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Future Cities Engineering: Early Engineering Interventions in the Middle Grades

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ABSTRACT

This paper describes qualitative and quantitative research conducted with middle school students participating in a Future Cities Engineering course. Insights were sought regarding both affective and cognitive changes which transpired during the one semester schedule of activities focused on modeling the infrastructure of a city built 150 years in the future. Modeling activities consisted of both a computer simulation, *SimCity 3000 Unlimited*, and the construction of a physical scale model depicting student visions. To determine the efficacy of *SimCity* in serving as a realistic modeling tool, the software was "ground-truthed" by comparing *Sim* dimensions to the dimensions of analogous objects (roads, water pipes) in the real world. An age-appropriate attitude survey was developed and administered with the goal of measuring student disposition towards the engineering profession. Additionally, a multiple-choice content test was developed and administered both pre and post instruction to obtain a quantifiable measure of student learning. Findings show that student participation in such a course can lay favorable foundations for appreciation of and participation in the engineering profession.

Keywords: middle school, engineering interventions, future cities engineering

BACKGROUND

The booming world population and the necessary evolution to cleaner, more environmentally-sound methods of living daily life are creating a need for improved planning and innovation in city infrastructure and operations. Civil engineering is at the heart of this challenge, with the United States and the world as a whole experiencing a growing need for well-prepared, enthusiastic students to pursue undergraduate degrees and work as professional engineers. While bachelor's degrees awarded in engineering at American universities have been increasing slightly over the past several years, civil engineering enrollment has not enjoyed the same percentage growth as aerospace, biomedical, electrical/computer and mechanical engineering fields [1], making it all the more difficult to meet the national and international need.

Pre-college institutions may provide students at the middle school and high school level (Grade 6–12) the only formal instruction they will encounter in engineering-related activities. The extent of these engineering experiences, however, is often limited and consists mainly of projects embedded in science courses—usually middle school physical science and high school physics—or in vocational classes. Most teachers are not trained in the distinction between "science" and "engineering" and thus do not transfer an appreciation of the problem-solving aspect of engineering to their classes. Students, through laboratory experiments and book study, come to believe that science is about following a sequence of established patterns, working as, "consumers of science, rather than inquirers in science" [2].

Informal engineering encounters including FIRST LEGO League robotics competition, the West Point Bridge Design contest (http://bridgecontest.usma.edu/) and the *Design Squad* (http://pbskids.org/designsquad/) television series (broadcast on PBS) provide excellent early exposure to the engineering field. However, if exposed only to typical school resources, teachers and curricula, most American K-12 students head towards college with poorly-formed concepts about what engineering is, and what engineers do. Such limited understanding about the engineering field makes it unlikely that students will choose engineering as a course or university study and career. To this end, pre-college schools and educators must work to expose students in a positive way to the engineering profession—not just in words but through opportunities to think and work as junior engineers on real-world engineering problems.

Additionally, because engineering fields are evolving to include more technology in the form of data collection and analysis, simulation and modeling, pre-college students must also be provided opportunities to explore not only the physical aspects of engineering, but also the computer-mediated components as well. IEEE has noted that, "increasingly, mechanical, civil and microwave engineers engage in expansive and complex modeling, simulation, data collection and data analysis using computers. Without proper education these engineers approach these tasks (at least initially) as amateurs" [3]. As an example relevant to preparing engineering instruction for the middle school audience, teachers can target both the physical and technological routes to a task such bridge-building by combining classical Popsicle-stick model-building with a design task in WestPoint Bridge Designer software.

OVERVIEW: FUTURE CITIES ENGINEERING COURSE

To explore the effects of early exposure to the field of civil engineering, a Future Cities Engineering (FCE) course was conducted with middle school students during Fall/Winter 2006–2007 semester at The Alexander Dawson School in Las Vegas, Nevada (http://www.alexanderdawsonschool.org/). The mission of the course was to provide to students authentic experiences in working as junior civil engineers, tackling real problems similar to those encountered by professional civil engineers in their daily work. The overarching philosophy of the course was aligned with the mission of the National Engineers Week Future City Competition [4]. Data on cognitive and affective measures related to FCE participation were obtained with the use of content tests and a survey.

Course Participants

Fifteen middle schoolers—twelve male, three female—enrolled in the semester-long elective course. Of the fifteen students, six were sixth-graders, two were seventh-graders and seven were eighth-graders. Students self-selected their enrollment in the course and possessed a wide range of aptitudes in supporting disciplines including mathematics, science, literacy and technology.

Course Instruction

Course curriculum and instruction, including technology instruction, was designed and conducted by the FCE teacher (author McCue). A teacher colleague with expertise in woodworking and other artistic media collaborated with the FCE teacher by working with students on model-building activities.

Course Goals

Participating FCE students were guided in working towards the following goals:

- Define and describe the components of city “infrastructure.”
- Design and build a computer model of a city and simulate a 150+ year life span.
- Design and build a computer model of a bridge to be incorporated in the city’s design.
- Analyze the success of the simulated city, evaluating growth, property values, crime, community satisfaction, transportation, education levels and pollution.
- Plan, blueprint and build a scale model of a city section using recycled materials.
- Reflect and comment on the evolution of city design and the role of engineering in developing livable, sustainable cities of the future.

