



Digital-Storytelling for Apprenticeships in Sustainability Science and Engineering Design

Dr. Tamara Ball, UCSC Baskin School of Engineering

Dr. Tamara Ball is a project-scientist working with the the Sustainable Engineering and Ecological Design (SEED) collaborative at UCSC. She is the program director for Impact Designs - Engineering and Sustainability through Student Service (IDEASS) and Apprenticeships in Sustainability Science and Engineering Design (ASCEND). She is interested in understanding how extracurricular and co-curricular innovations can support meaningful campus-community connections in higher education and improve learning outcomes. Her research to date has focused on educational designs that emphasize learner initiative and agency through inquiry or problem-based learning in formal and informal learning contexts. She has published several papers on the characteristics of learning environments that support or constrain opportunities for any students (including those from non-dominant backgrounds) to participate in key science and engineering process skills such as scientific argumentation. Her work is largely informed by the principles and perspectives on human development and cognition articulated by Cultural Historical Activity Theory. Putting theory into practice, she teaches a service-learning course at UCSC wherein interdisciplinary teams of students work in an layered apprenticeship model with community mentors to design and implement sustainable solutions to water, energy, waste, transportation and social challenges using "green technology". Dr. Ball has worked as a research fellow with two NSF Centers for Learning and Teaching and most recently on several NSF projects that focus the integration of engineering and social science to support the advancement of experiential learning for sustainability in higher education.

Dr. Michael S. Isaacson, University of California, Santa Cruz

Michael Isaacson is the Narinder Singh Kapany Professor emeritus, professor of electrical engineering, Director of the Center for Sustainable Energy and Power Systems (CenSEPS) and a member of the Sustainable Engineering and Ecological Design Program at UCSC. He is recipient of numerous awards including a Sloan Foundation Faculty Fellowship, the Burton Medal from the Microscopy Society of America, an Alexander von Humboldt Senior Scientist Award, the Rank Prize in Optoelectronics and the Distinguished Scientist Award from the Microscopy Society of America. He is a Fellow of the AAAS and the MSA. He has been elected to the executive board of the Engineering Research Council of the American Society of Engineering Education and is series co-editor of "Advances in Microscopy and Microanalysis" published by Cambridge University Press. He is the PI on an NSF-PIRE grant on "US-Denmark Cooperative Research and Education in Intermittency-Friendly Community-scale Renewable Energy Micro-grids". Professor Isaacson has a B.S. in Engineering Physics from the University of Illinois at Urbana-Champaign and an M.S. and PhD in physics from the University of Chicago. He came to UC Santa Cruz in 2003 from Cornell University where he was a professor of Applied and Engineering Physics, director of the Keck Foundation Program in Nanobiotechnology and Associate Dean of Research, Graduate Studies and Professional Education in the College of Engineering.

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Overview

Our research team is investigating whether and how involving at-risk youth in “digital storytelling” production projects can motivate, support and transform their interests in STEM education and/or in pursuing STEM- related careers. These fledgling digital media artists are recruited from vocational training centers to apprentice with undergraduate and professional videographers who are themselves collaborating with interdisciplinary teams of undergraduates that use STEM to design, implement and evaluate innovative green technologies and sustainable systems that show potential to mitigate environmental impacts while improving society. Whereas the educational value of opportunities to work as apprentices with professionals in the field to design and build sustainable engineering projects are being established separately, our research team is now interested to learn whether students focused on documenting and narrating the progress and results of these projects can achieve comparable learning outcomes. For the purposes of this research we focus on a particular engineering process skill: a learner’s ability to formulate a problem statement and understand the implications of the way a problem is articulated on any proposed solutions.

Introduction: Educational Applications of Digital Storytelling

Our research investigates digital storytelling as a pedagogical approach that can be used to increase and diversify participation in Science Technology Engineering and Math (STEM). Digital storytelling differs significantly from documentary filmmaking, as it is a highly *reflexive* activity that leads participants through powerful forms of self-discovery in relation to their place in society and their intellectual and creative abilities, allowing them to engage in rigorous meaning-making¹. Hughes² observes that the multimodal design of digital storytelling offers multiple entry points of creativity providing greater potential for storytellers to claim ownership of their story without fundamentally changing target content. Altogether, this body of research examines how storytelling can create spaces that help learners, through the achievement of greater autonomy in and ownership of their learning processes, negotiate the sometimes oppressive “learning identities” created in formal and informal STEM learning contexts; communicate and explore new subjects with others; acquire “new literacies” and gain advantages in a workforce that must be increasingly savvy to the quickened pulse of the digital world.

Absent from much of this literature is research assessing whether the self-discovery and motivation to learn through storytelling can facilitate disciplinary learning about formal concepts and processes as participants connect what they know to what is known by experts in a field. The few studies that do consider such connections largely show changes in attitudinal and behavioral rather than evidence of cognitive learning outcomes. A report commissioned by the National Research Council³ suggests that even less is known about the specific impacts of digital media--in particular, audiovisual media--on STEM education, whatever the setting (formal or informal). Those few studies that do address this lacuna focus mainly on broadcast or animated media⁴ or “media-rich” situations⁵ in which interactive or “playable” media is designed to convey expert knowledge to novices, rather than on the media and content produced by learners themselves. A

notable exception in informal educational settings is the work by Calabrese-Barton and her colleagues⁶ which demonstrates that involvement of low-income, minority and other “at-risk” students in digital storytelling supports engagement with and achievement in science. For example, Calabrese-Barton’s and O’Neill’s exploration of young people’s production of a video about “life and science” in the inner city shows how “counter-storytelling” through visual media “can build community among those at the margins, challenge the perceived wisdom of those at society’s center by providing a context to transform established belief systems, and show new and different possibilities by combining elements of the story and the current reality”⁷ (p. 142).

