2018 ASEE Annual Conference & Exposition
June 24–27, 2018, Salt Palace Convention Center, Salt Lake City, UT

Paper ID #22522

Mapping as Design Thinking: Can GIS Help Engineering Students Approach Design?

Ms. Jessie Marshall Zarazaga, Southern Methodist University, Lyle School of Engineering

Jessie Zarazaga teaches GIS and Sustainability and Development in the Lyle School of Engineering at SMU. Working across the boundaries of urbanism, landscape mapping, and public engagement, Zarazaga explores ways to connect culture and community to place. Using GIS and participatory community mapping, she explores the impact of civil and environmental choices on the design of the sustainable city. Trained in architecture and urban design, her research spans education and practice, working on the integration of community research into project based learning. Her work overlaps areas of GIS mapping, global sustainable urbanism, design and creativity. She undertook a Fulbright in Valparaíso, Chile, to investigate, and map, devices of landscape as inspirations for the orders of community space.

Mapping as Design-Thinking: Can GIS Help Engineering Students Approach Design?

Abstract

Spatial site design, accessed through GIS mapping, teaches three-dimensional data analysis skills invaluable for the contemporary engineering student. Integrating design-thinking strategies into such spatial processes allows students additionally to access the cognitive operations of creative design processes. This study will investigate student responses to an innovative site design workshop in which GIS mapping becomes a tactical device for introducing both site planning and design-thinking to civil & environmental engineering students.

After a pre-test site design exercise 48 undergraduate engineering students were given a basic introduction to layered mapping (GIS) techniques, exploring both digital and analogue strategies for divergent exploration of site design. In the follow-up post-test design exercise students were taken through a more structured design-thinking approach for a similar site design project to the pre-test. This mixed-methods paper studies student self-assessment survey responses to the two design exercises as well as their written design commentaries, evaluating them for changes in attitude as well as in approach. Data reveal that even in such a short introductory exercise students reported an increase not only in GIS skills but in creative self-confidence, and their responses revealed a more iterative design process with generally higher values given by the students to their later-developing ideas, over a fixation on preliminary concepts.

The value of such a teaching model is that student engineers are able to gain access to open-ended creative design skills, widely accepted as critical to the educational development of the engineer. Furthermore this exploration, rather than an additive course or exercise, is integrated into valuable GIS mapping and environmental site design coursework.

Keywords: design-thinking, creativity, GIS, Mapping, design approach.

Introduction

The creative engineer is in great demand. With expectations of not only competency but a competitive urgency to innovate, the demands on the new engineer are multiple. While it is recognized that design and innovation are key areas for growth and development within engineering education, it remains difficult to integrate open-ended learning into what is already an overly dense, hugely broad, introductory package of courses [1]. We need to explore more efficient ways of fostering open-ended creativity training for engineering students.

The teaching model explored in this paper exposes students to creative design processes as an add-on benefit, whilst they are studying more traditional techniques of data visualization and spatial site analysis. This study will ask whether a first exposure to design practices can be effectively and efficiently introduced to engineers by embedding them into such spatial mapping processes. It will test whether such training can provide students with preliminary strategic approaches to design-thinking and whether, after such sessions, students will be better equipped to approach similar open-ended design contexts, with the skills necessary to develop a more divergent range of design options.

In this pre-test post-test experiment exploratory design techniques were integrated into a workshop on basic Geographic Information Systems (GIS) mapping, itself part of an introductory first-year engineering undergraduate course. The amended workshop was designed to explore the potential for GIS and site mapping to support creative learning practices for students through an embedded introduction to design-thinking processes.

Design and Engineering Education

Teaching Site Design in Engineering

Infrastructure design is land-design. Site design and community place-making grow out of the deep patterns marked onto a site by its infrastructure networks: water systems, transportation lines, communication systems, and physical structures. These systems are not static; flows of site reveal the temporal qualities of that place. And all these patterns, the underlying bones of place, mark the structure of our environment.

The process of marking the landscape through the design of its infrastructures is, in its essence, a creative practice and its practitioners are civil and environmental engineers. The first step in a site design is the thorough, thoughtful study of that place and its spatial attributes, a practice that starts with map-making and the observation and documentation of a site's physical, social and perceptual networks. The knowledge and skills of creative design are integral to engineering site practices.

The practice of creative design is rarely taught to civil engineers in early stages of their training. While there is increasing documentation of the importance and value, for industry, for young engineers to be both creative thinkers and innovators, and increasing agreement that such strategic skills must be taught in engineering schools [1], [2], there remain reservations and limits to the practical process of integrating such unwieldy content into the already over-scheduled requirements of the engineering undergraduate [2]–[4].

Supportive teaching structures have been developed for first or final year design courses in which students are introduced to idea generation and evaluation, idea sharing, team-work and concept critique based on user-needs, all of which are tied to creative design processes [3], [5]. But the specific teaching and practice of idea-generation techniques, while common in artistic fields such as music composition and dance, remain relatively rare in schools of engineering.

Even as design-thinking practices have emerged in a handful of engineering programs [6], [7] such as Olin or the d-school, they remain little known in most departments of Civil and Environmental engineering [1], [8], [9].

Integrating design-thinking into other coursework may be a useful strategy. Not only is it more efficient to double-load teaching time by combining design teaching with technical GIS training but, perhaps surprisingly, it also appears to be more effective. Mapping, as a context for teaching design to civil engineers, may have advantages over more independent ideation teaching techniques.

Design Creativity in Engineering Education

While early creativity literature focused on the personality traits of the creative individual, creativity education focuses rather on the characteristics of creative practice, and the processes which allow creativity to take place. Since Guilford there is broad recognition for the notion that not only can individual creativity be improved but, as a skill, it can be taught and learnt [10]–[12]. Specific creative stages in engineering processes have been identified, moving from context study, idea incubation and cross-fertilization to production processes. During the early phase of idea creation a divergent or open thinking phase is contrasted with that of convergent, or critical assessment; idea development emerges from an iterative interchange between the two [13]–[16] .

Engineers are accustomed to problem solving and some familiar creativity techniques, such as TRIZ [17] build on creative approaches to such convergent thinking. The divergent process of problem finding may be less familiar. However Sawyer, Guilford et al. argue that 'divergent production' is a key process of creative thinking and that, as in brainstorming, the production of a greater number and wider variety of ideas leads to higher possibilities of an optimum idea emerging [18].

Attempts to measure increases in creative approaches towards an engineering problem are complex and have spawned a range of tests and metrics, both of the creator and, following Amabile, of the product that ensues [14], [19]. Bringing together definitions from over 50 studies, Dean et al. have extracted an overarching consistency from such studies, in which creative work is measured using four scales where the originality or novelty of an idea must be balanced by its flexibility or workability, its relevance to the solution set, and its specific elaboration [20]–[22].

In this study, however, we are less interested in the eventual creative product and more interested in the self-efficacy, or change in design confidence gained by student engineers through the workshop process. While the metrics described above may serve to uncover changes in creative qualities of consecutive designs, they will not necessarily reveal changes in a student's creative approach, their confidence in approaching open-ended work or their self-perceived ability to engage in design. Unlike artists, engineers and engineering students tend to be more confident working in a deterministic process, in which a final target gives a direction and limits uncertainties [23]. Such an approach encourages early exclusion of divergent thinking and tends to lead not only to a narrower early set of design ideas but also supports a tendency to select and stick-with an early stage idea, or design fixation. Criticism of the use of CAD as a design tool is precisely its tendency to support, rather than reduce, engineering students' propensity for idea fixation [24], [25]. This study, then, will explore creative practice from the point of view of the students themselves. Following the workshop teaching experience do students approach design work with greater confidence? Are they more open to divergent approaches, and do their new skills and tools lead to any reduction in idea fixation?

GIS Mapping as the context for Design-Thinking

Spatial and visual explorations play a vital role in design; sketches and diagrams allow designers to visualize, abstract and manipulate their spatial processes [26], [27]. In a quick sketch an idea can be captured, recorded, and remembered in a loose structure that remains open to re-interpretation and exploration. Critical of the lack of teaching of sketching skills, researchers have explored ways to introduce such diagrammatic tactics into engineering education [28]–[30].

Maps, we propose, can also function for designers as spatial and diagrammatic structures that are able to reflect ideas. Beyond its expressive visualization and communicative role the map allows the designer to construct a simplification and abstraction of space, manipulating image and idea in the process of exploration [31]. Like diagramming, map-making is a subtractive process implying a fixation on one aspect of the world, be it roads, geology, or fluid current [32], [33]. Through observing and marking the map, decisions are made of what is seen and what omitted. Strategic thinking is embedded in such work, an active thinking process which can serve as an exploratory design tactic.