Course Skills

The FCE teacher sought to develop specific skills among her students, namely:

- The ability to research and analyze text, data, graphs and diagrams.
- The ability to question experts to refine understanding of engineering principles.
- The ability to compute scale.
- The ability to draw a model in two dimensions via a blueprint.
- The ability to collaborate with teammates in the design and construction of a physical scale model.
- The ability to plan and execute a timeline for successful completion of the model-building.
- The ability to build and modify computer models to design specifications.
- The ability to evaluate computer model accuracy and effectiveness.

Course Timeline

The FCE course met for one fifty-minute period every other day for a total of 45 class sessions (37.5 contact hours). The course commenced at the start of the first semester in August 2006 and ended at the completion of the semester in January 2007. The majority of class activities were conducted in the computer lab until mid-November; then most activities took place in the woodworking studio. This change occurred because of the transition from computer model-building to physical model-building in the course.

COURSE CONTENT AND ACTIVITIES

Course activities followed a general plan constructed by the FCE instructor, although modifications were made based on a variety of factors which arose as the course progressed. Course activities generally matched the official format of preparing for the Future Cities Engineering competition (http://www.futurecity.org/), an annual event sponsored by National Engineers Week and executed regionally by supporting organizations.

Review of Previous Future Cities Engineering Competition Projects

The introductory course activity was a review of past projects competing at the national level of the Future Cities Engineering competition. Students were asked to read the abstracts and view the model photos of previous projects which competed nationally and then select three which most intrigued them. Each student wrote a short explanation of what they found compelling about their selections into a course blog set up by the FCE instructor at www.blogger.com. Figure 1 shows an

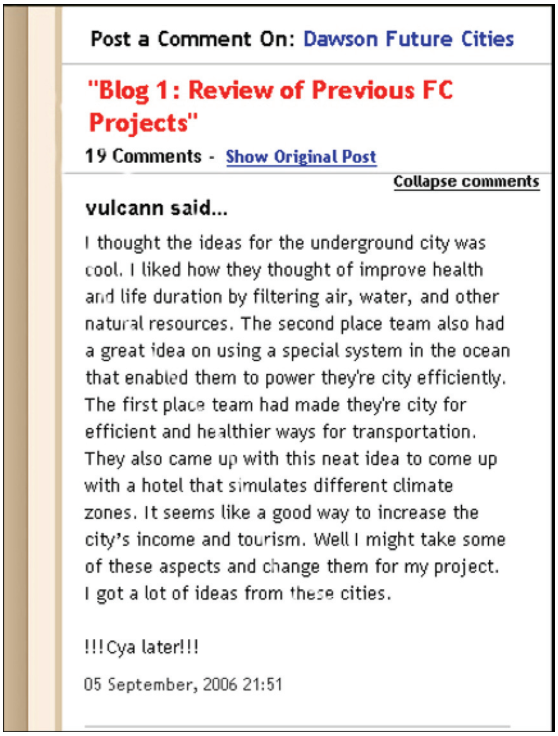

Figure 1. FCE students posted responses to discussion topics at the course blog.

example of a student blog posting. The FCE instructor also provided students with information and guidelines regarding the Las Vegas Regional FCE competition in the event that students chose to form teams and complete in the event.

SimCity 3000 Tutorials

Students began their computer modeling work using *SimCity 3000 Unlimited* (http://simcity3000unlimited.ea.com/us/guide/) as their tool for building basic city infrastructure and operating their cities to determine engineering success. The FCE instructor grouped students into trios and provided each group with a printed set of self-paced tutorials to complete. Tutorials included step-by-step directions and screen captures which led students through all basic city development tasks, specifically: zoning of residential, commercial, industrial and landfill areas; constructing roadways in *Sim-citizen* accessible configurations; supplying power; supplying water and routing water through underground pipes; adding basic community elements such as schools and parks; and adding basic aesthetic elements such as trees and water features.

Research and Discussion of Past-Present-Future Cities

During initial class discussions addressing the nature of the city, city design, and city operations, the FCE instructor observed that students possessed limited understanding of both characteristic city infrastructure and the pace at which city infrastructure has evolved. For example, as students began sharing ideas for their FCE physical models—cities set in the year 2150—many were still designing their plans to include traditional highways, cars and parking lots.

To help students better project city concepts 150 years into the future, the FCE instructor helped them mentally rewind and think about cities 150 years in the past. Using a Past-Present-Future chart (Figure 2) with categories including “modes of transportation,” “power sources,” and “sewage,” students researched online to determine how these and other aspect of the city appeared in 1850. They then used their own experience and performed additional research to describe how the city is constructed now. At this point, students were better able to appreciate the degree to which engineering techniques and technologies have evolved over 150 years and they were more effective at projecting at least the same amount of transformation as they predicted city features for 2150. With their modified perspectives, students moved from planning internal combustion engine cars driving on paved roads to Maglev vehicles and skyway hover cars navigating “travel zones” in their future cities.