Building on this work we are interested in investigating the educational benefits of learner-generated media through digital storytelling for at-risk youth enrolled in Regional Occupational Programs (ROP) at vocational training centers with respect to their engagement in STEM, understanding of key concepts in sustainable engineering, and interest and confidence in pursuing careers that involve new/green technologies. We are particularly interested in understanding how learning outcomes achieved by youth engaged in digital storytelling compare with learning outcomes achieved by youth involved in “hands-on” engineering projects that require physical work with materials, tools and equipment. To be clear, our goal is not to evaluate one approach as being superior to the other- we assume that each have their advantages and shortcomings - but rather to document and understand the different learning outcomes and pedagogical tradeoffs associated with each. Preliminary results from our own work suggest that that digital storytelling apprentices produce equally accurate and slightly more sophisticated problem statements for projects than apprentices working in more traditional “hands-on” modalities. These early results also suggest that digital-storytelling helps at-risk youth gain confidence with respect to their participation in STEM and to distinguish scientific from non-scientific arguments.

Situated Cognition and Cultural Historical Activity Theory

Our approach is heavily informed by theories of “situated cognition” in the learning sciences⁸, which emphasize that learning is a social endeavor that cannot be separated from the context in which it takes place⁹. Theories of situated cognition^{10,11,12} posit that skills and knowledge develop interdependently through increased degrees of “intent participation”¹³ in different learning communities organized around shared goals, and are reinforced through responsive facilitation or devices that function as learning scaffolds^{17,18}. Most prominent among these theories is *Cultural Historical Activity Theory* (CHAT)⁹, which emphasizes the influences of different components of the “activity system” including the motivating goal or “object of activity” and how that shared goal organizes and mediates the relationships between participants, the physical and/or symbolic tools they put into use, their understanding of the actions they engage in and so the meanings they are able to derive/create from the actions they undertake.

Apprenticeship-style learning is one way to put these theories into practice, and educational designs that allow for “cognitive apprenticeship”¹⁶ have been validated in both formal and informal STEM learning contexts¹⁸ as a productive alternative to “teacher-centered” classroom pedagogies. The latter assume, ineffectively, that explaining (“telling”) how scientists do science or how engineers create and validate their solutions can bring about transformative or lasting changes in how outsiders/novices themselves participate in STEM. Too often the

organizing goal (as perceived by learners) in didactic learning contexts that focus on “knowledge acquisition” is to satisfy the teacher that particular information has been received rather than to use that knowledge to accomplish practical outcomes with “real world” impacts. By contrast, research across the learning sciences has shown that *when learners themselves are compelled to explain or demonstrate what they are beginning to understand they engage in a transformative and lasting acts of knowledge-creation*¹⁹. Our program attempts to put these theories into practice using digital media as a creative platform to catalyze productive meaning-making and knowledge-transformation processes.

Program Description: Digital Storytelling Apprenticeships at a Green Careers Vocational Training Center

The primary audience for the ***Apprenticeships in Sustainability Science and Engineering Design (ASCEND)*** program consists of approximately 40 at-risk youth between the ages of 15 and 19 at the Natural Bridges and Ponderosa Green Career Training Centers, two vocational training centers (VTCs) that offer alternative education and training for youth struggling to achieve social, interpersonal and academic success in formal educational settings. These two VTCs are part of a larger network of 467 so called “California Partnership Academies” (CPAs). Each CPA serves 100 to 200 students in grades 10 through 12 and combines academics with vocational coursework. The VTCs that have partnered with ASCEND specialize in environmental education and green careers workforce training. They also support service-based learning opportunities with local employers through the Santa Cruz County Regional Occupation Program (ROP). ROP centers, such as the Natural Bridges Green Career center, receive funding from the California Department of Education for programs that include career and workforce preparation for high school students and adults, preparation for advanced workforce development and training, and upgrading of existing vocational skills. Given the focus of these particular VTCs on “green careers” they are encouraged by California Governor Brown’s recent (2013) signature on SB X 1-2, which provides \$8 million a year for five years to fund existing or new CPAs focused on clean technology and renewable energy.

The majority of the “at-risk” youth enrolled at these VTCs are low-income or minority students who often face a variety of personal challenges and are not on track to graduate from a comprehensive high school. Some have been diagnosed with learning disabilities while others have found the public education system to be unresponsive to their diverse needs. While they are working towards high school equivalency credentials by satisfying GED requirements, many of these youth are unlikely to graduate with skills they need to find green jobs in fields that require Science Technology, Engineering or Mathematics (STEM).

When at-risk youth stop learning in school, the burden of integrating them into a community falls on alternative educational programs and informal learning venues such as after-school programs, community centers, museums, science centers and other local organizations (Rahm & Ash, 2008). For this reason one focus of ASCEND has been to build partnerships that leverage the resources of a variety of formal and informal learning venues, including the two VTCs, a major research university (UCSC), two local science museums—Santa Cruz Museum of Natural History (Natural History Museum) and the NOAA-subsidized Monterey Bay National Marine Sanctuary Exploration Center (Exploration Center)—and public spaces supported by municipal

government such as the Santa Cruz Municipal Wharf. ASCEND benefits from a network of existing partnerships with local companies, private entrepreneurs and other organizations that have been established through an undergraduate service-learning program at the UCSC Baskin School of Engineering. This program focuses on sustainable development in the built-environment and requires partners to submit projects organized around a tangible engineering-design type deliverable. New partnerships with the two museums were expected to motivate youth participation by providing prominent and public venues for showcasing their digital narratives to a broader cross-section of community members than might be expected to attend the same kind of event if it were hosted at the training center. As of Fall 2014, ASCEND successfully hosted the first community public screening event “*Seeding Innovation*” showcasing four films at the Exploration Center. The event attracted over 100 viewers who participated in post-viewing discussions, explored demonstration materials provided by project teams and partners, and gave additional feedback by writing their responses to four prompts on paper “leaves” that were fixed to the ‘branches’ of a three-dimensional cardboard tree located just outside the theater. This event was significant for attending VTC apprentices because their won work was being featured and because the Exploration Center represents a somewhat austere space that they might not otherwise step into or a community that they might otherwise identify with.

Two types of apprenticeships: Design-and-build and Digital-storytelling

Given our focus on understanding the educational benefits of digital storytelling as an alternative approach to support apprenticeship learning, we thought it instructive to compare the learning outcomes for digital story-telling apprentices with learning outcomes for apprentices engaged in more conventional “hands-on” learning activities. For that reason we designed a program that included two apprenticeship “tracks”: **digital-storytelling** and **design-build**.

