on its side. The largest one, the Big Horn Medicine Wheel in the state of Wyoming, measures 80 feet across with 28 rows of stones that radiate from a central cairn to an encircling stone rim. The 28 “spokes” may symbolize the days in a lunar month. Placed around the outside edge of the wheel are five smaller stone circles [20]. According to Ian Brace, an archaeologist with the Royal Museum, the Moose Mountain Medicine Wheel in Saskatchewan, Canada, was reported by land surveyors in 1895 and noted that the central cairn of the wheel was about 14 feet high [21].

The colors and totems that make up the circle vary with tribes across North America [22], but are summarized in Table I. The points of the two intersecting axes may represent the four cardinal directions (north, south, east, and west), the four grandfathers, the four winds, the four races (red, yellow, black, and white), the four elements (earth, water, fire, and air), four aspects of human nature (physical, mental, spiritual,

and emotional), or other relationships. The center of the wheel represents personal will - with wisdom and guidance gained within the wheel through one’s lifetime for growth, wholeness, protection, and nourishment [22].

TABLE I
 SOME REPRESENTATIVE SYMBOLS FOR NATIVE AMERICAN MEDICINE
 WHEELS IN NORTH AMERICA

Direction	North	East	West	South
Season	Winter	Spring	Summer	Fall
Color	White	Yellow	Red	Black or Purple
Symbols	Earth	Air	Fire	Water
Time	Healing Old Age	Birth Rebirth Childhood	Passion Fertility Adulthood	Emotion Youth
Animals	White Buffalo Polar Bear Snowy Owl	Eagle Mouse	Bear Turtle	Cougar Buffalo
Lessons	Wisdom Fulfillment	Leadership Service	Power Caution	Love Art Discipline

Spearheaded by the Native American student organization at the university, individuals and fifteen student organizations joined the effort to produce and cultivate a campus garden 60 feet in diameter. A photograph taken soon after construction is shown in Fig. 1. At the dedication ceremony, Native American drummers and singers performed traditional songs and prayers. Elders demonstrated how to plant and tend crops in the traditional way, without the use of chemicals and fertilizers. While maintaining its status as a cultural icon and sanctuary for Native Americans, the wheel garden is also an aesthetically pleasing gathering place for students and faculty, an outdoor site for artists and musicians, a teaching laboratory for biologists, and an outdoor learning center for science and mathematics. Thus, the wheel garden provides a place for spending time alone, engaging in spiritual activities, and for teaching and learning.



Fig. 1 Photograph of the university wheel garden in its early development

The wheel garden is circular in shape, divided along cardinal directions into quadrants which are further subdivided into five sections each. Colored poles are stationed due north, south, east, and west, and represent the four

directions and seasons, as well as all the people of the earth. The directions are also associated with the cycle of life and pay homage to specific gifts. Yellow, the color of East, represents the morning star, birth and childhood, knowledge, hope, and trust. Black or purple, the colors of South, represents summer, youth, compassion and generosity. Red, the color of West, represents thunderstorms and life-giving rain, adulthood, awareness, respect, and humility. White, the color of North, represents winter, our elders, and wisdom. While the garden represents the traditions of Native American culture, it gives students from all walks of life the opportunity to come together for a common cause and a place for meditation and self-reflection.

The university community was invited to adopt one or more sections of the garden. With support from across the university, student organizations and individuals planted appropriate species, placed symbolic sculptures, mosaics, and other artifacts in their sections. Three years after initial construction, the garden continues to be a dynamic place as shown in Fig. 2. Some of the plants currently growing in the garden are listed in Table II.