CITY INFRASTRUCTURE AND DAILY LIFE… PAST – PRESENT – FUTURE
By ______DORI AND AMANDA_____

Attribute	Past ~1850	Present ~2000	FUTURE ~2150
Located where geographically?	NEAR A BODY OF WATER	NEAR A BODY OF WATER	EARTH AND SPACE
Population of average large city	250,000 PEOPLE	ABOUT 6 MILION PEOPLE	25 MILLION PEOPLE
Housing	TEPEES AND HUTES	BIG AND SPACED OUT	FLOATING
Drinking water source	LAKES AND WELL RIVERS	SPRINGS, LAKES, WITH A WATER TREATMENT PLANT	MACHINES
Transportation of water to home	BUKETS	PIPES	TUBES
Bathing / laundry	BATH TUBS AND RIVERS	A BATH AND A WASHING MACHINE	ROBOTS
Toilets / sewage	HOLE IN A GROUND	THEY ALL GO DOWN BY PIPES	VAPOORIZE

Figure 2. Constructing a Past-Present-Future chart helped students project attributes of their future cities.

Discussions with Mentor Engineers

To promote an appreciation of how real engineers work and to create personal connections with practicing engineers, students were visited in the classroom by two professional engineers. A civil engineer from a commercial entity met with students near the beginning of the course to talk generally about city planning and to show sample blueprints. Towards the end of the semester—during the model-building phases of the course—the FCE teacher's own mentor engineer (author James)—visited the woodworking studio to observe the students in action, hear their ideas regarding their constructions and suggest improvements.

Engineering the City Readings and Blogs

To promote acquisition of basic content knowledge in civil engineering, the FCE instructor obtained copies of the *Engineering the City* [5] text for her students to read and discuss. Weekly readings on topics such as "Water Transportation," and "Wires, Wires Everywhere," were assigned for students to complete at home. Students were then asked to reflect and respond to the readings via the course blog, writing a paragraph that summarized the chapter and explained how the featured concept applied to their city of the future.

Model Building Practice

The Future Cities Engineering course instructor planned activities so that students would begin considering what sorts of buildings and city layouts were possible and how representing their ideas physically, in three dimensions, related to how they represented them two-dimensionally in *SimCity*. FCE students were shown examples of how they could invoke their imaginations to transform everyday materials into aesthetically-appealing city structures. For example, the woodworking teacher showed how a simple rectangle of cardboard and a mail tube could be manipulated with an Exacto knife and hot glue to produce a futuristic, office building with angular facades and portal windows. He also showed how plastic water bottles and caps could be cut and reconfigured with hot glue to craft glass-like enclosures and accents. Ideas for texturing surface with spackle, gesso and paint were also shared.

Students then worked with their own self-selected recycled materials, trying their hands at making items similar to the examples they viewed. They enjoyed the opportunity to be inventive and experienced a range of successes in their creations: some found the challenge of making "something from nothing" tremendous fun, while others were frustrated that they were not greatly skilled at thinking up creative structures or manipulating the tools and materials. Most students made structures too large for later incorporation in their physical models but still found the practice session useful for generating ideas for their future city concepts.

SimCity Computer Model, Plus Evaluation of Model

The bulk of the first half of the semester in Future Cities Engineering was spent using *SimCity 3000 Unlimited* to build a computer model of a city. *SimCity* is a Maxis product that is part of the popular *Sim* series including *The Sims* (http://thesims.ea.com/) and *SimCity Societies* (http://simcitysocieties.ea.com/index.php). *SimCity 3000 Unlimited* was selected as the computer modeling software in alignment with the national FCE competition rules.

Students were given the task of creating a *SimCity* and operating it successfully for 150 or more years. Each student's city needed to possess a carefully designed and balanced infrastructure to achieve model success. Key considerations in laying out the city included:

- Zoning to produce an initial mix of approximately 50% residential, 25% commercial and 25% industrial, with a smaller landfill zone. Seaport and airport zones could be added as a city evolved. Students needed to constantly monitor and adjust zones according to an R-C-I (residential-commercial-industrial) indicator.
- Constructing roadways and local transportation (surface streets, highways, bridges, bus routes, trains, subways) as well as transportation via sea (seaports) and air (airports).
- Building multiple power plants in zones or connected to zones via power lines. "Green" power plants supplied cleaner energy, thus reducing pollution, but, of course, were more costly. Students often under-powered regions and needed to add new plants as their cities grew. However, power plants aged and expired after certain lifetimes (defined by plant type) and so students needed to keep tabs on power distribution at all times.
- Providing water via pumping stations, water towers or other sources. Water pipes needed to be distributed in network fashion, radiating out from each water source, in order to effectively supply water to buildings in the vicinity.
- Adding public services such as police and fire stations, hospitals and schools.
- Building cultural and entertainment complexes such as museums, zoos and sports parks.
- Adding aesthetic landscape elements such as parks, fountains, ponds and trees. Without these elements, *Sims* expressed dissatisfaction with their city.
- Accepting reward buildings, such as a casino or haunted house (see the *SimCity* screen capture in Figure 3) and placing them in appropriate locations in the city, usually with the goal of driving business and increasing revenue.

Students enjoyed the challenge of working to add the above key elements, then running the simulation and monitoring the evolution—and growing pains—of their creations. Not only did students need to continue building as their city grew, they needed to respond to the needs of the community by enacting ordinances and answering requests by city advisors. Simultaneously, students needed keep taxes low, minimize the number of debts, demolish abandoned buildings support education

***Figure 3. Students captured snapshots at various stages of city evolution in* SimCity 3000 Unlimited.**

and culture, alleviate traffic congestion, attract high-tech industry, discourage crime and reduce pollution. *SimCity* provides a rich set of graphs and data indices to help students track these variables and aid in their decision-making regarding specific adjustments. At the end of the computer model-building phase of the course, students used a score sheet provided by the Future Cities Engineering competition to evaluate their computer models, primarily based on measurements retrieved from the abovementioned graphs and data indices.