In the digital storytelling track apprentices were first instructed (50 minutes per week over a period of approximately three months) in the technical aspects of using videography equipment for recording and in using computer software for editing audiovisual digital media. Subsequently, apprentices in the digital-storytelling track chose to follow and document either the sustainable design project happening on site at their VTC or one of two others happening off-site (see below for more details on these projects). For the remaining five months of the school term, the youth were responsible for shadowing and collaborating with their professional and undergraduate videography mentors to produce a short (5-7 minute) “digital story” about a sustainable design project that could be presented to public audiences. While the burden of the final production fell to the professional and undergraduate mentors, youth at the VTC were expected to contribute throughout to editorial decisions and to help shape the structure of the narrative. They were also given discrete assignments to collect specific kinds of audio or visual materials that could be used in the films. Additionally, youth were invited to go in front of the camera and share their own perspectives on the featured project or find other creative ways to include their “voice” in the final product.

In the design-build track apprentices were first introduced to project topics through demonstrations/presentations by undergraduate teams leading the projects. Undergraduate project teams prepared and delivered mini-lessons to familiarize youth with some of the key

STEM concepts and practices essential to design-build activities. Subsequently, for the remaining five months of the school term, design-build apprentices participated in weekly on-site working sessions where they shadowed or worked side-by-side with undergraduates performing specific tasks such as gluing PVC conduit together to transport rainwater from a roof to a storage container, calculating distances and gradual fall to ensure proper flow, or using digital light meters to compare luminance levels in a classroom before and after the installation of an array of solar tubes (passive solar day-lighting technology). Again the burden of completing the design-build projects fell to the undergraduate team leaders, while youth participation as project apprentices was constrained to scheduled “work days”.

Projects completed in the 2013-2014 academic year

In the 2013-2014 school term three design-build projects and three digital stories directly involving VTC apprentices were completed. Short descriptions of each project are provided in the table below. However the project that gained the most sustained and consistent participation from VTC apprentices, in both tracks, was one that focused on rainwater catchment and “smart” irrigation because it was happening on site at the Natural Bridges Green Career Center (NBGC) VTC. For the purposes of this analysis we have focused our discussion on the learning outcomes associated with participants associated with this project in particular.

Table 1. VTC involvement in Design-and-Build Projects

Project Title	Description
Rainwater Catchment and Smart Irrigation	Design and installation of two 4,000 gallon rainwater tanks, with appropriate transfers, filters and pvc conduit. Develop solar-generated pumping infrastructure for moving water from storage to irrigation and greywater uses regulated by moisture sensors in garden beds supported by wireless data feeds.
Solar Tube Design and Installation	Luminance testing in the classroom to gauge optimal placement of 12 tubular daylighting devices (“solatubes”) in classroom. Youth assist professional roofing contractor to plan and execute circular incisions in ceiling and roof and install, to bring daylight into interior spaces where traditional skylights and windows simply can’t reach.
Waste-to-Energy and Waste Management	Complete waste assessment of the Santa Cruz Municipal Wharf’s waste stream. Results guide feasibility and selection of a technology (pyrolysis or anaerobic digestion) to introduce waste-to-energy system on the wharf. Assessment includes comparisons with calculated costs, both environmental and monetary, of different waste disposal options.

Table 2. Digital Storytelling Projects

Project Title	Description
Supercharged with	Follows the story of a dedicated philanthropist and his team of

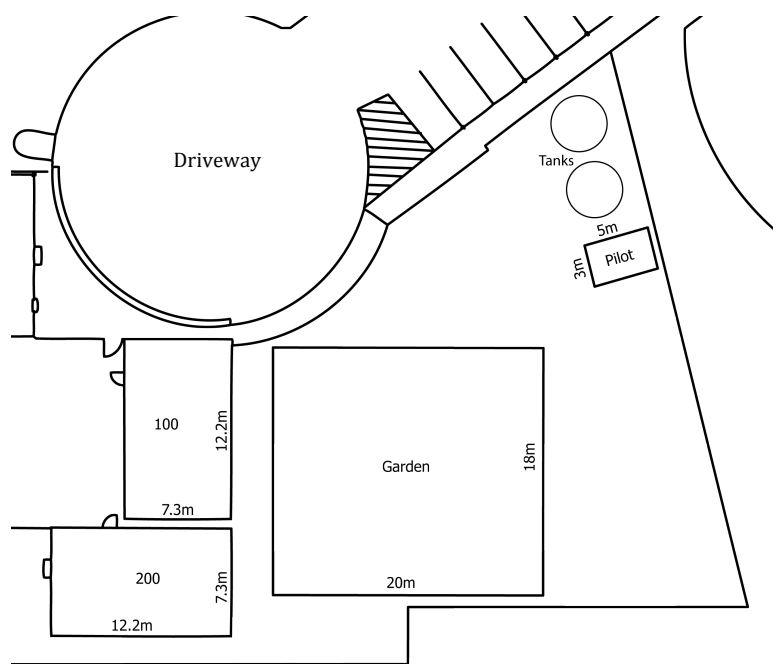
Supercapacitors	undergraduate researchers seeking to improve the capacitance of lithium-ion batteries through supercapacitor designs using a new material – graphene – to improve performance.
Catching the Rain: Water Conservation in Santa Cruz	Captures impacts of 2014 drought conditions in California and narrates the steps a team of dedicated undergraduates working with teenage apprentices are taking to provide a rainwater catchment system as a viable solution.
Waste Not Want Not	Documents municipal refuse disposal practices and conditions near Santa Cruz and follows the efforts of municipal leaders including the Wharf Master at the Santa Cruz Municipal Wharf to broker partnerships with neighboring municipalities as they explore the feasibility waste-to-energy technology for the region.

Design-build: Rainwater Catchment

The rainwater catchment project at the Natural Bridges Green Career Center was a multi-year project, which benefitted from the involvement of a variety of stakeholders including VTC youth, VTC teaching staff, municipal legislators, community members, industry professionals, university researchers and undergraduates. It was a highly interdisciplinary project that required knowledge and skills in a variety of fields including green-building, landscaping and gardening, plumbing and water management, conservation, geology, agroecology, STEM education, power systems and renewable energy science, applied physics computer and electrical engineering, computer science, environmental economics and policy.