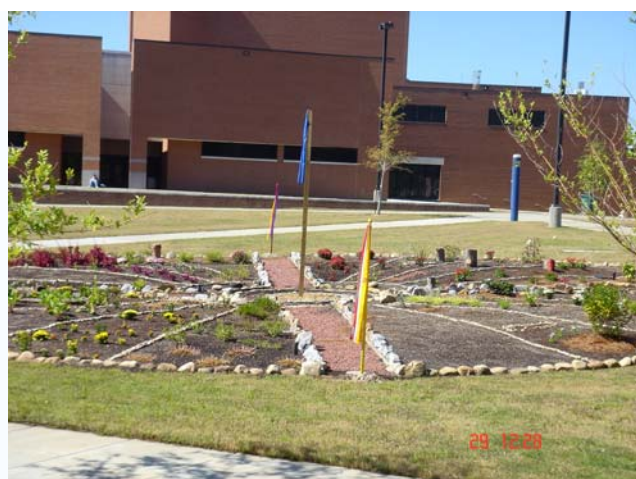


Fig. 2 Recent photograph of university wheel garden

TABLE II
 SOME OF THE PLANTS IN THE UNIVERSITY WHEEL GARDEN

East Quadrant	Shiny Coneflower (<i>Rudbeckia nitida</i>) Yellow Purslane (<i>Portulaca oleracea</i>) Moonbeam Cosmos (<i>Cosmos verticillatus</i> "Moonbeam") Shiny Coneflower (<i>Rudbeckia nitida</i>) Gloriosa Daisy (<i>Rudbeckia hirta</i> "Cherokee Sunset")
South Quadrant	Coleus Purple Sweet Potato Vine (<i>Ipomoea batatas</i> "Blackie") Purple Coneflower (<i>Echinacea purpurea</i>) Purple Heart (<i>Tradescantia pallida</i>)
West Quadrant	Coral Honeysuckle (<i>Lonicera sempervirens</i>) Bee Balm (<i>Monarda didyma</i>) Red Purslane (<i>Portulaca oleracea</i>) Bat-face Flower (<i>Cliphlea ilavea</i>) Cardinal Flower (<i>Lobelia cardinalis</i>) Navajo Sage, Red Pepper, Barbery, Clematis, & Cleome
North Quadrant	White Purslane (<i>Portulaca oleracea</i>) White Sage, Verbena, Peppermint White Coneflower (<i>Echinacea purpurea</i>) Cat's Whiskers (<i>Orthocentron stamineus</i>) Aztec grass (<i>Ophiopogon japonicus</i>) Garden Phlox (<i>Phlox paniculata</i> "David")

Promoted by university faculty members, an urban high school in a neighboring city undertook a similar, but unique, project. The school's principal and teachers were seeking ways to improve student achievement and morale after a failed bond issue and reports of below average achievement scores. The opportunity to simultaneously promote learning, school spirit, and motivation convinced the faculty to engage in a school-wide garden project. The opportunity to incorporate native materials (for which the area is noted) and to plant regional flora (after the devastating effects of a hurricane) has produced a garden that is a source of pride for the school and community. Teachers of history, art, special education, horticulture, algebra, physics, and biology are continuing to develop and implement lesson plans incorporating the wheel garden.

V. THE WHEEL GARDEN, ART, AND COGNITION

The wheel garden provides the opportunity for students to create an aesthetically pleasing site on their school campus. The garden can be used as a gathering site not only to study Native American art, music, and dance but any other art, music, and dance forms as well. Art can be incorporated into the planning stages in preparation for construction, and continued as seasons change or subdivisions created within the garden. Art and photography teachers can use the wheel garden as the site for student work. The garden provides a natural opportunity to teach the color wheel, an important concept in introductory art classes. Students can be involved in planting sections of the wheel in the appropriate primary and secondary colors. Sculptures and mosaics can be created for placement in the garden. Stone inscriptions such as those found in Nepal may be incorporated. The garden can include school icons to promote school spirit or icons associated with the community or region. The garden itself can be utilized as the site for nature journaling, with students keeping a sketchbook of changes in the garden through the seasons. Since half of it forms an outdoor amphitheater, a wheel garden provides a site for concerts, group singing, or small dramatic presentations. Students can sit on the grass or on mats around the garden with the director or performer in the center.