Beginning in 2009, the Future Cities Engineering competition will upgrade from requiring the use of *SimCity 3000 Unlimited* to *SimCity 4* software for the computer model. This newer version of the software provides a similar model-building experience with richer graphics and more realistic city-management attributes (such as urban decay).

Scale Model Blueprint and Construction

From November 2006 to January 2007, FCE participants developed a physical model of a future city set in the year 2150. Students could choose to render a section of their *SimCity* computer model or invent completely original, innovative city designs. Thus students were at liberty to plan their physical models from scratch. The FCE instructor encouraged students to tap into futuristic ideas they had researched and brainstormed in their Past-Present-Future activities for inspiration. Each student was charged with determining what his or her city would look like, how would people live, travel and work, and what would the landscape look like—would the city be on Earth, on another planet, or take the form of an orbiting space station? Additional criteria were as follows:

- Students were told to focus on a small section of their cities to model. They could show their arts district and waterways, residential skyscrapers and spaceport, underwater park business district, hospital and scientific research complex, or even their entertainment arenas and holographic museums. They were limited only by their imaginations.
- Students were told to draw a 16″ by 24″ blueprint representing the footprint of their model visions prior to beginning model construction. To introduce the concept of scale, the FCE instructor conducted a problem-solving session in which students explored MoMA's online exhibit *Tall Buildings* (www.moma.org/exhibitions/2004/tallbuildings) and computed the heights of scale model versions of the real buildings. Students were then given a 1/4″ = 1′ grid as a computer file and shown how to represent the footprints of scaled buildings in the x-y plane. The instructor demonstrated

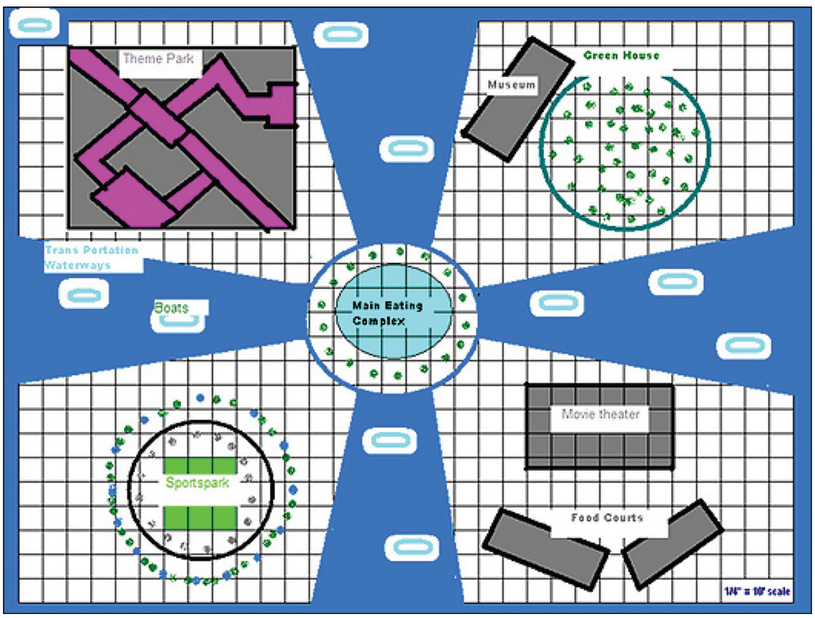

***Figure 4. A city blueprint created by a student using* Paint.**

techniques for drawing elements on the grid in Windows *Paint*. Figure 4 shows the completed blueprint created by a sixth-grade student. The instructor also provided directions for printing out finished blueprints in poster format. Some students chose instead to hand draw their ideas in blueprint or perspective formats.

- The FCE instructor provided each student a baseboard on which to construct a scale model from his or her blueprint (Figure 5). Students were required to indicate a scale for their models, such as 1″ = 10′ and follow it. No structure in a city was permitted to be taller than 18″.
- Finished models were to include a moving part which could be mechanical or electrical in nature—but not living. Multiple requests to place goldfish in a miniature pond were rejected by the FCE instructor.
- Students were encouraged to use recycled and found materials (bottles, pebbles, twigs) and a minimal number of purchased goods (construction paper, paint, spackle, foil, balloons, mirrors, plastic) to build their models. The individual budget for each student model was $30; however, the FCE instructor purchased reusable items such as paintbrushes, scissors and glue guns for which the students did not need to account.

Students self-evaluated their completed models using a score sheet provide by the Future Cities Engineering competition. The score sheet provided a rubric with rating criteria addressing scale, design innovation, materials, inclusion of a moving part and infrastructure plan.