With funding through a cooperative agreement between the municipality and the university to reduce carbon emissions, the overarching goal of the project was to set up an off-grid rainwater catchment system with a capacity of 8,000 gallons (2 x 4,000 gallon tanks) and powered by solar photovoltaics. The system is designed to be self-regulating through the integration of moisture sensors, a pump and a seven-valve control system, and to incrementally release stores of rainwater according to pre-set specifications for responses to changes in soil moisture. VTC

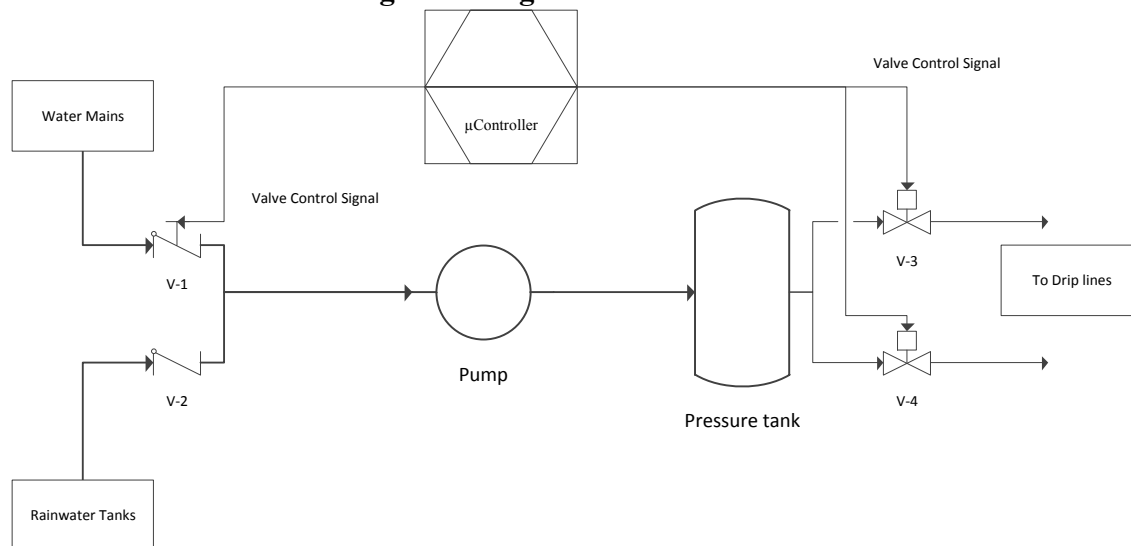
Figure 1. VTC Rainwater Installation Site



teenage apprentices worked side-by-side with undergraduates to design the system, install and connect tanks, conduit, filters, and irrigation equipment. They were privy to demonstrations but not directly involved in the work by computer and electrical engineering students to create the hardware and software for the system controlling water flow to irrigation lines in the school garden.

In addition to their “hands-on” work outside, VTC apprentices participated in a set of 12 classroom activities designed to increase their knowledge of local decentralized rainwater catchment as an alternative to centralized municipal water. They learned about the hydrology of the surrounding area as well as state and local legislation and policy impacting building codes and sanctions for rainwater catchment systems in general. They learned about the tradeoffs between rainwater catchment and other efforts to conserve water (e.g. desalination) as well as the technical engineering requirements for a system to perform as expected. Youth used math to make predictions about the total roof area and rainfall that would be required to satisfy irrigation needs; to calculate the maximum feasible height of the tanks and rise and run of the pvc conduit that would be used to transfer water from rooftop to tanks.

Figure 2. Logic Model for Valve Controls



Digital Storytelling: Rainwater Catchment

As summarized above, VTC digital storytelling apprentices participated in the production of several undergraduate film projects, however given that the rainwater catchment project was happening on site at the VTC– the team working on this production had more regular opportunities to apply the digital storytelling skills they were gaining directly to this particular project-topic. Digital storytelling apprentices began their apprenticeship with a local freelance professional videographer, and his undergraduate assistants with a set of eight technical training sessions. These sessions were designed to familiarize youth the equipment and software they would be using to document projects as well as to inspire them to find their own “voice” or perspective and explore how that could be represented through audio-visual media.

Training activities in this initial period included learning the basics of camera use, discovering the principals of digital storyboarding, specifics in documentary shooting, the importance and effect of lighting and audio, as well as how to professionally shoot an interview for a documentary film. With a strong focus on documentary digital storytelling involving local and sustainable projects, these apprentices were immediately thrown into a collaborative and creative experience that later could be shared with their community.

As apprentices became more adept at handling equipment, they were given field assignments and made responsible for documenting the progress of the rainwater catchment system as it was being installed on site and the extent to which their peers were involved. They also practiced interviewing each other, their design-build counter parts, undergraduate project leads and volunteers about the purpose and design of the system and about sustainability in general.

Research Goals & Hypothesis

The goal of this research was to understand whether digital-storytelling works as a viable alternative to more familiar “hands-on” approaches to apprenticeship learning and to discern and understand the pedagogical tradeoffs that choosing this alternative might incur. Specifically we were interested in whether digital-storytelling apprentices (as compared to their design-build counterparts) would a) understand multifaceted characteristics of the sustainable engineering “problems” that different design-build projects are attempting to resolve, b) understand the advantages, limitations and tradeoffs inherent to proposed solutions c) gain interest, awareness and confidence in pursuing / participating in local sustainable development projects c) gain awareness of more options for green careers that involve STEM skills and the interest and motivation to explore and later pursue them.

We hypothesize that tributes upholding apprenticeship learning in STEM as a favorable alternative to classroom learning need to look beyond the existing consensus around the importance of the benefits of physical and practical “hands on” experience of working with the “tools of the trade” (including equipment, materials, or analytic tools). The success of apprenticeship learning may also depend on the ability of mentors to provide opportunities for learners to experience a sense of joint-purpose, ownership, and responsibility for project deliverables, which in turn may culminate in opportunities to exercise creativity and agency. Accordingly, we postulated that despite the lack of “hands-on” exposure to engineering tools and processes, the production of a digital story may provide equally or more compelling reasons to learn and thus, could result in comparable incentives to learn and learning outcomes for the learners involved. Like apprentices who gain “first hand” opportunities to “learn by doing” as they engage in physical work, digital media can be used to reposition learners as “agents” rather than as “subjects” of the learning activity. Our purpose here is to learn whether this might be equally important in mobilizing their motivation to learn and pay attention to the STEM content and practices involved in the projects they witnessed. To be clear, we did not expect to find that one modality (design-build vs. digital storytelling) was patently “better” than the other; rather we expected that each approach to apprenticeship learning could be equally viable and beneficial but that we might observe tradeoffs between the two - or that each approach leads to different emphases on particular kinds of learning outcomes.