Furthermore, the designer's engagement in two active processes of map-making, observation and annotation, add additional value. Through careful observation and gathering of site data, the map-maker's own vision of the site and environment is broadened and often altered, allowing the development of a more divergent set of views [34]. Through mapping and visualization of apparent or hidden quantitative and qualitative site data possibilities emerge for moments of inspiration. But can engineering students learn to exploit and harness this by-product of the site visualization process and to uncover such inspiration in the diagrammatic phase of active mapping, when it is so often overshadowed in the path towards the completed map-product?

As a diagrammatic structure, a system that isolates and reveals only certain aspects of a reality, a map can serve as a tool for re-visioning and re-framing. Such conceptual processes of mapping have been identified by architects and landscape architects as valuable devices for creative agency and used to reveal abstract qualities of site, an uncovering that becomes a strategic tool enabling innovative approaches to spatial design [31], [35]. Yet such powerful process have not yet been similarly taken advantage of by engineers. Not only could engineers profit from such a creative tool; furthermore the process appears to give greatest support to early stages of creative thinking and to divergent thinking, that phase of creative research for which engineers traditionally have fewest models [18], [22], [36].

Finally, for engineering students, many of whom are more confident with technology than with visual exploration, the familiar systems-based structures of GIS may allow them to approach site design with greater daring than they might if exposed to design-thinking or even spatial mapping in a less structured studio environment [37].

Tactical Tools for Design Exploration

Familiar to painters who develop techniques to confront the paralysis of Van Gogh's blank canvas [38], similarly dancers, musicians and writers develop strategic tools for stepping out into the creative process of composition. Sets of composition or design heuristics, gathered into collections of methods or approaches and frequently packaged as a deck of cards, are somewhat familiar tools for facilitating creative processes in the arts. Precedents can be found in dance, for example, with Wayne McGregor's 'Mind and Movement Process' [39], and in design where the d-school 'Bootcamp'[40] has been shown to support the often frightening process of jumping into the unknown. Daly, Yilmaz, *et al.* have developed a large, encompassing set of design heuristic cards for the design context of mechanical engineering and have argued convincingly that such heuristic tools can assist engineering students with both design confidence and in developing divergent design solution sets [25], [41].

Building on these models a deck of thirteen tactical geo-design cards was created, over the course of three semesters by, and for, an engineering graduate course in GIS mapping and interdisciplinary research at SMU. Each card describes a strategy for using a GIS toolset or technique as a creative heuristic and illustrates that strategy with an example project completed by students in previous classes. The deck serves new students as a tactical set of possibilities helping to spark engineers to reach out towards an unfamiliar direction, giving clarity and confidence to their process and potentially widening their mapping design solution set. Introduced into the short context of the undergraduate workshop in this study, the primary intention of the cards was to serve as illustrations of GIS inspired creative site-mapping, but with some potential to inspire design exploration with spatial data-sets. Recognizing that their role remained minor both in the workshop and this study we were still interested to find out if the cards might, even in this context, assist students towards contemplating a broader range of mapping than otherwise imagined. While the role of the cards as design heuristic tools was neither fully explained nor developed for these undergraduate students nevertheless they may have served as idea triggers towards a more divergent set of design possibilities.

The teaching model proposed, then, is the integration of design-thinking techniques into a GIS mapping workshop such that the teaching of divergent approaches, as well as the introduction of specific GIS-based design tactics, are wrapped within the framework of the spatial mapping exercise.

Research Focus

After a workshop focused on design process one would expect to uncover two independent, measurable results; first, that students show improvements in design confidence, that is, confidence in approaching design with strategic understandings which could be used in their own work beyond this exercise. Secondly, that independent of the student one would be able to assess whether the creative quality of the post-workshop work itself is more effective. [14] Isolating these two goals, this paper chooses to defer the second to a later study and focus primarily on the first, that of confidence and approach in creative design.

The experiment thus explores a skills-based outcome: is there any change in students' attitude and approach which impacts their confidence in undertaking creative design work? We seek to assess the impact of specific GIS spatial and site-specific practices on these outcomes. Less interested in the designed products themselves this study focuses on changes in students' methods and approach uncovered through pre- and post-test surveys of their workshop experiences. How do they describe their motivation and apprehension? Do the words they use to describe their approach change?

Research Methods

Participants

A cluster sample was formed of 46 undergraduates from two different iterations of an introductory Civil and Environmental Engineering course. Although the sample is convenient it is also relevant as precisely the population whom the research intends to serve. Early in the semester students were introduced to sustainability in the context of civil and environmental engineering, discussing the interaction between ecological, social, economic and technical solutions to issues such as transportation and urban water supplies. Late semester a guest-taught workshop introduced sustainable site design through a hands-on exposure to geo-spatial data, digitizing and spatial analysis tools. The experiment was slipped into this workshop setting. Sampling bias was minimized by asking students about previous GIS or design exposure; while 11% of students (5) had some previous GIS none had design training. Of the 46 undergraduates who completed the experiment there was an equal ratio of men to women with 76% being 17 to 19 years old.

The workshop structure in which students were led through open-ended explorations of site meant that the GIS and creativity training were inextricable, with the mapping itself introduced as part of the design experience. Any impact of the inherent spatial qualities of mapping on student creativity was thus inseparable from the explicit design-exploration built into the workshop. Further, since GIS was taught as part of all students' coursework there was no control group who attempted the post-test study without GIS training. These elements would be both interesting to attempt to isolate and explore further in order to uncover the extent to which spatial mapping alone, as well as the learning experience of test repetition, might impact post-test results.

Description of Project and Data Collection Methods

After an introduction to the project themes and consent process students were given a pre-test site design exercise. A local site was introduced through maps, images and a description of civic and civil issues. Students were given a base map and a set of site-planning building blocks drawn to scale including roads, structures, drainage systems, trees etc. and a stack of transparent paper and colored markers. After four minutes to 'investigate and think about ideas' the students had 35 minutes to draw site-plan ideas. (*Figure 1*) Asked to 'do as many different design ideas for the site as you can in the time', 'write notes on the drawings', and 'move on to new ideas when you are ready', the exercise context was purposefully casual and accompanied by conversation and laughter. Afterwards, a one-page survey assessed student approach to the work and their confidence in their own design process.

The second session was a hands-on workshop structured around an introduction to ArcGIS and mapping in which students were introduced to GIS data layering, attribute isolation, feature drawing, buffers and the inter-connectedness of spatial and social datasets. As part of their exploration students were introduced to the possibility of using GIS in their creative process and given a deck of 'geo-design cards'. These design-process cards, originally created for an upper-level GIS course, help students apply creative exploration tactics using GIS processes. (*Figure 2*) Although the undergraduate students taking the workshop would clearly master neither the use of the cards nor GIS in this short exercise, the intention was to expose them to tactical strategies in which GIS and mapping could be used creatively. Working in pairs students playfully explored both GIS and site design; they tested the use of at least one geo-design tactic and shared it in an open design review.

The post-test exercise at the third session was structured as the first; with a similar local site presented with context, history and, in this case, geo-spatial data. As before students were given paper site maps, the site-element set, and tracing-paper mapping tools. However, they also had GIS laptop access to assist their exploration and a deck of 'geo-design cards'. Use of either was optional. The forty minute exercise was somewhat more structured than the pre-test, loosely developed from aspects of the d-school crash course model worksheets [7] with the instructor encouraging casually timed segments. Similarly, additional process structure was provided; where before students had been asked to 'write notes' now they were offered optional design-process boxes on the back of their map-sheets to fill out with observations and insights to assist their design reflection process. Most wrote at least a little in these boxes. (*Figure 1*) A one-page survey again asked students for self-assessment of their confidence, approach, and requested information about their opinions and use of the tools. (*Figure 3*)

To sum up, students experienced their post-test exercise armed with three new site design strategies. First, and with greatest time having been dedicated to it, was the GIS teaching spatial ways of working with the site and community data. Methods of working with GIS layering and isolation enabled students to re-visualize site issues in new diagrammatic ways. Second, at post-test, students were given some design-process structure in which pauses for re-thinking parameters gave the opportunity for them re-focus their impetus for design iteration. Although fully integrated into the exercise structure this methodology was not explicitly emphasized in the teaching process. Finally, students were given the set of 'geo-design cards', open ended heuristics for spatial design providing them with alternative ways to jump-start their design ideas.

The total number of map drawings produced by each student was summed, both pre-and post-test. All other data was gathered through the two surveys. Beyond the simple nominal and Likert scale data gathered from student survey responses data was also gathered from students' written responses to open questions about both their process and their projects. This data was coded into comparative thematic groupings which emerged from the qualitative text answers and the numbers of responses within similar thematic groups were compared, pre and post-test. Finally, responses to two questions were passed through Voyant, a web-based text-analysis tool, which allowed comparison of pre and post-test word use and frequency; extracted words were then related to the categorical groups.