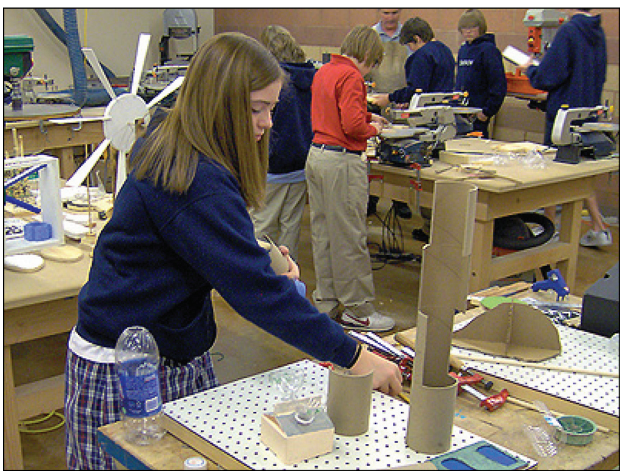

Figure 5. An FCE student constructed her physical model using recycled materials on a baseboard.

Figures 6a, 6b. Completed physical models are on display in the middle school lobby.

At the completion of the model-building, models were put on display in the middle school lobby in a desert garden setting (Figures 6a, 6b). Peer students, teachers, parents and school visitors have enjoyed viewing the creative models assembled by the Future Cities Engineering class. Hopefully, many new students are inspired to enroll in the FCE course in future semesters.

GROUND-TRUTHING THE *SIMCITY* SOFTWARE

A key question in evaluating the success of the FCE course is determining how well students came to understand the layout and function of a real city based on their interactions with the simulation city on the computer. An important component in evaluating their understanding is determining the accuracy of the *SimCity* software itself in modeling a realistically dimensioned city.

To perform such a "reality-check" on *SimCity*, it is necessary to measure various features of the city layout, compute their theoretical size based on the scale of the *Sim* grid, and then compare the features with their analogues in a real city. This comparison process, called "ground-truthing," can be conducted by the students themselves, with guidance from the classroom teacher. Ground-truthing the *SimCity* software may proceed as follows:

Using the "one tile equals one acre" method

One difficulty in ground truthing *SimCity*'s ability to accurately model the actual world is determining the scale of the *Sim* grid. Extensive research turned up only one reference to *SimCity* grid size: a website entitled, "What is a Mile?", located at the *SimCity 3000* Resource Center, states that each tile (one square on the grid) represents one acre [6]. Thus, *SimCity* tile area = 1 acre = (*SimCity* tile side)^2 = 43,560 ft^2

SimCity tile side = 208.7 ft

Cursory observation of the *SimCity* layout leads to the conclusion that individual *SimCity* tiles are substantially smaller than the theoretical dimensions.

To determine the number of pixels (px) of a *SimCity* tile side requires measuring the tile side using some type of digital ruler. This was accomplished, first, by screen capturing an image of a tile and pasting it into *PhotoShop* Elements at an image resolution of 72 px/in. Then, since the tile side is not horizontal or vertical, the tile side was treated as the hypotenuse of a right triangle (Figure 7). By constructing the sides of the triangle and cropping, the triangle side lengths can by easily obtained—they are the horizontal and vertical dimensions of the cropped picture of the triangle. Repeated measurements and computations resulted in a *SimCity* tile side of 74 px. Now, the conversion factor between pixels and feet for a *SimCity* tile side is computed as follows:

Computation of SimCity Tile Size via "One Tile 5 One Acre"

SimCity tile side = 74 px = 208.7 ft

So, 1 px = 2.8 ft. for *SimCity* tiles (@72px/in screen res)

At this point, we can check a few objects in *SimCity* to see how their measurements in pixels translate to feet—and thus compare them to their real-world counterparts. Several objects were screen captured and again pasted into *PhotoShop Elements* at an image resolution of 72 px/in. First, a *Sim* male construction worker measured 14 px in height. Using the 1 px = 2.8 ft conversion factor, this worker would measure 39.2 ft in actual height—unnaturally tall when compared with the average American male height of 5.8 ft. Using

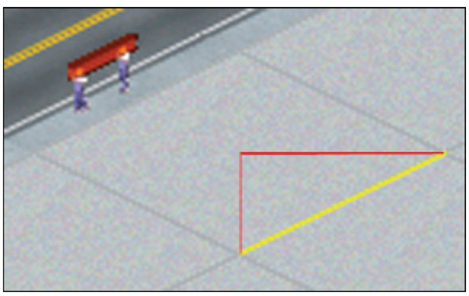

Figure 7. The length of a tile side is measured and computed in pixels at a resolution of 72 px/in.

this same procedure, five more objects were measured and compared, consisting of a two-story house, a roadway, a woman, a railroad track and a water main pipe. Table 1 summarizes the pixel measurements of each object and the converted sizes in feet. A comparison with actual object sizes is included.

Using the "Human Walking Rate" Method

Clearly, the "one tile equals one acre" method provides computed measurements of actual objects which are wildly inaccurate. One tile does not reasonably appear to be one acre in area. In seeking another method of measuring the actual size of objects in *SimCity*, it seemed feasible to make use of the motion of the *Sims* themselves. Supplemental file "SimWalk" is a video capture of a section of a *SimCity* in which *Sims* are walking along, traversing several tiles as they make their way down the street. Using a stopwatch, the number of seconds was recorded for a *Sim* to walk down a straight roadway or sidewalk traversing four or five tiles. The unit time for traversal of one tile was then computed. Repeated walking measurements and computations were made (Table 2).