We did anticipate that one particular advantage of apprenticeship through digital storytelling is the possibilities it provides to not only communicate advancements in sustainable engineering to wider audiences, but also to expand actual participation in STEM. Due to the complex or technical nature of some design-build sustainable engineering projects it can be difficult to include new participants who don't have the relevant background or skill set in the actual implementation of a project without jeopardizing or impeding the steps required to deliver a new system or technology on time. However through digital storytelling, we predicted, participants inexperienced in engineering / using technical tools could get up close to the kinds of technical project activities that they might not otherwise have access to. At the same time they were able to maintain ongoing legitimacy for their peripheral participation by leveraging their responsibility for documenting projects as they progressed.

Methodology

In order to test our hypothesis we set up a design-experiment involving the two types of youth apprentices at the Natural Bridges Green Career Center. All participants were informed of the research being conducted and its purpose and were asked to either sign consent forms or (if they were less than eighteen years old) return consent form with signatures of their parent or legal guardian. Provisions were made for individuals who agreed to participate in the research but did not want to be recorded. **DS apprentices** focused on the digital storytelling curriculum as described above and **DB apprentices** focused on the design-build curriculum as described above. Both groups completed a number of pre/post and formative assessment activities as described below.

Pre/ Post Survey –Perspectives on Green Careers

We designed a survey to learn more about the incoming and outgoing perspectives of the apprentices involved. The survey including prompts that queried their awareness and perspective on the importance of STEM to sustainable development, their interest and confidence in pursuing jobs that to some extent involve STEM in the emerging 'green-tech' workforce, perceptions of themselves as individuals who belong and can make a difference in their community, their familiarity and confidence in a) using technical devices and their reflections on how they believe they learn best. Participants used a Likert scale (Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree) to respond to most features, a few of which were followed by a short answer prompt (e.g. "Give an example of technology with which you could imagine working"). The survey also used images of people working in jobs that could or could not be seen as directly related to sustainability issues. For example one image depicts a farmer riding a tractor through a green field. Another image depicts a person working with a laptop sitting in front of a huge data server. After each image (five images total) participants were asked to first write a one-line response to this question: *What job could this person be doing?* Then they were asked to check a box indicating a response of "Yes", "No", "Maybe" or "I don't know" to each of the following four statements:

- ☐ This job requires a lot of technical skill or knowledge
- ☐ This job is accessible to me

- ☐ This job is a green career
- ☐ This is a job I could see myself doing

Subsequently they were asked: *How might this job be important to sustainability?* And prompted to choose one or more responses from the following list:

- ☐ It involves the management of natural resources
- ☐ It directly impacts energy use
- ☐ It directly impacts land use
- ☐ It directly impacts water use
- ☐ It has social impacts
- ☐ It has economic impacts
- ☐ It is related to urban planning
- ☐ Other:

Learning Reflections – First Response

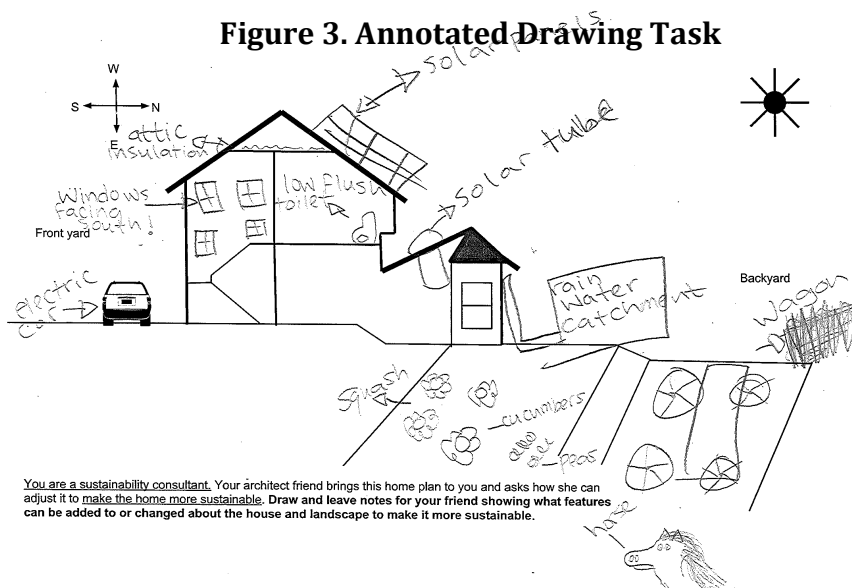
In order to understand participants' first reactions to each of the learning activities they were involved in, we asked them to complete a “quick and dirty” written response sheet which asked them to rate the primary learning activity of the day (on a scale of 1 – 5 with 5 being the best) and to record something they thought they had learned and would “take away” from the activity. Respondents were also asked if they had suggestions for how the activity might be improved.

Pre/post Drawing Assessment - Sustainability Systems

In order to understand whether and how their different responsibilities as either digital storytelling or design build apprentices were impacting their understanding of “sustainability” as an interlocking and multifaceted system, we created a pre/post “annotated drawing task” (See Figure 3). The task open-ended and intended to flush out individuals' original perspectives and thinking on the characteristics of sustainable systems in the built environment and the degree to which they understand sustainable technologies as part of larger ecological and human systems. Participants responded to a written prompt (as shown in Figure) and were encouraged and

supervised by undergraduates and adults circulating around the room. Including the introduction to the activity, participants were allocated about 30 minutes to work on their drawings.