Positive benefits are realized by the integration of the arts across the curriculum. In his book *Arts with the Brain in Mind*, Jensen, [23], documents neurobiological research that supports the unique effects of musical arts, visual arts, and kinesthetic arts (dance and theater, but also auto mechanics and chess) on neural systems including visual-spatial, analytical, mathematical, logical, perceptual-motor and creative thinking. The impact of the arts on the affective domain is well documented [24]. The arts "reach students who are not otherwise being reached...in ways that they are not otherwise being reached" [25]. Research shows that the arts promote feelings of competence and engagement in students, leading to increased motivation to achieve in school as evidenced, in one study, by increased attendance and fewer discipline referrals, particularly among economically disadvantaged children [26]. High school students in Great Britain reported increased enjoyment, relief of tension, and enriched expressive skills, self-confidence, and personal

development as a result of their participation in at least one art form [27]. Studies show that multiple-arts exposure fosters positive risk-taking, empathy for others, task persistence, and ownership of learning in students [28].

According to Sylwester, "one marvelous aspect of the arts is that they cognitively stimulate both those who do them and those who observe others do them" [29, p. 34]. A constructivist view of cognition tells us that learners construct their own knowledge as they encounter new experiences and attempt to assimilate them into a pre-existing cognitive framework [30]. The learner's mental structures or schemata may have to change, however, in order to accommodate new stimuli. According to constructivist learning theory, this cycle of assimilation and accommodation is the underlying process by which we learn [30]. Cognition, according to Howard Gardner's [31] research on multiple intelligences, is not limited to one schema that results in a single way of knowing, but occurs via varied pathways for different people when triggered by different types of stimuli resulting in dissimilar, yet equally acceptable, understandings.

Art educators and researchers believe that the nature of cognition in art is more qualitative, relational, connotative, and affective than in other disciplines because of the visual, perceptual, and representational nature of art production [32]. As a result, creating art of various forms provides a broadened range of schemata against which to compare new experiences, enhancing cognition as viewed from a constructivist perspective. Art by its very nature is open to interpretation or conjecture; therefore, it implicitly asks questions regarding interpretation of meaning or evaluation of significance. These questions involve students in active construction of knowledge and meaning [32], which is critical thinking, a form of cognition valued by educators [33], [34].

Arts education is about more than just art production, however; it appears that art programs that emphasize non-studio work by considering aesthetics, art history, or art criticism achieve results that may transfer to other academic disciplines [32]. Any discussion of aesthetics or art criticism requires consideration of "contested concepts," [32 p. 193] which calls upon students to examine their thinking about what constitutes value or worth. This evaluative or analytical thinking is recognized by educators as "higher-order" thinking [35].

These thinking skills—deductive and inductive reasoning, problem solving, investigation, analysis, and synthesis—sound surprisingly like the scientific processes that are valued in science education [36], [37], [38]. Root-Bernstein [39] observed that several recent studies of successful scientists and engineers showed that active participation and demonstrated ability in one or more of the arts was more predictive of success in science than standard measures such as IQ, the Scholastic Aptitude Test, or academic degrees.

Much of the research that has been conducted on learning in and through the arts over the past twenty years is summarized in *Critical Links* [34] and in a special issue of *The Journal of Aesthetic Education* called "The Arts and Academic Achievement: What the Evidence Shows", which conducted ten meta-analyses of 188 studies. The evidence shows that teaching and learning in and through the arts

should be commended, because such engagement is related to positive changes in student attitude, motivation, cognitive skills and academic achievement, particularly in the areas of reading, writing, and math. These changes affect students of all races and levels of socioeconomic status. Catterall [33a, b], however, notes that high levels of participation in the arts make a more significant difference to students from low-income backgrounds than those from high-income backgrounds. Yet the frequency and continuity of arts education varies by school type, with students in urban schools receiving less instruction in the arts in first and third grades (the only data available) than their suburban or rural counterparts [41]. Seemingly, the students who might benefit the most from the arts have the least access to them, possibly due to budgetary constraints.