Then, estimating that the average actual human walks "purposefully" at a rate of 2.5 mi/hr (which equals 3.7 ft/s), a computation of the *Sim* tile side (in feet) was made for each walking

		"One tile = One acre"	
SimCity *Object*	*(px) Measured*	*(ft) Converted*	*(ft) Actual*
Male worker (height)	14	39.2	5.8
Two-story house (height)	30	84.0	20
Road, side-to-midline (width)	24	67.7	9
Woman (height)	14	39.2	5.4
Railroad, between track (width)	10	28	4.7
Water main pipe (width)	12	33.6	2

Table 1. Size of* SimCity *Objects vs. Actual Objects.

Rate of Sim walking	*(s) Time to traverse 1 tile*	*Conversion factor*	*(ft) Tile side*
4 tiles / 35 s	8.8	3.7 ft/s	32.4
4 tiles / 30 s	7.5	3.7 ft/s	27.8
4 tiles / 31 s	7.8	3.7 ft/s	28.7
5 tiles / 46 s	9.2	3.7 ft/s	34.0
			30.7 ft average

Table 2. Computation of* SimCity *Tile Size via Human Walking Rate (converted using a human walking rate of 2.5 mi/hr = 3.7 ft/s).

measurement. Table 2 shows that the assembled data and computations yielded an average *SimCity* tile side computation of 30.7 ft:

Recalling that a *SimCity* tile side is 74 px, we can compute the new pixels-to-feet conversion factor—based on the human walking rate—for a *SimCity* tile side as,

SimCity tile side = 74 px = 30.7 ft

So, 1 px = 0.4 ft. for *SimCity* tiles (@72px/in screen res)

Additionally, this means that one *SimCity* tile has an area of 30.7 ft × 30.7 ft which equals 942.5 ft^2. Since an acre is equivalent to 43,560 ft^2, one *SimCity* tile is 43,560 ft^2/942.5 ft^2 or 1/46 of an acre in area.

Table 3 summarizes the pixel measurements of each object and the converted sizes in feet, showing both the "one tile = one acre" and the "human walking rate" conversion factors. The comparison with actual object sizes shows that the conversions made using the "human walking rate" factor provide substantially more realistic object sizes, especially for the *Sim* citizens, the road and the railroad. The house and water main are still disproportionately sized—the house is too short and the pipe is too wide.

Overall, the ground-truthing measurements and computations show that the *SimCity* 3000 *Unlimited* software serves as a reasonable, albeit spatially inconsistent, modeling tool for representing city infrastructure. However, the stated "one tile = one acre" rule does not provide accurate sizing when comparing the computer model to the real world. Developing a pixel-to-feet conversion factor based on the "human walking rate" yields better sizing of many objects. For instance, the height of a male worker is 14 pixels (at a screen resolution of 72 pixels/inch) which converts to 5.6 feet using the "human walking rate" conversion factor. Still, many other model objects are either too large or

		"One tile = One acre"		"Human Walking Rate"
SimCity Object	*(px) Measured*	*(ft) Converted*	*(ft)* Actual	*(ft) Converted*
Male worker (height)	14	39.2	5.8	5.6
Two-story house (height)	30	84.0	20	12.0
Road, side-to-midline (width)	24	67.7	9	9.7
Woman (height)	14	39.2	5.4	5.6
Railroad, between track (width)	10	28	4.7	4.0
Water main pipe (width)	12	33.6	2	4.8

Table 3. Size of* SimCity *Objects vs. Actual Objects.

too small relative to their real world analogues. The measured width of a water main pipe is 12 pixels which converts to 4.8 feet. An actual water pipe would likely not exceed 2 feet in width. Nonetheless, even with these inconsistencies, the simulated city evolves correctly. *SimCity* gives students a fair understanding of the challenges associated with managing multiple variables to build and grow a city of realistic layout and dimensions.

EVALUATION OF COGNITIVE AND AFFECTIVE DIMENSIONS

In addition to qualitative data collected via observations and student work samples throughout the FCE course, a quantitative evaluation of overall course effectiveness was sought. Measures of both cognitive and affective performance were obtained in order to determine both how student content knowledge evolved and how participating in the FCE course impacted student attitudes towards engineering.

Cognitive Changes Measured By Pretest-Posttest

To measure cognitive changes in FCE participants, a content pretest and posttest was administered at the beginning and end of the course, respectively (Appendix A). The pretest and posttest forms were identical, thirty-question, multiple-choice exams addressing eleven topics: zoning, water, bridges, trash, sewage, education, transportation, telecommunications, power, police/fire and budgeting. The exams were written by the FCE instructor in collaboration with her mentor engineer (author James) as there were no existing exams that covered the relevant FCE content. Questions were developed from content related to *SimCity* modeling, concepts covered in the *Engineering the City* text and material addressed during class discussions.

Pretest scores averaged nearly 12 out of 35 points and rose to a mean of approximately 20 out of 35 points on the posttest. Individual student pretest-to-posttest score increases ranged from 0 to 19

Measure	*N*	*Min*	*Max*	*Mean*	*SD*
Pretest	15	5	21	11.87	4.809
Posttest	15	11	27	20.13	4.486
Test Δ	15	0	19	8.53	4.719

Table 4. Pretest/Posttest Scores.

points with a mean of 8.5 points. (The one student who obtained a zero increase was absent on the posttest date and hurriedly took the posttest on a makeup date.) Thus, students averaged a 28.4% rise in scores on tests of engineering concepts from the beginning of the FCE course to the end. A repeated measures *t*-test of pretest-posttest scores yielded value of $t = -7.99$ ($p = 0.00$) meaning the mean rise in scores for the class was not random but was due to an intervention—logically, the semester-long FCE course instruction.