A rubric was developed to score writing



and illustrative features** of the completed drawings. Scoring criteria focused on a) the total number of illustrated features b) whether or not features included reflected technologies students were working with directly (e.g. solar tubes and rainwater catchment) c) descriptive codes for features in the following categories: Landscape, Alternative energy generation, Energy conservation / efficiency, Sustainable transportation, Water conservation and Other (i.e. features such as a table or a chimney that were not obviously related to sustainable design). Two evaluators used a sample set of the data to establish inter-rater reliability using this rubric and 75% agreement was established before a single coder was tasked with coding the remaining data.

Audio Diaries – Understanding the Problem

We employed free open source software from *Sound Cloud* (<https://soundcloud.com/>) to delve further into participants' understanding of the projects they were involved in – and more specifically of how they understood project tasks in the context of the purpose they served or the “problems” they were intended to address. Participants were asked to record an entry for each of the major topics introduced. Prompts consisted of variations on three basic questions:

- i) Describe what you are working on.
- ii) What is the purpose of [insert technology] / Why is [insert technology] important?
- iii) Does this / how does this make a difference to you personally / your own life or your community?

Originally this assessment was conceived as an “audio diary” where participants would individually and privately record their thoughts in response to each of three written prompts. However we quickly realized that these teenagers required more structure and supervision to complete the task and so the weekly exercise was adjusted to an interview question and answer format with participants working in pairs under the supervision of one of the undergraduate interns working on site.

Challenges and Limitations

We encountered a number of challenges while working with VTC youth participants. Youth participating in this alternative education program were typically there for remedial purposes; for example they needed to earn specific credits in courses (e.g. math) that they had been unable to complete prior, had been suspended or dismissed from high-school for disorderly conduct, considered at risk (but not yet diagnosed) with learning disorder or involved in a variety of other circumstances that put them at risk of failing to earn a high-school diploma or GED. The circumstances that brought these teenagers to the VTC were always changing which meant we could never be sure how long they would be participating in the programs on offer. Enrollment could span anywhere from six weeks to two years. Furthermore the qualities of their home lives were such that their attendance from one week to the next was often inconsistent and unpredictable. For these reasons the data we were able to collect – particularly that which was designed to be collected through pre/post measures was compromised. Many of the youth who

* In this analysis we counted multiple additions or “mentions” of a feature by the same participant. For example if the same participant added a low flow toilet as well as laundry -to-landscape feature that drawing would be scored as showing 2 mentions of water efficiency features.

completed pre-assessments at the beginning of the term were no longer at the VTC by the end of the school term. Meanwhile others joined the program midway through. Some participants were simply absent on the days when the assessment was administered. In hindsight we realized that in working with this population, ongoing assessment measures – such as the First Response and Sound Cloud Audio diaries – were more appropriate and effective than pre/post measures. For that reason we are only able to report here in detail and with confidence on the results of those two measures but will include discussion of some observations gleaned from the annotated drawing task.

Results

Written responses to **First Response** reflection prompts were collected for a total of fifteen learning activities, eight of which focused on design-and-build tasks and seven of which focused on digital-storytelling (number of respondents = 20). Five of the eight design-and-build activities touched on topics related to water/water conservation, irrigation, or energy and water. As mentioned above, respondents were asked to rank their overall enjoyment of the activity on a scale of one to five with higher numbers representing a greater sense of enjoyment. Figure 4. summarizes responses to this prompt.

As a follow up question, participants were also asked if there was “...anything they could think of to improve [the quality of the learning activity]”. As illustrated in Figure 5, we found that participants offered more suggestions to improve design-and-build activities than they did for digital media activities and gave more indications that that they were satisfied with the way that digital media activities were conducted.

Taken together, these results support the conclusion that respondents were more satisfied with and found learning activities focused on digital media production more enjoyable than design-build activities. However further analysis was required to determine whether their enjoyment of these activities correlated to improvement in their content understanding and for this we relied on evidence collected through “Sound Cloud” **audio diary entries**.

Figure 4: First Response - "enjoyment" average ratings

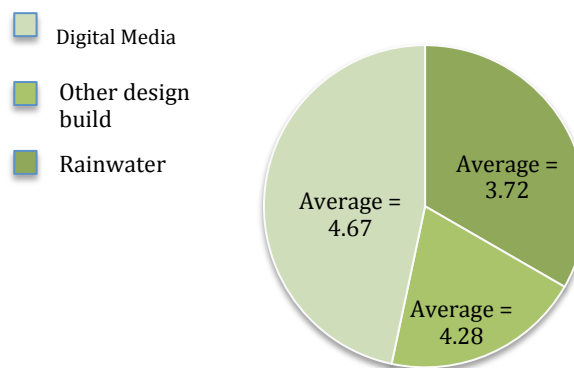
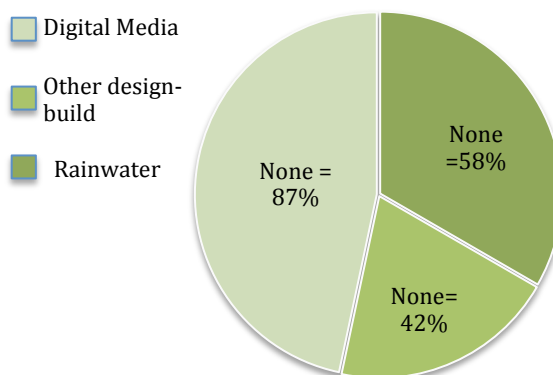


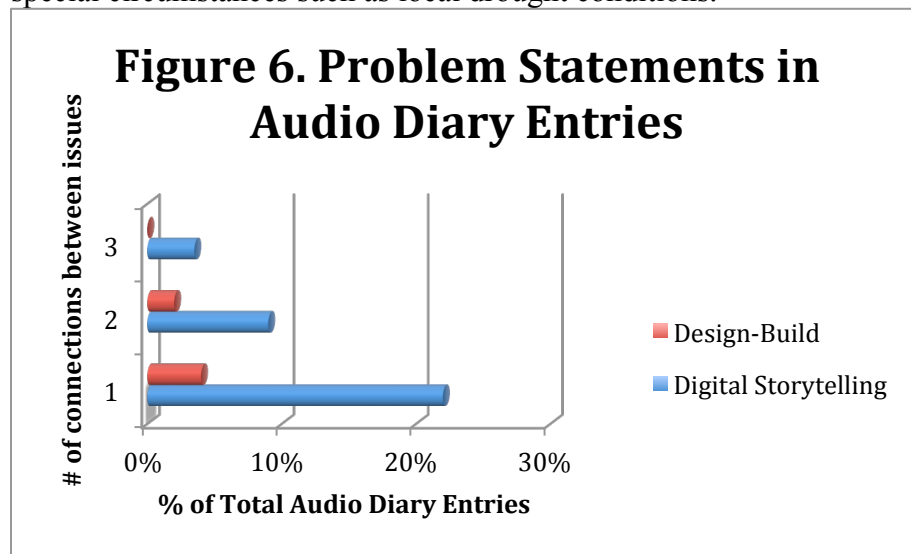
Figure 5: First Response - suggestions for improvements