Data Analysis & Discussion

Three specific aspects of design approach were analyzed. The first was any change in self-assessed creative confidence when approaching design work. Second, we measured any increased value students gave to idea evolution; that is, any move away from design fixation towards multiple divergent options. Finally, through text analysis of the students' self-assessment we attempted to determine to what extent students had become more self-aware of their design process and of their own ability to manage it.

Creative Confidence

Students self-assessed their general or overall design confidence consistently, retaining a solid level of 65% both pre- and post-test, with a reduction post-test (from 7 to 4) only in the small number of students who reported no confidence at all. (*Figure 4a*) More suggestive was the confidence change students reported for 'today's workshop'. During 'this specific design process' those who felt at least somewhat confident increased from 62% to 79% post-test (17% change). While a low level of confidence in the first exercise might be partially explained due to lack of familiarity with this type of site planning exercise, even if we compare this result to the general 65% overall confidence level reported, we find a solid design-confidence improvement of 14%. This more modest result is interesting since it reveals greater student confidence in approaching the second site design than other engineering design work based, presumably, on the GIS mapping tactics, even though no actual site-design teaching had taken place.

One intention in introducing the GIS mapping was to assist students' exploration and their ability to expand divergent design possibilities. Pre-test, a consistent 60% reported usually finding it hard to get started on creative work. However, when asked about 'today's' post-workshop experience there was an 18% reduction (to 46%) in those who said they got stuck on preliminary ideas with 81% reporting that the new GIS mapping process helped them get started. (*Figure 4b*) Such an increase, regardless of design quality, is a vital stage leading to divergent processes.

Building on the idea of computational creativity support, it was hoped that technical comfort with the GIS system might assist student design confidence in addition to its primary role as a tool for assisting in open design exploration. Responses showed, for example, that even if they didn't really enjoy the creativity exercise fully 93% of the students quite enjoyed the GIS mapping, appearing to confirm, at least, a level of digital comfort.

While pre-test explorations were drawn with layered maps on tracing paper, the GIS workshop introduced both analogue and digital technologies. In the final exercise students were invited to use both technologies to develop their design, submitting their final sketches on paper. Interestingly, 54% of the students did use the computer when given the option, a high percentage given the new tool's complexity. Although only 19% primarily used digital GIS to develop their ideas another 35% combined digital and paper mapping processes. The system's greatest value seems to have been as a tool for re-visualizing; whereas only a fifth used the GIS to draw, two-thirds used layering or isolations tools.

Asked to assess the value of the different elements of their toolbox 21% of students found the digital GIS tools very useful to their process (54% somewhat useful) and 23% ranked the 'design tactics cards' as useful (62% found them somewhat useful). Most powerfully 45% found the combination of both the design cards and GIS to be very useful in their design process, with a combined 93% of the students reporting the combined set at least somewhat useful. It's interesting not only that the response was so positive but that bringing the two tools together seems to have helped students find greater value than in either one separately. In the future, it would be valuable to redo this exercise with a wider range of control groups; while the cards cannot be used without GIS the map process could certainty be taught without the cards.

Of the thirteen cards, most students used the two which introduced revisualization methods, exposing unexpected site visions through manipulation of GIS layers, and 67% found the cards at least somewhat fun to use. Interestingly, 70% found the card tactics open enough that they added their own process ideas to those discovered in the cards.

Design Fixation or Idea Evolution

An average of 3.92 site design maps were drawn by each student post-test, compared to 1.60 pre-test. (*Figure 5*) This result that appears to powerfully confirm students' move away from design fixation, however, it must be taken cautiously. Although in both cases students were asked to 'draw as many ideas as you can', in the post-test exercise students were offered more design-thinking structure as they worked. They were invited to pause, think through issues and return to drawing. This imposed framework, although optional, may have influenced their creative pace and, in addition to repetition, be credited for some of the post-test change in quantity.

More interesting, perhaps, is the design evolution that students appear to have integrated into this process. Beyond creating more designs students started to experiment and, moreover, to give value to their experimentation process. In pre-test 81% (39) described their first effort as their favorite design; by post-test only 23% liked their first or even second design best (5 preferred 1st, 6 2nd). The biggest group (63%) now preferred their 3rd or 4th drawing, (13 liked 3rd, and 17 4th) and a small group (11%) liked one even later in the process.

Looking deeper, when asked why any particular design was their favorite, post-test answers show, for some, a change in attitude focused on the site design less as a solution to a problem and more as an exploration of ideas. Pre-test (for those with more than one map) favorite designs were selected for three reasons. Most enjoyed the way their site design responded to environmental quality: 36% (15) focused on open space: "I put in more landscape in a very urban area" and "bike path creates community attraction to exercise in a good environment"; while 12% (5) prioritized community. Another 17% focused on measurable issues such as organization, or drainage. "I was able to introduce an appropriate green to grey ratio in terms of houses and open areas". Voyant text-mining of this pre-test data [42] confirms that students' comments focused heavily on site qualities, the highest frequency word extracted from the response text files being 'park', followed by 'community', 'green' and 'pond".

Post-test, however, a new primary category of response emerged revealing students' new awareness of design as a process leading to multiple solutions, in which 38% of students (as opposed to 10%) now gave greater value to their range of site design proposals and posed one as a preferred rather than an ideal solution. Of their favorite design students wrote, "the most complete drawing, [it] incorporates most of my ideas", or "it has more ideas, several that carried over from earlier designs." Thus even when selecting favorites we find new awareness of the rich potential of combining ideas into alternate visions. While half the students did retain a tangible focus (26% on the environment, 14% on technical solutions, and a slight increase to 17% on community) the powerful change was in the other students increased focus on the abstractions of design and form. Voyant post-test text-mining similarly confirms this greater focus on process; when submitted for analysis, the word 'ideas' was extracted as the most frequent followed by 'incorporates', a word intriguingly linked to the GIS concept of overlapping layers.

In pre-test descriptions of their creative process many were unsettled; "never done [this] before and not sure if any design could actually work", and very few mentioned time as part of their creative process. Four actually wrote they were not creative. Pre-test 30% (14 students) described their creative process as a single intuitive moment: “Hope a cool idea just comes to me”, or “sometimes good, sometimes not”, and 65% identified their most creative moment as their first sketch.

Post-test, not only did GIS mapping processes seem to have helped them get started but responses made clear that student thinking about their creative approach was affected by the workshop. Some revealed struggles, their process was “forced, difficult” or “needs improvement.” For others new notions had emerged. Creative work was “a bit more fast paced” or “random, because what I'm inspired by changes each time” and even “browsing, random, trying things; this has changed!” Powerfully, 48% of students (23) now included the issue of time and design-development in their post-test descriptions, an increase of 17%, writing “it takes several times to get a solid idea” and “come up with an idea and then build off that until more ideas pop-up.” Some even referred to the training, “it is hard to make up designs, the toolbox is helpful” and “I start with analyzing present physical features then build around”. Only 21% (10) reported that their design process had not changed at all.

Several described changes to their structure: “process has changed a little bit, most ideas at first, then slowly build” and “step by step, yes, it has changed”. Others referred to particular tactics taught; “Yes. The tools help you come up with new ideas as your design progresses” or “browsing, random, trying, yes, this has changed.” In a beautiful description, one student wrote, [the process is] “abundant, and has changed to be more logical with respect to design and mapping.” Post-test, when asked about idea development fully 73% reported having more ideas later in the process, revealing a clear move away from design fixation towards idea development. It appears that at least some aspects of the new multiple tool-set: the GIS techniques, the design cards and a measured process, clearly assisted students to expand creative explorations.

Self-awareness of Process

When asked what they ‘loved’ about their set of project designs pre-test student response focused overwhelmingly on tangible content, specifically the design’s connection to nature. Ecological issues excited 66% (23) of those who responded. [I loved] “all the parks!!” and “I want to live by the pond.” Only 14% (5) focused on the creative design challenge itself. “I like that everything is included in one drawing”, “they are my own ideas and there were no boundaries, I can design anything.” (*Figure 6*)

We were interested in assessing whether the GIS based teaching model might help students become more aware of their own control of the design process, something which might be seen in a discussion focused less on site content and more on process. Such self- awareness could impact their approach to future design efforts even beyond the specifics of this exercise. Attention to nature and water did, however, retain the majority of students’ primary interest post-test. They were focused on “the big green recreational parks & pavilions, the bike trails were pretty cool too”, and “the use of water as a feature.” However the proportion who responded thus was reduced from 66% to 46%, with a slight increase in focus on human-centered issues

(28% up from 20%). Most interesting in terms of this study, however, was the post-test increase in the proportion of students who, when asked what they ‘loved’, now chose to describe spatial or methodological aspects of their design-process. While remaining the smallest group overall, an increased 26% (from 14%) of students described “the wide variety of ideas and unlimited amounts of generators [I was] able to produce”, and that “[my designs] give the same goals with different layouts”.