Affective Changes Measured By Attitude Survey

Student attitudes towards engineering as a function of participation in the FCE course were measured by a survey at the end of the course (Appendix B). Existing, engineering attitude surveys were examined for possible use with the FCE students. However, most of these surveys targeted current, undergraduate engineering students and did not possess age-appropriate phrasing nor questions relevant to the experiences of middle school students, male and female. Several survey categories from the University of Pittsburgh School of Engineering Student Assessment System [7] provided useful focal points for developing a new engineering attitude survey for our target audience. Questions indicative of these broad category concepts were then developed, with most questions leading with the phrase, "This course has made me…" This new, engineering attitude survey for middle schoolers was written by the FCE instructor in collaboration with her mentor engineer (author James).

The new survey was a thirty-question, Likert-style instrument with a five-point scale of Strongly Disagree = 1; Disagree = 2; Don't Know = 3; Agree = 4; and Strongly Agree = 5. Questions addressed multiple dimensions of engineering attitudes as follows:

- General Interest in Engineering Activities—7 questions
- Financial Influences for Studying Engineering—3 questions
- Perception of the Engineering Profession—7 questions
- Understanding of Working as an Engineer—10 questions
- Social Influences to Studying Engineering—3 questions

Students were also asked to write their answers to two open-ended questions regarding what they liked most and least about the course. The goal of the survey was not simply to gauge engineering attitudes but to quantify engineering attitudes as a result of taking part in the Future Cities Engineering course.

Results of the engineering attitude survey are shown in Table 5. A composite (average) score for each attitude dimension was computed. The lowest composite mean was the Financial Composite at 3.62, indicating a group attitude midway between neutrality (Don't Know) and agreement with positive statements about the financial feasibility of working as an engineer. The highest composite mean

Measure	*N*	*Min*	*Max*	*Mean*	*SD*
General Composite	15	3	5	3.81	.506
Financial Composite	15	2	5	3.62	.815
Perception Composite	15	3	5	3.91	.500
Understanding Composite	15	3	5	4.09	.528
Social Composite	15	2	5	3.82	.958
Attitude Composite	15	3	5	3.85	.441

Table 5. Attitude Survey: Composite Scores.

was the Understanding Composite at 4.09, indicating a group attitude that agrees with statements indicating an understanding of what it means to work as an engineer. An overall Attitude Composite score was computed by averaging the composite scores across the five dimension composites for each student. The mean Attitude Composite (mean of the other five composite scores) for the class was 3.85, indicating a group attitude that falls just below agreement with positive statements about multiple dimensions of the engineering field.

Certain individual survey item scores (Table 6) demand additional attention because of their unusually high or low values compared to all other item scores. The three lowest scoring items and possible rationales for these values follow.

- *Financial Influences for Studying Engineering 3 (**Fin3**): "This course has made me think that if I become an engineer, I will earn enough money to live the way I want*." At a mean of 3.07 this item presented the lowest score of all attitude survey questions. Given the affluent profile of the school in which the survey was conducted, it is not surprising that the salaries associated with the engineering profession do not seem competitive with those earned by the parents of students in the FCE course.
- *General Interest in Engineering Activities 3 (**Gen3**): "This course has increased my enjoyment of building models using LEGOs, blocks or other construction materials*." The mean score for this item was 3.13, falling just above the "Don't Know" agreement level. It is unclear whether the LEGO reference confounded students as no LEGOs were ever used in the course. Other possibilities were that students—having just completed their models—had tired of the physical model-building, or that they simply did not find building the physical models as enjoyable as other parts of the course. However, the SD of 1.457 indicates a great variation in responses to this question when compared with other survey questions: some students liked building the physical model and some didn't. Free responses at the end of the survey parallel this conclusion.

Measure	*N*	*Minimum*	*Maximum*	*Mean*	*SD*
Gen1	15	2	5	4.07	.884
Gen2	15	3	5	3.93	.704
Gen3	15	1	5	3.13	1.457
Gen4	15	2	5	3.60	1.298
Gen5	15	2	5	3.73	.884
Gen6	15	2	5	4.27	.961
Gen7	15	1	5	3.93	1.033
Fin1	15	1	5	3.93	1.100
Fin2	15	2	5	3.87	.915
Fin3	15	2	5	3.07	1.100
Perc1	15	3	5	4.27	.704
Perc2	15	2	5	3.87	.834
Perc3	15	2	5	3.73	1.100
Perc4	15	3	5	3.73	.704
Perc5	15	3	5	4.40	.737
Perc6	15	2	5	3.93	.961
Perc7	15	2	5	3.47	.990
Und1	15	2	5	4.00	.926
Und2	15	2	5	3.80	.941
Und3	15	4	5	4.33	.488
Und4	15	2	5	3.93	.884
Und5	15	2	5	4.07	.961
Und6	15	4	5	4.47	.516
Und7	15	2	5	4.33	.900
Und8	15	2	5	3.87	.915
Und9	15	3	5	4.13	.516
Und10	15	2	5	3.93	.884
Soc1	15	1	5	3.33	1.397
Soc2	15	2	5	3.87	.990
Soc3	15	1	5	4.27	1.100

Table 6. Attitude Survey: Item Analysis.