In our review and analysis of approximately 70 audio diary entries (by 16 participants) related to either digital media, rainwater catchment or other design-and-build projects we were

focused on three major queries: what was the sophistication of their understanding of the purpose of this project (or the problem it was solving); how well could they explain the technical requirements for the system to work and; how well could they explain the relevance of discrete tasks or activities to the overall design and construction of the system. Due to the conversational nature of these audio diary entries it was difficult to devise a scoring method to quantify results and we must instead give a qualitative description of what we found.

During the first three weeks of the project period, we found that, across the board, apprentices in both tracks demonstrated only a rudimentary understanding of the purpose(s) rainwater catchment systems are meant to serve. Early responses included statements like “we need rainwater catchment so that we can save the water and use it for other things” or “water is important because we use it everyday for our everyday needs” or “we need rainwater catchment to store water and make it into fresh water” or “we need rainwater catchment because it can help us when we don’t have any water”. These responses indicated that participants saw rainwater catchment systems a kind of temporary stopgap – a “Bandaid” solution that could be applied to special circumstances such as local drought conditions.

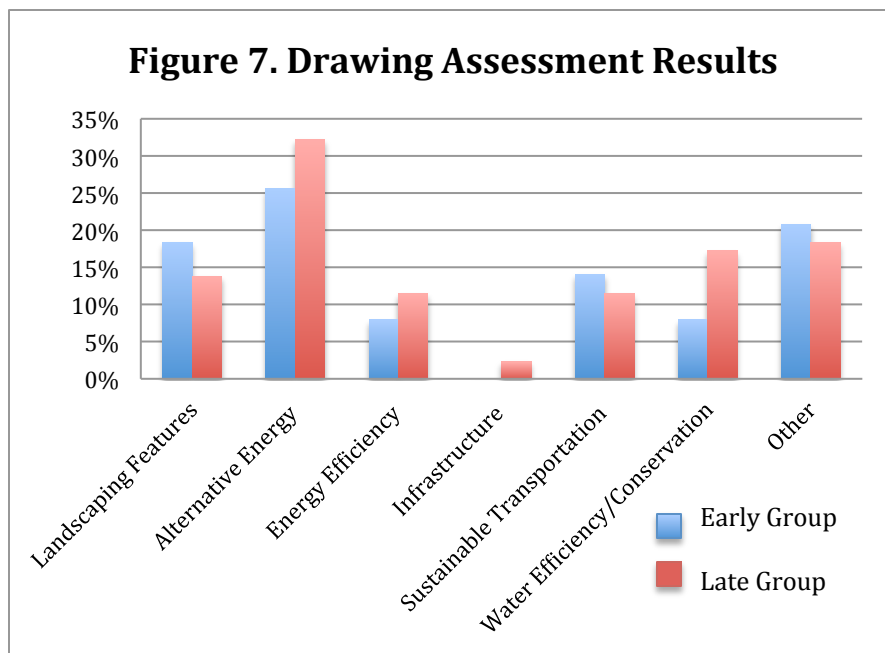


In comparison, audio diary entries collected during the final three weeks provide evidence that some of our participants were developing a more sophisticated view of the purpose of rainwater catchment – or of the problems it could be instrumental in solving (see Figure 6.) Most prominently, we found that 22% of the entries

by digital storytelling apprentices as compared to < 5% of the entries by design-build apprentices collected in the last three weeks of the project period made some connection between water and energy, recognizing that collecting and distributing water locally as compared to pumping it over long distances could save energy. Of the 22% entries by digital storytelling apprentices that made the connection to energy, 9% went further to make the connection that saving energy also meant someone was saving money. We were surprised to find that about these results six of the nine apprentices who offered these insights were affiliated with the digital-storytelling track rather than design-and-build. It was also notable that a few (< 5%) of the entries by three apprentices recorded in the last three weeks of the project period included mention of connections to multiple other problems: they recognized that rainwater catchment might be instrumental in solving (e.g flooding, pollutants being swept by storm water runoff feeding into the ocean, or evidence of recent increases in the acidity of the ocean). All three of the three apprentices who recorded entries touching on these additional topics identified most closely with the digital storytelling track.

We were pleased with the results of the **Annotated Drawing Assessment** in so far as it proved efficacious as an evaluation tool. Giving apprentices the opportunity to add sketches and annotate line drawings was revealing in ways that written feedback may not have been. Apprentices were able to reveal and communicate their thinking about sustainability as a system in ways that were not dependent on their ability to write in complete sentences and paragraphs. However, for reasons explained earlier – we were not able to use these results to track change over time as originally planned (i.e. given that less than 30% of the participants completing the exercise as a post –assessment had also completed the exercise as a pre-assessment). Given the circumstances, we treated data gleaned from these two assessments as independent events representing two independent participant samples: **Early Group** (n =29; 16 DS apprentices and 13 DB apprentices) and **Late Group** (n= 19 11 DS apprentices and 8 DB apprentices) rather than as an assessment of change over time. We made the assumption that all members of the Late Group had, to some degree, participated as apprentices – either working with digital media artists or in planning, constructing and installing aspects of sustainable systems.