A comparison between pre- and post-test responses to a question about the ‘next step’ they would take provides similarly revealing evidence of change in design-process thinking. Nervous about stepping into open-ended design pre-test, many students proposed a swift move into more familiar technical aspects of their project. The majority, 73%, proposed “after this rough design I would calculate materials needed & find proper drainage patterns”, “design drainage systems” and, “see if my idea made sense with the environment and was possible.” (*Figure 7*)

Although still focused on technical development as a logical next step post-test student visions revealed more process-oriented consideration: “I'd relate infrastructure like roads, water, management” or “I would include drainage systems, schools and roads”; a layered description of structure perhaps influenced by GIS. A slightly greater focus on human-centered issues such as “plan out how it would best fit with the existing community”, reveals a more holistic site approach. However the tendency towards abstraction is most powerfully confirmed in the increase from 4% to 13% in the number who proposed ‘next steps’ in strict design terms, wanting to “[add] something in the right side”, “rearrange structures/ design to use space better”, and “try to bring all the ideas together”. Voyant text-analysis [42] finds that while words related to the development of water and roads remain primary in the both pre and post-test descriptions, heightened awareness of the inter-relatedness of issues is revealed through the post-test frequency of words like ‘community’ and ‘systems’, preoccupations which may have emerged through the layering of diverse data sets as well as new design processes.

Conclusion

Design Confidence

Open-ended design can be a leap into the unknown for engineering students. One way to make this leap less daunting is to help students become familiar, early in their educational experience, with strategies and tactics to support creative processes. Practicing site design gives students an opportunity to work through such strategies as they explore ways in which the development patterns of infrastructure networks impact the design framework of an urban proposal.

Creative thinking in GIS itself has mostly taken place within the context of the specific creative map-product. Kwan’s groundbreaking geographic work on qualitative GIS and, within engineering, visual exploration of dynamic time-space interactions have begun to stretch GIS mapping possibilities [43], [44]. However these explorations have not yet been exploited for the creative potential they might bring to exploratory processes beyond map making. Researchers in the digital humanities, such as Travis, have started to explore GIS's potential to suggest unexpected directions, however such processes remain firmly literary, not straying into spatial design [45]. Most critically, few of such explorations have made their way into engineering or civil site design. This is perhaps surprising given engineering students' confidence with computing technology. Certainly digital creativity support tools have been studied extensively in the context of game design and computation [46], however there has been little exploration, beyond some studies of the graphic capabilities of CAD, of the potential for digital spatial systems to serve as support tools for creative thinking in civil and environmental engineering.

In this teaching model both digital and analogue GIS mapping were brought into the laboratory as tools. They were presented as additional tactics not just for map-making but for design exploration. Familiar in the context of computational creativity support, the role of the technical tool is not only to open up creative exploration but, in its technological familiarity, to support students on the path towards design confidence. Although our students' self-assessment of their long-term creative confidence didn't change they did report having developed greater confidence in approaching this particular kind of site design process. Such a result, of course, could be biased due to the duplication of the exercise post-test. A further control group, while educationally difficult to arrange, could help clarify this.

However, if we take the notion of no longer 'getting stuck' at a project's start as a confidence measure then the results are more powerful. Survey evidence confirms that the availability and use of two new tools for divergent exploration, the GIS mapping and the design cards, increased student confidence in 'starting-off' by 18%. This finding is particularly important because the wider exploration of divergent concepts can be the first invaluable step in developing more creative solution sets and a step that is difficult for engineering students, who tend to have been better trained in convergent, critical analysis.

Because students were given three new tools to assist them in their site design process it is difficult to assess the independent value of the parts. The primary focus of the workshop was the GIS mapping itself and the layered spatial thinking which emerges from its use. Both the workshop timing process and the geo-design cards were developed as secondary teaching tools to help students strategically better access the GIS as a creative tool. Neither the design process nor the cards can be used without the GIS mapping. At the very least, with the help of these devices, evidence shows that GIS mapping used tactically can indeed allow engineering students an improved degree of design confidence. Supporting this statement is the evidence from students' value assessments; that almost all students found the GIS, the geo-cards and most especially the combined set of tools, to be useful in their creative exploration.

Design Fixation

Evidence of increased idea iteration confirms that the GIS workshop tactics did impact student design processes. Certainly, we must be cautious of giving too much credence to merely increased numbers of site designs produced. Student responses, however, support the claim that the process taught students to generate not only more, but more thoughtful collections of solution sets. Design fixation evident pre-test in which 81% preferred their first effort was eclipsed by the more than 68% who, post-test, were instead delighted by their 3rd, 4th or later iteration. Such a finding might be even more valuable longer term if student confidence were found to grow further once iteration is practiced. Another future impact of such reduction in design fixation might be quicker starts: first ideas are less daunting if they aren't expected to be the right answer. Finally, their comfort level with technology may explain, to some extent, the high 81% who reported that the GIS mapping process helped in this struggle to get started. Rather than criticizing students' reliance on technology this methodology reveals an opportunity to exploit it.

Self-awareness of Process

While unable to contribute to research into student idea development beyond primary ideation this study does explore the potential for students to begin to become self-aware of their own design process, a vital cognitive step in design-thinking. Stepping outside a narrow focus on numbers of ideas this study attempts to evaluate broader impacts on students' developing abilities to question their work and their processes [47]. Not only did students become aware and give greater value to the iterative, 'browsing' nature of design but they began to move away from site-based design descriptions to more process-based discourses. While the total number of students who had taken this step towards abstraction was small, post-test evidence does seem to show a tendency towards broader spatial design aims. It would be very interesting to follow up on the extent to which the spatial qualities of GIS play a role in this change. Can the shift from site-specific ideas to more abstract notions of idea transformation be facilitated by the spatial nature of the GIS framework and its tendency towards abstraction through layering? The place-based abstraction of a GIS map may be helpful for engineering students to the extent to which it remains tangibly grounded to site and data while at the same time allowing transformative idea exploration.

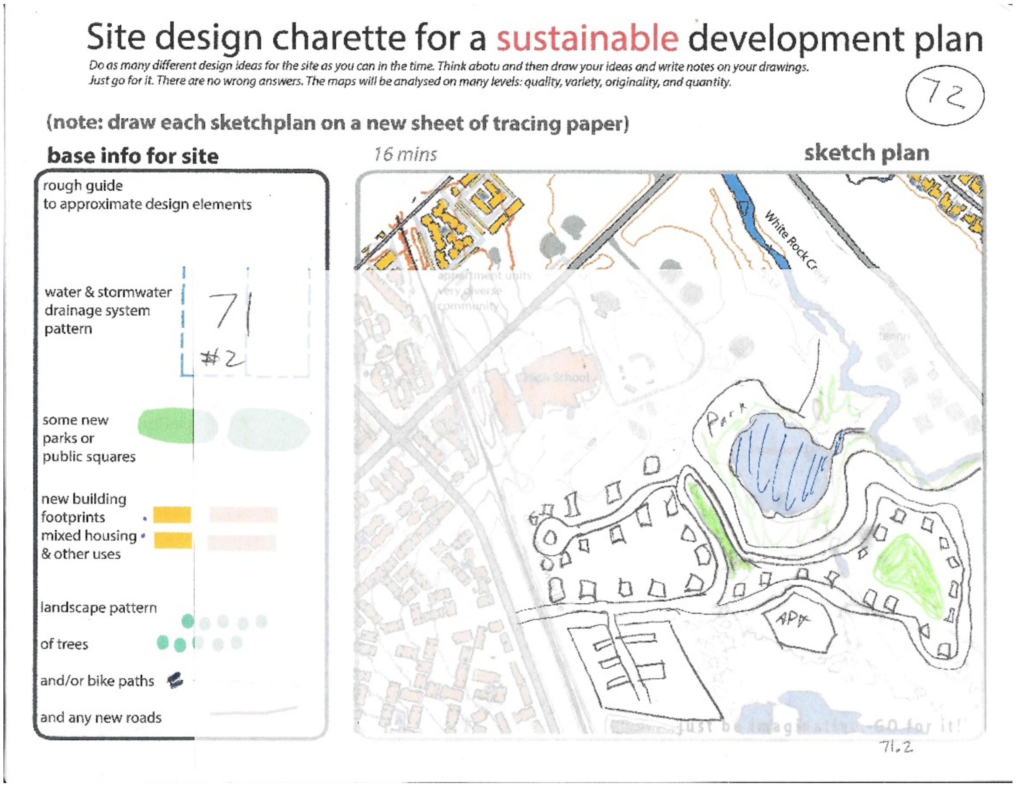
Limitations and Future Work

The short nature of the workshop severely limited this study. Not only was the GIS skill level obtained very minor but even student familiarity with the site design process was low, given that they were in early stages of their engineering degree. This population had been purposefully selected in order to test the value of this methodology as an introduction to design-processes for early stages in the engineering curriculum. However, such a population also imposes limits on the results. It would be interesting to test student responses were these same tools to be introduced to, say, final year civil engineering students or to those with GIS expertise but little design experience.