- *Social Influences to Studying Engineering 1 (**Soc 1**): "My friends are interested in hearing about what we are doing in the Future Cities Engineering course*." With a mean score of 3.33, this item—the first of three item regarding social influences—possessed the third-lowest level of agreement of all survey questions. Interestingly, the second item in this group, (***Soc2***), "*My family is interested in hearing about what we are doing in the Future Cities Engineering course*" scored higher at 3.87. Evidently, family is a bit more willing to listen to students talk about FCE than friends. Even more interesting is the rating of the third item in the social group, (***Soc3***), "*When I tell people about school activities, I mention my Future Cities Engineering course*" at 4.27—one of the highest mean scores in the survey. It appears that students are talking about FCE regardless of whether family and friends want to hear about it.

The four highest scoring items in the attitude survey were:

- *Perception of the Engineering Profession 5* (***Perc5***): "*This course has made me think that engineers are intelligent people*." ($\bar{x}$ = 4.40)
- *Understanding of Working as an Engineer 3* (***Und3***): "*This course has increased my understanding of how technology is used in solving real engineering problems*." ($\bar{x}$ = 4.33)
- *Understanding of Working as an Engineer 6* (***Und6***): "*This course has showed me that working in engineering is challenging*." ($\bar{x}$ = 4.47)
- *Understanding of Working as an Engineer 7* (***Und7***): "*This course has showed me that working in engineering requires patience*." ($\bar{x}$ = 4.33)

Understanding 3, regarding how technology is used in solving engineering problems, received scores of only 4 and 5 by the entire class. This strong attitude polarity may have been influenced by the extended time invested by students in completing their *SimCity* models and to a lesser degree by their use of *West Point Bridge Builder* to construct bridges. Similarly, students rated Understanding 6, "working in engineering is challenging," with scores of only 4 and 5. This item, along with Perception 5 and Understanding 7 listed above, collectively indicate that students exited the course believing that engineers are intelligent people who require patience in performing challenging work—no doubt, an accurate assessment.

Cognitive-Affective Correlation

Little correlation existed among any of the data categories representing test scores and attitude survey responses (Table 7). Only one significant relationship existed and that was between pretest scores and composite attitude. This Pearson *r* correlation was 0.518 at the $p = 0.05$ level,

Measure	*Correlation*	*Pretest*	*Posttest*	*AttComp*
Grade Level	Pearson Correlation	.358	.429	.061
	Sig. (2-tailed)	.191	.111	.828
	N	15	15	15
Pretest	Pearson Correlation		.630*	.518*
	Sig. (2-tailed)		.012	.048
	N		15	15
Posttest	Pearson Correlation			.364
	Sig. (2-tailed)			.182
	N			15

* Correlation is significant at the 0.05 level (2-tailed).

Table 7. Correlational Data.

meaning that students who earned high scores on the FCE pretest answered that, more often than their peers, they agreed or strongly agreed with favorable statements about engineering. Thus, students who possessed the strongest content knowledge at the outset of the course are the same students who feel expressed the most positive overall disposition towards engineering at the completion of the course.

CONCLUSIONS AND NEXT STEPS

The Future Cities Engineering course proved to be a successful venture in providing middle school students opportunities to work as junior civil engineers on real-world challenges. Students experienced both the technological and hands-on components of engineering practice by computer modeling city infrastructure via *SimCity* and by constructing physical scale models of futuristic cities.

Cognitive measures showed that the mean group score on a content exam rose by 28.4% from pretest to posttest. A survey of engineering attitudes showed that students perceived participation in the course as having favorably impacted their feelings towards engineering, with one exception: most students did not believe that working as engineer would yield sufficient financial rewards.

Ground-truthing of the *SimCity 3000 Unlimited* software found that the "one tile = one acre" scale is not reasonable. A more feasible scale is derived using the rate at which *Sim*-citizens walk as they traverse the *Sim*-tiles. Using the "human walking rate" conversion factor, a more realistic sizing of objects is obtained, although not all objects in the computer model are sized in correct proportion. Nonetheless, the *SimCity* software provided a sufficiently accurate portrayal of the real-world for middle school students to explore and assimilate the fundamental concepts of city infrastructure.

The success of this inaugural Future Cities Engineering course at The Alexander Dawson School resulted in a second year of the course offering during the 2007–2008 school year. Data regarding cognitive and affective outcomes of this year's participants is currently being analyzed. One team of seventh-grade girls moved their city concept, "Arvo Blaze" (a manmade island situated off the Australian coast) forward to the 2008 regional competition. The team earned a special award for Best Transportation Model and the team mentor (Author James) won Mentor of the Year. The momentum which these experiences inspired will result in a third year of the FCE course offering; four teams have already formed and all are brainstorming their visions of cities of the future.

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APPENDIX A

Future Cities Engineering Pretest/Posttest

APPENDIX B

Future Cities Engineering Attitude Survey

SUPPLEMENTAL FILE

SimWalk Video Capture of Sims traversing tiles in a *SimCity*