The total number of features added by 29 Early Group participants was 164 while the total features added by 19 Late Group participants was 87 (eight identifying with digital storytelling and eleven identifying with design/build) with the result that, on average, participants in each group added about the same number of features (Early Group average = 5.66 features; Late Group average = 5.8 features). The most consistent/common addition, for both groups, was



solar photovoltaic panels (Early Group = 26%; Late Group = 32%) despite the fact that this was not a technology they had first hand experience working with. The second most common/consistent addition, across both groups, was the addition of a garden or other food-producing landscaping features (Early Group = 18%; Late Group = 14%) which was not surprising given that

sustainable agriculture / gardening was already a sustained and prominent activity at the site. Other observations that held consistent across both treatments include an emphasis on energy generation or regeneration (e.g. windmills) rather than energy efficiency (e.g. efficient lighting, south facing windows); the inclusion of personal alternative transportation (e.g. bikes, electric vehicles) but exclusion of public transportation options; along with a general scarcity of features or labels making connections to public infrastructure.

We did notice some differences between the two groups. We found that Late Group participants in both tracks were more likely than Early Group participants to include the technologies that had been physically introduced to the VTC campus through the apprenticeship program. For example we found that of 87 items drawn or labeled by respondents in the Late Group referenced rainwater catchment 12 times (13%) as compared to only 5 mentions out of 164 (3%) in the Early Group – accounting for the bulk of the difference in “Water Efficiency/Conservation” as shown in Figure 7. The same was true for solar tubes (passive solar day lighting technology installed from ceiling to roof). We found that there was only one mention (3.4%) by Early Group participants of passive day lighting features whereas this feature accounted for 8% of the total additions Late Group participants.

Conclusion

This study provides evidence showing the efficacy of digital storytelling as an alternative to traditional “hands-on” or “design-and-build” apprenticeships. Measures of target learning outcomes indicated that performances by youth apprentices concentrating on digital storytelling were equal to those produced by their design-build counterparts. Both groups could reference a wider range of new technologies considered important to sustainable systems/development and both gained greater understanding of how STEM was relevant to sustainability and to their own career goals. Our results did reveal one notable difference in the outcomes of these two types apprenticeship experiences. Our evaluation of these youth apprentices’ ability to articulate the problem statements incentivizing the sustainable design projects they worked on or followed revealed that digital-storytelling apprentices surpassed their design-build counterparts in the sophistication of their understanding of the interrelated issues defining the problem these projects were attempting to solve. Finally as a whole, this study confirms that digital-storytelling is highly useful as an alternative to more traditional apprenticeship learning because it allows for broader participation in technical engineering projects that might not otherwise be amenable to youth participation due to technical/practical/safety related considerations. Youth who were not able to visit actual project research sites or use technical tools were still able to closely follow the week-to-week development of project activities through the digital media that they were viewing and editing in the film-production process. Finally results from the First Response questionnaires show that overall, participants reported feeling more satisfied and excited by learning/training activities designed to support digital storytelling apprenticeships than by learning activities included as training for design and build apprenticeships.

Implications for Practice

For engineers and technicians working in the field of sustainable design the importance of understanding the problem and its contingencies cannot be overstated. Through our analysis of Sound Cloud diary entries we were able to document the evolution of some participants’ understanding of rainwater catchment as a technology that can address multiple interrelated issues (water conservation, runoff and pollution, energy efficiency, economic savings, local resource management) pressing the development of sustainable communities. Notably we found that this kind of evolution in thinking was more common and robust among apprentices participating in the digital-storytelling track than among apprentices affiliated with

the design-and-build track. This was an encouraging finding given that apprentices in the digital-storytelling track expressed greater overall satisfaction with and enjoyment of the training activities than their design-build counterparts.

These results are supportive of our original hypothesis: the physical and practical aspects of project-based or “hands-on” learning may not be the only or most critical benefits of these learning opportunities. Apprentices who have opportunities to engage in designing and building new technologies or systems enjoy many other benefits beyond the “hands on” experience of working with materials and tools. They work side-by-side with professionals or other specialists and may share in a sense of camaraderie, purpose and productivity surrounding such projects. They may be motivated by the sense of ownership, agency or pride that accompanies the construction of something new and valued by others. Similarly apprentices engaged in documenting/representing (and understanding) the technicalities, challenges and accomplishments of sustainable design projects are participating in decision making and taking responsibility for a final product rather than following a teacher’s instructions or acting only on the authority of others. Like their design-build counterparts they enjoy the status of “legitimate peripheral participants” in a “community of practice”¹¹ by participating in low-risk tasks that are nonetheless productive and necessary and further the goals of the community. According to CHAT, if newcomers can directly observe the practices of experts, they understand the broader context into which their own efforts fit. Legitimate peripheral participation provides the foundation for the slow process of becoming a full participant and of mastering certain knowledgeable skills central to a particular community of practice. This is important to increasing diversity in STEM since educational researchers have shown how “Hegemony over resources for learning and alienation from full participation are inherent in the shaping of the legitimacy and peripherality of participation in its historical realizations” (p. 42)¹¹. For these reasons we conclude that digital-storytelling shows excellent potential as a pedagogical tool capable of disrupting long-standing biases in STEM education and in the preparation of a tech-savvy workforce. This alternative is also appealing because in many respects the logistics of mounting a digital storytelling apprenticeship program are preferable to involving apprentices in “hands-on” tasks critical to the success of the actual project and allow one to reach a wider audience than with purely “hands-on” tasks.

Further Research

In this study we explored contrasting cases to learn whether apprentices immersed in digital-storytelling would achieve learning outcomes comparable to apprentices immersed in hands-on implementation of a sustainable design. Therefore our design experiment focused on projects that were accessible to apprentices working in either track –such as rainwater catchment and passive solar (daylighting) in so far as the only practical skills required of design-and-build apprentices were within their reach (measuring, gluing, cutting, drilling, digging etc.). In the future we would be interested to conjoin digital-storytelling with sustainable design projects that require a degree of sophistication and/or technical skill and knowledge that would otherwise make it prohibitive for untrained newcomers to play a meaningful role in advancing project objectives (e.g. research and development of graphene enhanced supercapacitors to improve the lifespan of lithium-ion batteries). In these instances we would be interested to learn whether legitimate peripheral participation - by way of digital storytelling - would remain sufficiently

robust for newcomers (working as digital artists) to gain interest and knowledge in topics that presumably would be otherwise inaccessible to them. Further study would focus on improvements in their ability to perform valued STEM skills such as articulating and defending the problem statements driving technical solutions. For this we would need to continue to refine evaluation strategies and tools appropriate to these ends.

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