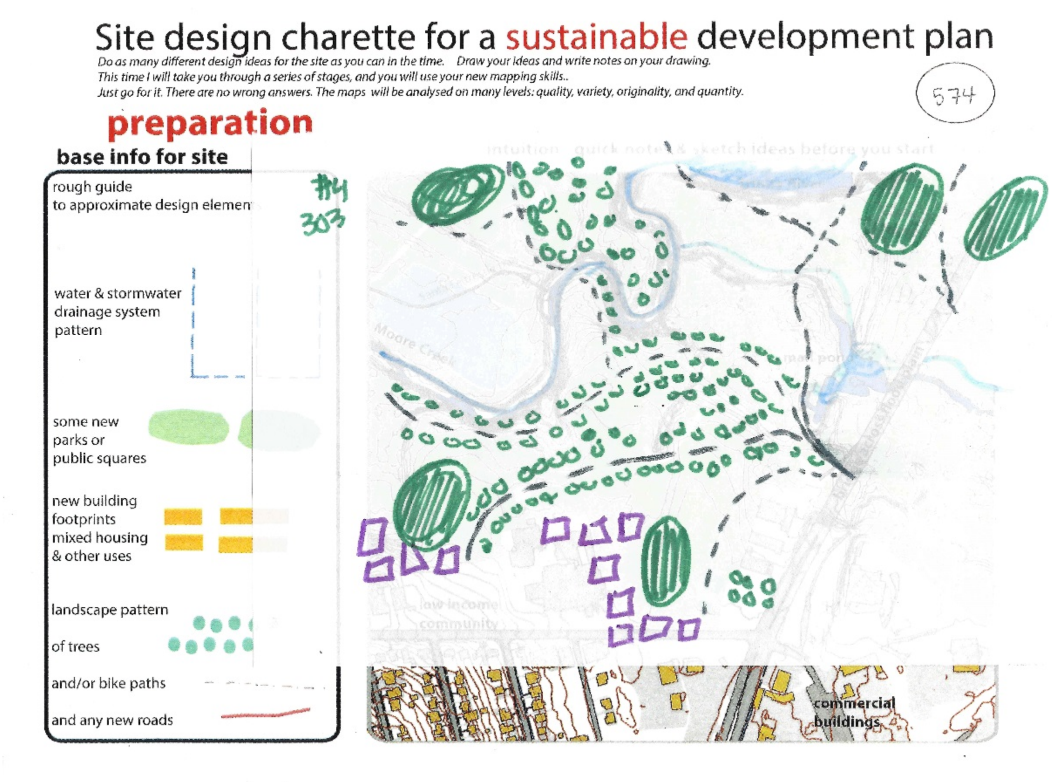
This paper chooses to focus specifically on the extent to which certain tools and teaching methodologies allowed students to improve specific design skills including design confidence, openness to iterative practices and self-understanding of their design process. What the study has not tested is the effect that these processes and tools had on the design work itself or any outcome showing improvement upon the ensuing site design project. It also did not test the possibility for using such tools in a collaborative design environment, another aspect of student learning which has been shown to support creative practice. Both of these issues would be worth following up in future research.

In more conceptual terms, a powerful aspect of GIS and mapping and, indeed, of several of the specific geo-design card methods is the extent to which GIS may be able to assist students' creative exploration through an abstraction of social and civic data by taking such tangible site structures into the realm of spatial transformation. It would be interesting to further explore this aspect of spatial abstraction and to uncover the extent to which student designers might be able to conceptually separate spatial explorations from the specifics of actual site plans. One can imagine that it could be precisely the potential spatial abstraction of non-visual site data that could give mapping, like diagraming, an increasingly powerful role on the path to more creative, divergent idea sets. An analysis of these kinds of exploratory design processes, however, would require a more detailed focus on specific steps, ambitions and tools used by individual designers, and a longer, narrower qualitative study of the ways in which student engineers can learn to navigate the spatial design process.

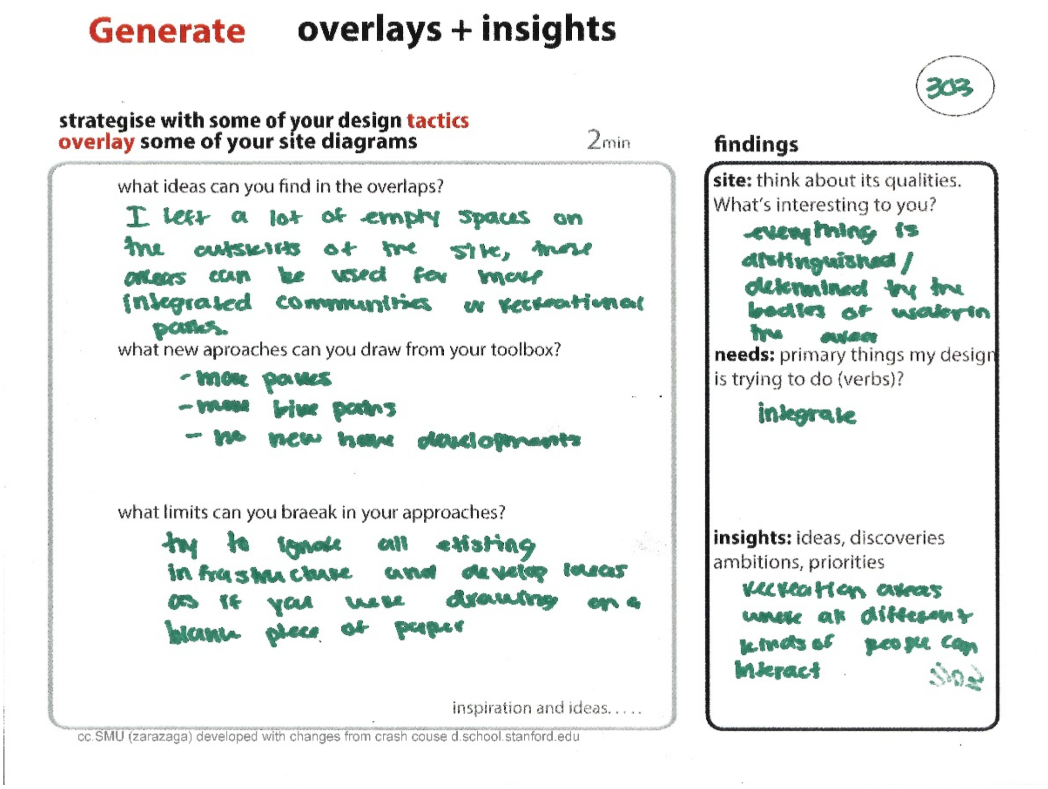
Figures



Site design charette for a sustainable development plan
Do as many different design ideas for the site as you can in the time. Think abotu and then draw your ideas and write notes on your drawings.
Just go for it. There are no wrong answers. The maps will be analysed on many levels: quality, variety, originality, and quantity.
72
(note: draw each sketchplan on a new sheet of tracing paper)
base info for site
16 mins
sketch plan
rough guide
to approximate design elements
water & stormwater
drainage system
pattern
71
#2
some new
parks or
public squares
new building
footprints
mixed housing
& other uses
landscape pattern
of trees
and/or bike paths
and any new roads
White Rock Creek
Park
APA
71.2



Site design charette for a sustainable development plan
Do as many different design ideas for the site as you can in the time. Draw your ideas and write notes on your drawing.
This time I will take you through a series of stages, and you will use your new mapping skills..
Just go for it. There are no wrong answers. The maps will be analysed on many levels: quality, variety, originality, and quantity.
574
preparation
base info for site
rough guide
to approximate design elemen
#4
303
water & stormwater
drainage system
pattern
some new
parks or
public squares
new building
footprints
mixed housing
& other uses
landscape pattern
of trees
and/or bike paths
and any new roads
commercial
buildings