VI. METHODS

As will become evident in this discussion, a wheel garden lends itself to making more connections within the sciences and mathematics than with a traditional rectangular garden. Most concepts within the earth, space, physical, and life sciences can be tied to the wheel garden. As discussed in *How People Learn: Brain, Mind, Experience, and School* [30], learning is enhanced when explicit connections can be made with prior knowledge. The science concepts learned in connection with the wheel garden provide scaffolding for additional concepts. Authentic learning has also been shown to enhance learning [30]. Active student involvement in every stage of the wheel garden project puts real-world learning on the campus. Educators are encouraged to provide opportunities for students to receive feedback and guidance, to self-reflect, and to learn within a community environment [30]. Each of these opportunities is continuously met as students design, build, cultivate, replant, remodel, and subdivide a wheel garden.

Labeled as indispensable by the U.S. *National Science Education Standards* [4], authentic student investigations and inquiry-based instruction allow students to learn effectively. In the U.S., the 2001 *No Child Left Behind Act*, in part, attempts to mandate effective science education:

Academic Standards, Academic Assessments, And Accountability - The State shall have such academic standards for all public elementary school and secondary school children, including children served under this part, in subjects determined by the State, but including at least mathematics, reading or language arts, and (beginning in the 2005-2006 school year) science, which shall include the same knowledge, skills, and levels of achievement expected of all children [42].

Graduate students in science education developed lessons over the course of one year to assist teachers in using a wheel garden to teach science concepts. Of the nine graduate students participating in the project, two were science teachers of 12 and 13 year old students, one taught college-level

biology, three taught high school mathematics, two taught college-level mathematics, and one taught high school physics and chemistry. Three of the teachers were in a masters (M.S.) degree program and six were in a doctoral (Ph.D.) program. Years of teaching experience in the group ranged from four and twelve. Each graduate student developed a series of lessons based on a related theme or concept in his or her discipline. For example, one series of lessons that focused on honeybees was developed for life science at the middle grades. Another series focused on circular geometry for high school. Each student presented a PowerPoint presentation of the lesson series along with the student materials to the entire group. Others in the class participated as if they were students and then critiqued the lesson. Finally, revisions were made in response to their feedback. The lessons are available online at [43].

VII. THE WHEEL GARDEN AND SCIENCE

As quickly realized by the group, unlimited investigations can be derived from the wheel garden. In earth science, concepts such as the solar system, the seasons, and geology can be studied in a way not possible from textbooks or videos. From a fixed position in the wheel garden, students can record the location of the sun and moon at set times each day, week, or month. For independent or additional research, students can access the garden for astronomical viewings at night. Lunar phases, solar and lunar eclipses, and sunspots can be studied. Seasons of the year can become real as students collect air and soil temperature, precipitation levels, and record cloud cover at set times in the wheel garden. Class data can be compiled; school data can be compiled. If following GLOBE™ protocols, the data can be shared with the entire world. An outreach of NASA and NOAA, GLOBE™ is an interdisciplinary program aligned with the National Science Education Standards and consistent with the U.S. Department of Education's priorities for international education [44]. GLOBE™ lesson plans provide structure and protocols provide the validity necessary for accurate data collection. Data is submitted to the GLOBE™ Student Data Server via the Internet and becomes part of the Student Data Archive to be accessed and utilized by scientists, civilians, and students around the world.

If rocks are used to construct the wheel garden, the study of geology moves from the realm of tiny rocks in little boxes to the study of real rocks in the real world. An attempt to incorporate the three major types of rock (igneous, metamorphic, and sedimentary) and families within the major types can be made. Igneous rocks such as the granites, basalts, and pumice; metamorphic rocks such as marble, schist, and gneiss, and slate; and sedimentary rocks such as sandstones, shales, and limestones may be represented in different sections or interspersed in the wheel garden. Minerals such as quartz, feldspar, mica, and amphibole will add beauty and interest. Rock features such as wind and water erosion patterns, banding patterns, foliation, and fossil impressions can be identified. Hardness tests for rock identification can become a fun activity!

