From Peripheral to Full Participation: Implications of Learning Theory for Educational Design and Learning Assessment in STEM Apprenticeships

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Linnea Beckett is a PhD Candidate in Education at the University of California, Santa Cruz. Beckett’s continuing dissertation research examines a community-university collaboration situated in a low-income, predominantly Latino community, that created and used digital stories as artifacts and learning tools to engage members of the community (parents, teachers, district officials, union leaders, students, non-profit service providers, etc.) in reflection and dialogue around the economic, social, and cultural barriers that constituents face when advocating for student academic achievement, and to identify the strengths and solidarities that can be created to change the school system to better serve the student body (Beckett, Glass, & Moreno, 2012). Beckett has presented her research at numerous national and international conferences in the fields of education and women’s studies (AERA, AESA, & NWSA). In 2009, Beckett served as a Program Evaluator for the world renowned Apprenticeship in Ecological Horticulture at the Center for Agroecology and Sustainable Food Systems (CASFS) at UC Santa Cruz. She co-authored an evaluation of two decades of the apprenticeship program (Perez, Par, & Beckett, 2010). She served as the Program Evaluator for Apprenticeships in Sustainability Science and Engineering Design (ASCEND) at UC Santa Cruz in the 2014-2015 academic year, where she collaborated with the Program Director to build new assessment to measure STEM learning through "audio diaries," and piloted an assessment that measures "legitimate peripheral participation" or learning-by-doing, which is the theoretical foundation to an apprenticeship model of learning.

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Abstract

This paper reports on a set of assessment methods and instruments being developed as part of a larger agenda to research, develop and institutionalize participatory and inclusive STEM-learning experiences. The authors have been investigating and testing educational strategies to incentivize the legitimate participation of youth that would otherwise be considered “STEM-outsiders” in selected STEM-linked sustainable design projects moving forward in their local community. More specifically, this research explores the efficacy of apprenticeship (a.k.a. legitimate peripheral participation) through digital storytelling as a possible alternative to more familiar “hands-on” apprenticeship models. We present several assessment instruments, developed in alignment with socio-cultural theories of situated cognition and more specifically, with Jeanne Lave and Etienne Wenger’s analytic framework for understanding apprenticeship learning through the lens of legitimate peripheral participation. Illustrative examples of the kinds of data that can be generated using these pilot instruments are taken from the results of a pilot case study. The pilot program at the center of this study offers two alternative possibilities for youth to apprentice with interdisciplinary teams of undergraduates and local professionals working collaboratively to innovate, design, implement and validate sustainable technologies and systems in their surrounding community. Opportunities for youth to get involved in the production of “digital stories” narrating the challenges, outcomes and local impacts of these projects serve as an alternative to a parallel, hands-on, “design-and-build” apprenticeship track. Compilations of sequential audio recordings, archived as online “audio-diaries”, are analyzed for evidence of changes in the youths’ involvement in these projects and their related abilities to productively participate in problem-definition and problem-solving activities. These data are compared with on-site observations and data collected from focus group exit interviews. Methods used in the pilot study to generate and assess evidence of participants’ overall understanding of the problems or issues motivating a specific sustainable engineering project, their ability to formulate and articulate valid problem statements are also discussed. Two new instruments are proposed: a new third-party observation instrument and an adaptation of the protocol for eliciting and analyzing audio-diary entries used during the pilot. Both instruments are designed to monitor and correlate changes in participation and membership over time with evidence of developments in formal cognitive reasoning processes recognized as important to the practice of engineering-design.

Introduction

Researchers in the learning sciences following in the tradition of Lev Vygotsky’s seminal work at the turn of the 20th century, recognize that knowledge and cognition do not occur separately from other forms of human activity, but rather are interdependent with the material and socio-historical aspects of the contexts in which they occur or are “situated.” It is the “situation-with-learner” that co-produce cognition or new knowledge rather than individual learners/knowers independently producing or accessing knowledge. Knowledge (or more
precisely meaning-making, the activity) is not only contingent on the particulars of a given situation (including individuals, material and symbolic tools in use, socio-cultural norms, and historical background) but is understood as literally being integral with them. This perspective undermines assumptions that definite bodies of factual knowledge can be transmitted to learners who are expected to “receive” presumably immutable truths about the world or the way the world works. Moreover, theories of situated cognition go beyond a “constructivist” view of knowledge as a controlled byproduct of specific interactions with the social, material or historical realities of any given situation to posit an even more dynamic ontology of meaning-making as an ongoing and continuously evolving endeavor where “the agent, the activity and the world mutually constitute each other”\textsuperscript{4}. As Lave & Wenger\textsuperscript{4} are careful to emphasize, learning cannot be “reified” as a particular or singular kind of activity, neither can it be ontologically separated out from other activities; it must instead be understood as part of the total gestalt of a larger activity system or “community of practice” which is also constantly shifting and evolving as different cultural, social, historical and material aspects come into play.