Generate overlays + insights

303

strategise with some of your design tactics
overlay some of your site diagrams 2min

what ideas can you find in the overlaps?
I left a lot of empty spaces on the outskirts of the site, these areas can be used for more integrated communities or recreational parks.

what new aproaches can you draw from your toolbox?
- more parks
- more blue paths
- no new home developments

what limits can you braeak in your approaches?
try to ignore all existing infrastructure and develop ideas as if you were drawing on a blank piece of paper

inspiration and ideas.....

findings

site: think about its qualities. What's interesting to you?
everything is distinguished / determined by the bodies of water in the area

needs: primary things my design is trying to do (verbs)?
integrate

insights: ideas, discoveries ambitions, priorities
recreation areas where all different kinds of people can interact

cc.SMU (zarazaga) developed with changes from crash couse d.school.stanford.edu

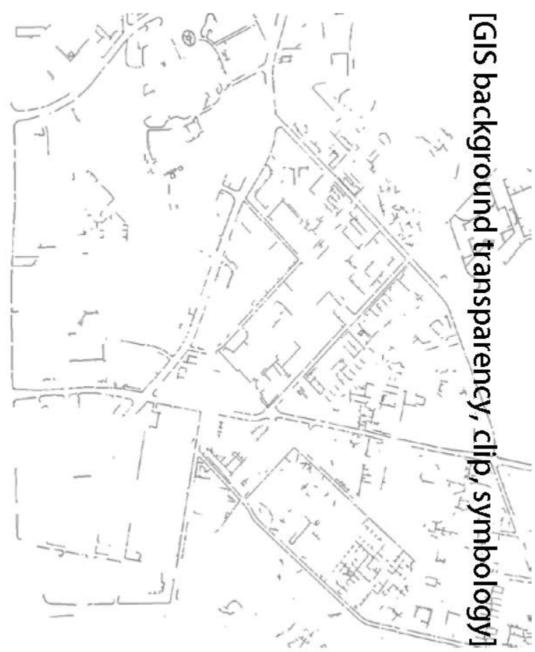
Figure 1: Sample illustrations of site design exercises; pre-test, and post-test (front and back)..

TOOL 2

ISOLATE
extract aspects or issues of the site and see each separately

mapping heuristic
- see unexpected patterns
- uncover hidden voids
- juxtapose differences

examples
- walkable pavement gaps
- see topography alone
- only trees, no buildings
- movement without roads

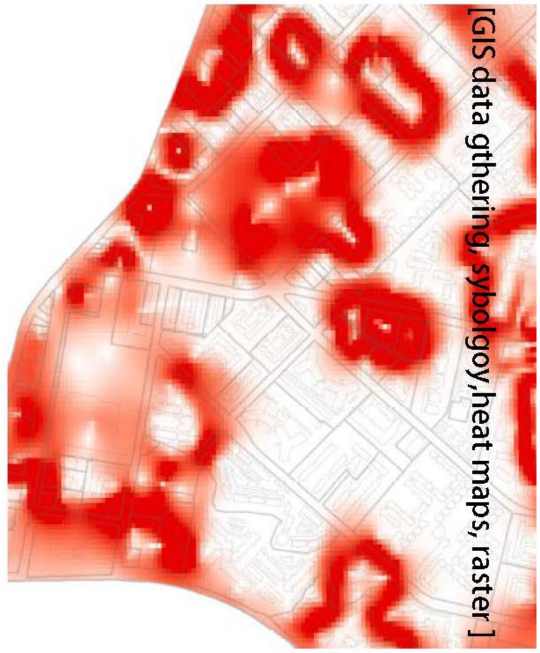


TOOL 5

PERCEPTION
map the invisible site

mapping heuristic
- map an aspect of the site which is perceived but not seen
- observe and annotate user perceptions through ways of acting and knowing

examples
- perceptions of incongruity between structure & difference of quality
- wind, sunshine, soil types, noise levels
- sensation of safety, warmth



TOOL 13

PROVOCATION & MISUSE
creative misuse of the toolkit

mapping heuristic
- modify plan with idea provoking operators
- search for aspects of difference, break symmetry, remove, unite, divide

examples
- intercept conventional pattern by slicing through, and inserting
- visualize crime zones as topography integrated with streetlight buffers

engineering idea
modify concept using idea provoking operators: unification, multiplication, division, object removal

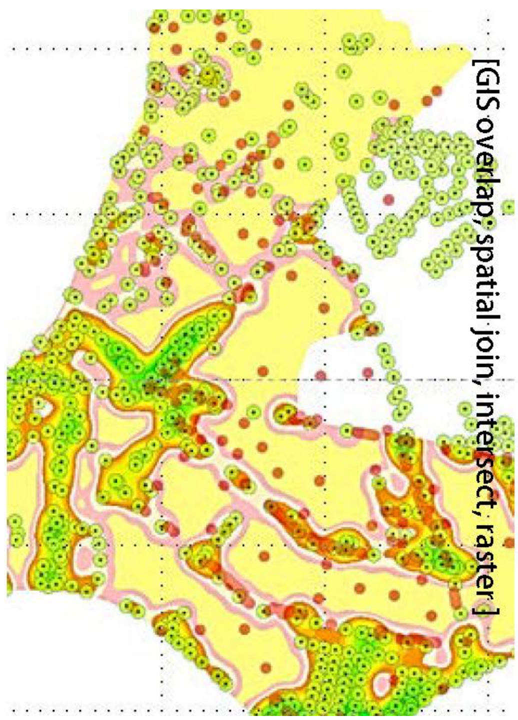
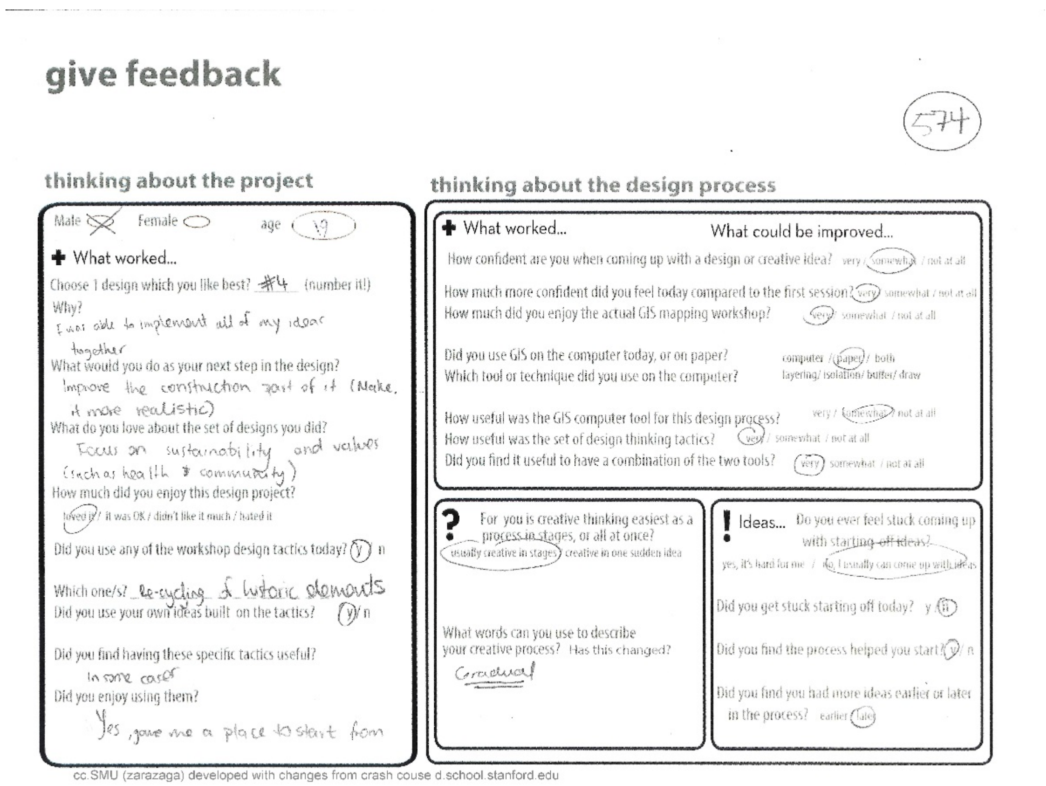


Figure 2: Sample illustrations of Geo-Design Cards



give feedback

574

thinking about the project

Male ✗ Female age 19

✚ What worked...

Choose 1 design which you like best? #4 (number it!)

Why?

I was able to implement all of my ideas together

What would you do as your next step in the design?

Improve the construction part of it (Make it more realistic)

What do you love about the set of designs you did?