The physics of energy, mass, force (push, pull, speed, acceleration, centripetal force, centrifugal force, gravity, weight, friction), and mechanics can be addressed in preparation for moving the rocks into place. Actual measurements can be made as the rocks arrive and are moved providing a way to collect data in metric units or English units. Students can learn how to convert from one system to the other. Studying the physics involved in building Stonehenge, the Egyptian pyramids, and statues on Easter Island prior to the industrial age will tie in history. Temperature, pressure, and heat, as it relates to the sun can be studied.

The results of rock erosion can be studied in terms of soil. Actual soil composition (and resulting soil properties) can be analyzed and compared to ideal soils for specific plants. The study of soils lends itself to the study of chemistry. As any gardener knows, plants are adapted to living in soils of a certain pH. Soil contains a multitude of living organisms and decaying material including bacteria, fungi, worms, snails and slugs, insects and their larvae, spiders, and salamanders – an absolute wealth of material for the study of biology.

The physics of sound can be explored as students construct their own drums, flutes, and idiophones (such as palm pipes, stamping tubes, stamping sticks, gourds, singing bowls, triangles, rattles, bells, gongs, marimbas, maracas, xylophones) in science or art classes to be played around the wheel garden. The study of cultures from which each instrument originated can simultaneously be studied in social studies, as can the not-so-ancient practice of listening to the ground to obtain information. Many resources are available to assist teachers in providing the materials for such construction, including coffee cans, rubber bands, electrical tape, PVC pipe, straws, film canisters, balloons, and bamboo. Technology can be infused with the incorporation of microphones, graphing calculators, and computers such as those available from Texas Instrument's Calculator-Based Laboratory™ System (CBL™), Vernier LabPro®, or PASCO's Xplorer GLX™. Concepts such as waves, vibrations, frequencies, fundamental pitches, harmonics, volume, noise, sonar, ultrasound, acoustics, thunder, and the Doppler Effect can be learned in a real way. Students in band and chorus can be encouraged to demonstrate the sounds and explain the physics of their instruments and voices.

Thus, the biology of hearing and speaking is related to the physics of sound, and the biology of sight is related to waves. The comparative biology of hearing and voice ranges for various animals (such as bats, cats, dogs, dolphins, humans, and birds) is related. Ecological ramifications of sound (such as train horns sounding like the calls of male moose, thus resulting in many dead female moose) can be infused for practical applications. Of course, mathematics provides the tool to classify and analyze all of it and must be integrated into every aspect of science.

Practically every aspect of biology relates to a garden project. A garden can be thematic and include only medicinal plants, indigenous plants, or crop plants, thus making natural connections to history and economics. Students can assess the availability and amount of water, the amount of direct and indirect sunlight, the type of soil or ground cover available,

and the season of the year in order to make decisions about plant selections. Studies of plant adaptations and symbiotic relationships, the life cycles of plants and animals, the structure and functions of plants, and plant products can be tied directly to the student's own efforts. Photosynthesis, respiration, protein synthesis and other metabolic pathways can be tied directly to the plants in their garden. Assays of carbohydrates, lipids, and proteins, and extraction of DNA from fruits, seeds, grains, and vegetables that students actually grow makes laboratory work directly relevant to the students. Mendel's genetics studies can be replicated or adapted. Gardeners or farmers in the surrounding communities may be happy to supply plants for hybrid studies.

VIII. THE WHEEL GARDEN AND MATHEMATICS

During the planning stage, students design the wheel using theoretical understanding of the geometric circle. They draw the wheel as a circle and divide the wheel into segments of equal sizes. In the process, students learn about angle at center of a circle and how to subdivide this angle equally to form segments. The circular shape of the wheel provides a practical understanding of concepts of diameter and radius. Students learn about the relationships between diameter and radius, radius and circumference, radius and area, and others. Knowledge of direct and indirect variation is also exploited as students begin to learn that increasing radius means increasing circumference and area. Pathways of equal width are considered in the plans.