Focus on sustainability and values (such as health & community)

How much did you enjoy this design project?

loved it / it was OK / didn't like it much / hated it

Did you use any of the workshop design tactics today? y n

Which one/s? Re-cycling of historic elements

Did you use your own ideas built on the tactics? y/ n

Did you find having these specific tactics useful?

In some cases

Did you enjoy using them?

Yes, gave me a place to start from

thinking about the design process

✚ What worked... What could be improved...

How confident are you when coming up with a design or creative idea? very / somewhat / not at all

How much more confident did you feel today compared to the first session? very / somewhat / not at all

How much did you enjoy the actual GIS mapping workshop? very / somewhat / not at all

Did you use GIS on the computer today, or on paper? computer / paper / both

Which tool or technique did you use on the computer? layering/ isolation/ buffer/ draw

How useful was the GIS computer tool for this design process? very / somewhat / not at all

How useful was the set of design thinking tactics? very / somewhat / not at all

Did you find it useful to have a combination of the two tools? very / somewhat / not at all

? For you is creative thinking easiest as a process in stages, or all at once?

usually creative in stages / creative in one sudden idea

What words can you use to describe your creative process? Has this changed?

Gradual

! Ideas... Do you ever feel stuck coming up with starting off ideas?

yes, it's hard for me / no, I usually can come up with ideas

Did you get stuck starting off today? y / n

Did you find the process helped you start? y / n

Did you find you had more ideas earlier or later in the process? earlier / later

cc.SMU (zarazaga) developed with changes from crash couse d.school.stanford.edu

Figure 3: Sample of students' pre and post-test written survey responses to questions about project and process.

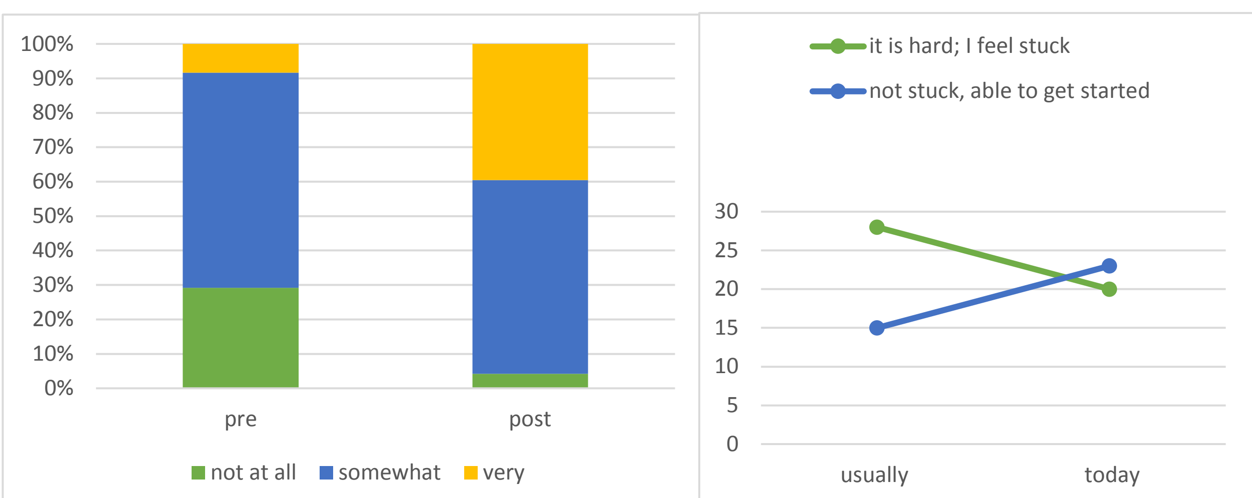


Figure 4(a) students survey responses to design confidence. 4(b) feeling stuck in getting started 'today', compared to usually.

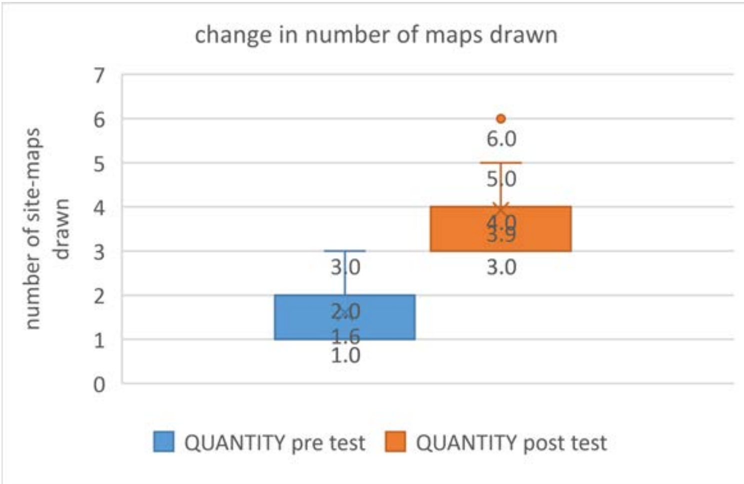


Figure 5: Change in total numbers of design ideas drawn by each student pre and post test

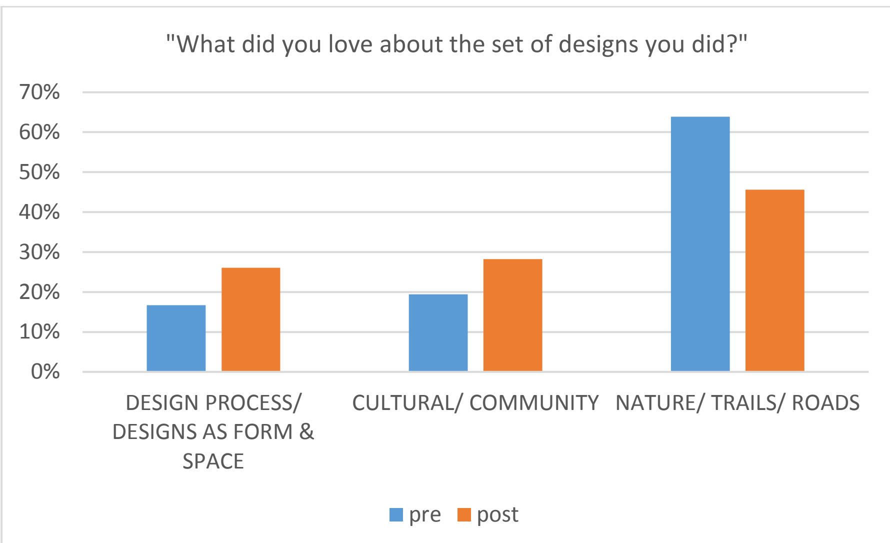


Figure 6:Pre and post-test responses to: "What did you love about the set of designs you did?"

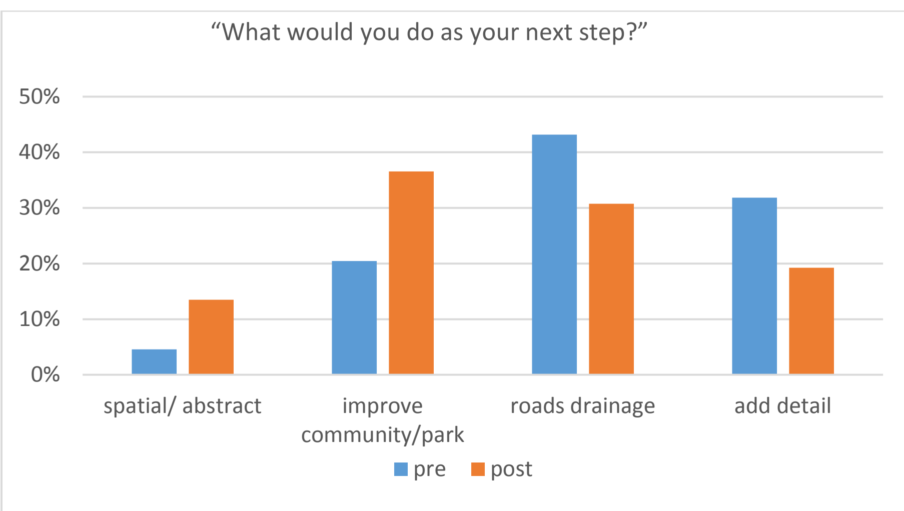


Figure 7: Pre and post-test responses to: "What would you do as your next step?"

References

[1] P. G. Klukken, J. R. Parsons, and P. J. Columbus, “The Creative Experience in Engineering Practice: Implications for Engineering Education,” *J. Eng. Educ.*, vol. 86, no. 2, pp. 133–138, Apr. 1997.

[2] C. Baillie and P. Walker, “Fostering Creative Thinking in Student Engineers,” *Eur. J. Eng. Educ.*, vol. 23, no. 1, pp. 35–44, Mar. 1998.

[3] O. Eris, C. L. Dym, A. M. Agogino, D. D. Frey, and L. J. Leifer, “Engineering Design Thinking, Teaching, and Learning,” *J. Eng. Educ.*, vol. 94, no. 1, pp. 103–120, 2005.

[4] D. H. Cropley and A. J. Cropley, “Fostering creativity in engineering undergraduates,” *High Abil. Stud.*, vol. 11, no. 2, pp. 207–219, 2000.

[5] C. Baillie, “Enhancing creativity in engineering students,” *Eng. Sci. Educ. J.*, vol. 11, no. 5, pp. 185–192, 2002.

[6] D. E. Goldberg, M. Somerville, and C. Whitney, *A whole new engineer: the coming revolution in engineering education*. Douglas, MI: ThreeJoy Associates Inc., 2016.

[7] H. Plattner, “Welcome to the Virtual Crash Course in Design Thinking,” *Stanford d.school*, 2012. [Online]. Available: http://dschool.stanford.edu/resources. [Accessed: 09-Dec-2015].

[8] M. Lande and L. Leifer, “Introducing A ‘Ways Of Thinking’ Framework For Student Engineers Learning To Do Design,” presented at the 2009 Annual Conference & Exposition, 2009, p. 14.796.1-14.796.12.

[9] S. R. Daly, J. L. Christian, S. Yilmaz, C. M. Seifert, and R. Gonzalez, “Teaching design ideation,” in *2011 Annual Conference & Exposition, American Society for Engineering Education*, 2011.

[10] J. P. Guilford, “Characteristics of Creativity,” 1973.

[11] R. A. Finke, T. B. Ward, and S. M. Smith, *Creative cognition: theory, research, and applications*, 1st pbk. ed. Cambridge, Mass: MIT Press, 1996.

[12] J. C. Gowan, “Some New Thoughts on the Development of Creativity,” *J. Creat. Behav.*, vol. 11, no. 2, pp. 77–90, Jun. 1977.

[13] Ö. Eris and others, “Asking generative design questions: a fundamental cognitive mechanism in design thinking,” in *DS 31: Proceedings of ICED 03, the 14th International Conference on Engineering Design, Stockholm*, 2003.

[14] T. M. Amabile, “Social psychology of creativity: A consensual assessment technique,” *J. Pers. Soc. Psychol.*, vol. 43, no. 5, pp. 997–1013, Nov. 1982.

[15] R. K. Sawyer, *Explaining Creativity: The Science of Human Innovation*. Oxford University Press, USA, 2012.

[16] D. J. Treffinger, G. C. Young, E. C. Selby, and C. Shepardson, “Assessing Creativity: A Guide for Educators.,” *Natl. Res. Cent. Gift. Talent.*, 2002.

[17] G. S. Alʹtshuller, *And suddenly the inventor appeared : TRIZ, the theory of inventive problem solving*. Worcester, Mass: Technical Innovation Center, Inc, 1996.

[18] J. P. Guilford, “Varieties of Divergent Production,” *J. Creat. Behav.*, vol. 18, no. 1, pp. 1–10, Mar. 1984.

[19] E. P. Torrance, “Can We Teach Children To Think Creatively?*,” *J. Creat. Behav.*, vol. 6, no. 2, pp. 114–143, Jun. 1972.

[20] D. L. Dean, J. M. Hender, T. L. Rodgers, and E. Santanen, “Identifying Quality, Novel, and Creative Ideas: Constructs and Scales for Idea Evaluation,” *J. Assoc. Inf. Syst.*, vol. 7, no. 10, p. 30, 2006.

[21] J. J. Shah, S. M. Smith, and N. Vargas-Hernandez, “Metrics for measuring ideation effectiveness,” *Des. Stud.*, vol. 24, no. 2, pp. 111–134, Mar. 2003.
[22] J. P. Guilford, “Creativity.,” *Am. Psychol.*, vol. 5, no. 9, p. 444, Sep. 1950.
[23] J. Fantauzzacoffin, J. D. Rogers, and J. D. Bolter, “Creative strategies in artists’ and engineers’ approaches to technology development: first results of a case study,” in *Proceedings of the 8th ACM conference on Creativity and cognition*, 2011, pp. 333–334.
[24] B. F. Robertson and D. F. Radcliffe, “Impact of CAD tools on creative problem solving in engineering design,” *Comput.-Aided Des.*, vol. 41, no. 3, pp. 136–146, Mar. 2009.
[25] J. Kramer, S. R. Daly, S. Yilmaz, and C. M. Seifert, “A Case-Study Analysis of Design Heuristics in an Upper-Level Cross-Disciplinary Design Course,” in *Proceedings of the Annual Conference of American Society of Engineering Education*, 2014, p. 24.23.1-17.
[26] B. Buxton, *Sketching User Experiences: Getting the Design Right and the Right Design*, 1 edition. Amsterdam: Morgan Kaufmann, 2007.
[27] I. Verstijnen, C. van Leeuwen, G. Goldschmidt, R. Hamel, and J. Hennessey, “Sketching and creative discovery,” *Des. Stud.*, vol. 19, no. 4, pp. 519–546, Oct. 1998.
[28] J. W. Booth, E. A. Taborda, K. Ramani, and T. Reid, “Interventions for teaching sketching skills and reducing inhibition for novice engineering designers,” *Des. Stud.*, vol. 43, pp. 1–23, Mar. 2016.
[29] D. G. Ullman, S. Wood, and D. Craig, “The importance of drawing in the mechanical design process,” *Comput. Graph.*, vol. 14, no. 2, pp. 263–274, 1990.
[30] M. C. Yang, “Observations on concept generation and sketching in engineering design,” *Res. Eng. Des.*, vol. 20, no. 1, pp. 1–11, Mar. 2009.
[31] J. Corner, “The agency of mapping: speculation, critique and invention,” in *Mappings*, D. Cosgrove, Ed. Reaktion Books, 1999.
[32] D. Wood and J. Fels, *The power of maps*. Guilford Press, 1992.
[33] I. Glass and D. Wood, “Mapping,” *This American Life*, 04-Sep-1998. [Online]. Available: https://www.thisamericanlife.org/radio-archives/episode/110/mapping. [Accessed: 31-Oct-2017].
[34] F. Cruz Prieto, “Una clase de la Observación - e[ad] Escuela de Arquitectura y Diseño,” presented at the Taller de Amereida, Pontificia Universidad Católica de Valparaíso, 1993.
[35] P. Eisenman, *Diagram Diaries*. New York, NY: Universe, 1999.
[36] Z. Liu and D. J. Schonwetter, “Teaching creativity in engineering,” *Int. J. Eng. Educ.*, vol. 20, no. 5, pp. 801–808, 2004.
[37] K. Overveld, R. Ahn, I. Reymen, and M. Ivashkov, “Teaching creativity in a technological design context,” *Int. J. Eng. Educ.*, vol. 19, no. 2, pp. 260–271, 2003.
[38] Vincent van Gogh, “Vincent van Gogh letters to Theo van Gogh. Nuenen,” 02-Oct-1884.
[39] Wayne McGregor, *Mind and Movement*. 2014.
[40] d-school, “The Bootcamp Bootleg,” *Stanford d.school*. [Online]. Available: https://dschool.stanford.edu/resources/the-bootcamp-bootleg. [Accessed: 20-Apr-2017].
[41] S. R. Daly, J. L. Christian, S. Yilmaz, C. M. Seifert, and R. Gonzalez, “Assessing Design Heuristics for Idea Generation in an Introductory Engineering Course,” *Int. J. Eng. Educ.*, vol. 28, no. 2, p. 463, 2012.
[42] Sinclair, Stéfan and G. Rockwell, “Voyant Tools,” 2016. [Online]. Available: https://voyant-tools.org/. [Accessed: 11-Jan-2018].
[43] M.-P. Kwan, “From place-based to people-based exposure measures,” *Soc. Sci. Med.*, vol. 69, no. 9, pp. 1311–1313, Nov. 2009.

[44] S.-L. Shaw and X. Xin, “Integrated land use and transportation interaction: a temporal GIS exploratory data analysis approach,” *J. Transp. Geogr.*, vol. 11, no. 2, pp. 103–115, Jun. 2003.
[45] C. Travis, *Abstract Machine: Humanities GIS (2015)*. ESRI Press, 2015.
[46] B. Shneiderman, “Creativity support tools: accelerating discovery and innovation,” *Commun. ACM*, vol. 50, no. 12, pp. 20–32, Dec. 2007.
[47] Ö. Eris, *Effective Inquiry for Innovative Engineering Design*. Boston, MA: Springer US, 2004.