While students construct a wheel garden, they are engaged in the mathematical application of angles, arcs, and segments. The extent to which this knowledge is pursued depends on grade level and prior knowledge. Apart from the standard knowledge of area of a circle and circumference, students learn about angles: some are measured from the center; others are angles subtended by some chord of a circle; some chords are special; and some angles are special. Using compasses and protractors to take actual field measurements, students learn the following theorems: an angle subtended by the diameter equals ninety degrees; angles subtended by the same chord are equal; and an angle at the center of the circle is twice that at the circumference.

The concept of a circle is a challenging one. From a line segment to a simple figure, a circle is eventually managed as if one were to inscribe a polygon, each time increasing the number of sides of the polygon. Teachers can use this opportunity to promote understanding of the 'limit' concept, during which the properties of many geometric figures - from a triangle to an n-sided polygon - can be studied. Theorems including 1) interior angles of a triangle add up to 180° , 2) cyclic quadrilaterals, and 3) sum of angles of a regular polygon are discussed after site measurements at the garden are carried into classrooms for discussion and analytical proofs are made to complete their mathematical theory and boost their belief system. Therefore, students have the opportunity to learn mathematics from the concrete to the abstract. Then, students are introduced to concepts of concentric circles, sectors of various sizes and area of sectors.

The material acquisition stage is one that provides the bulk of mathematics curriculum in practice. Assuming materials are to be purchased for construction of the garden, a whole range of operations with numbers will take center stage. Rocks, stones, cement, manure, plants, garden tools, and planks of various sizes are some of the items that may be required to build the garden. They would need to determine those resources that require money and those that can be acquired from nature. A budget should be set aside to buy the necessary items for the construction. At this stage, almost all the U.S. National Mathematics Standards [45] can be met during the exercise. In working with money, students learn about ratios and proportions, accounting, and programming fractions and percentages. Students learn to economize, deal with concepts of discount and sale, and draw tables of various scenarios that allow them operate within a set budget. Students construct graphs to represent some of the linear relationships between purchased goods and costs in order to optimize the garden project budget.

During construction, students put theory into practice. The circumference of the garden may be constructed out of stones of various weights and sizes. The number of stones depends on the size of the circle of construction. Students learn about weight, mass, and volume, and apply this knowledge as they construct the wheel garden. The size of the wheel garden depends on available space. The area to be enclosed is a function of the radius. Students can calculate pi based on their own measurements taken from different parts of the wheel garden. Rope, yarn, string, or measuring tape can be used for radius and diameter, and a trundle wheel provides a fun and accurate method of measuring circumference. Most of the theorems discussed during the planning stages are now verifiable through empirical measurements.

A design of plant distribution on paper helps students determine what kinds of plants, the proper spacing to leave between plants, and how many plants to incorporate into the wheel garden. Again, an analysis of plants that can be acquired from nature, from donations, and by purchase provides the opportunity for covering multiple objectives.

The basic study of time can be presented with a wheel garden, and calendars from different cultures can be studied. Activities developed by Bazin and Tamez and the Exploratorium Teacher Institute [46], allow students to explore the two different calendars used by the Mayans. With an understanding of prime numbers, and using a compass and protractor to make circles of different diameters, students construct gears and determine when the two calendars coincide. In addition, this activity allows to students to gain a better understanding of physics in relation to mechanical advantage and the operation of watches.

IX. CONCLUSION

We present the argument that a wheel garden used as a school-based project can simultaneously motivate and educate students across multiple disciplines. With only 54 Native American students enrolled in the university during fall semester 2006 (comprising only 0.37% of the total student population), the wheel garden has been embraced by the entire

student body. While curriculum connections to the humanities are most obvious, we present conceptual links to the wheel garden in science and mathematics. The scope and sequence of learning objectives met through a wheel garden project is dependent only on the guidance provided by mentors and teachers overseeing the project. University students continue to develop lessons and activities for outreach activities. Currently, qualitative and quantitative research studies are in development to ascertain learning outcomes at both the secondary and postsecondary levels.

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