This paper is a result of a continuing effort to assess the degree to which a particular educational intervention (see description of the ASCEND program below) can be successful in enabling participants to practice and demonstrate STEM-linked abilities applicable to careers in sustainable design and development for the emerging green-tech economy. An initial review of data collected during a two-year pilot quickly led to the realization that attempts to evaluate the effectiveness of the intervention and assess learning outcomes would be limited by the kinds of instruments readily available. Instruments including exit-interviews and surveys that rely on retrospective participant “self-report” data can be helpful for evaluating changes in participants’ assumptions, attitudes, expectations etc., but are less helpful in generating evidence of changes in the kinds of applied STEM skills and reasoning abilities that the pilot intervention was intended to promote. Meanwhile, instruments designed to capture a learner’s acquisition of bits of knowledge or mastery of individual techniques/formal practices are misaligned with a theoretical understanding of learning as a highly situated and socio-cultural endeavor. Additionally, the research team recognized that in studies where a design-experiment approach is being used (i.e. case studies of disruptive educational interventions such as ASCEND) researchers must account for how changes in the underlying structure of an educational program or learning activity are impacting learning and that consequently it is insufficient to focus on learning outcomes associated with individuals. In such transitional situations, findings on participants’ individual progress towards target learning outcomes must also account for the gradual transformation of the normative practices and tacit expectations underlying the learning community as a total system and the implications of those transitions for the learners involved. Indeed, early analysis of data collected during the pilot revealed that instruments used to measure learning outcomes achieved by individual participants in ASCEND were insufficient for simultaneously documenting the degree to which the introduction of the apprenticeship-learning program was successful in disrupting or displacing didactic “teacher-centered” instructional practices already prevalent at the site.

In the remainder of this paper we will 1) clarify how the analytic framework for legitimate peripheral participation developed by Lave and Wenger informs theories of situated cognition 2) describe the background, context and motivation for the larger research agenda
motivating this work 3) explain the pressing need for the development of new assessment instruments and methods that are aligned with situated and participatory perspectives on learning through practice 4) explain how Lave and Wenger’s model of learning can also be used as an analytic frameworks to develop such instruments 5) provide illustrative examples of the kinds of data that can be generated with the assessment tools we are using this framework to develop. To reiterate this last point, this paper does not present conclusive results of a full study, rather it explains the rationale for new research methods and instruments then presents the results of a pilot study to demonstrate the potential of using these instruments to assess individual learning outcomes and evaluate those results in relation to a hypothesis about the efficacy of an “digital storytelling” apprenticeship model designed to facilitate STEM-learning in alternative educational contexts.

Situated Cognition in Theory and Apprenticeship Learning in Practice

Apprenticeship-style learning is one way that educators are striving to put theories of “situated cognition” into practice, an approach validated in both formal and informal STEM learning contexts as a productive alternative to didactic “teacher-centered” classroom pedagogies or “assembly-line instruction” which, according to Rogoff and colleagues, involves adults attempting to “control children’s attention, motivation, and learning” and relies on assumptions about transfer of factual information from the teacher to the student to evaluate evidence of learning. By contrast, apprenticeship learning is organized around the assumption that that skills and knowledge develop interdependently through increased degrees of “intent participation” in different learning communities, and are reinforced through responsive facilitation or devices that function as learning scaffolds. While “assembly-line” instructional models operate (albeit, often implicitly) on the premise that that explaining how scientists “do science”, or engineers “do engineering” is appropriate for training new scientists or engineers, proponents of apprenticeship-style learning and researchers familiar with theories of situated cognition remain skeptical that this “teaching as telling/showing” approach can actually bring about the transformative or lasting changes needed for outsiders/novices to become productive participants in STEM-linked endeavors.

Evidence from research across the learning sciences on the efficacy of “research apprenticeships” has supported many of the presumed positive associations between apprenticeship experiences and desired STEM-specific learning outcomes. For example, Barab and Hay used literature on the sociology of science and on apprenticeship to evaluate the Science Apprenticeship Camp (SAC) and conclude that learner achievement in SAC was highly related to their belief that that they were making legitimate contributions to an authentic research agenda. Based on these findings they argue that “learning opportunities that support students in doing participatory science ideally with scientists and in those places where scientists do science” should supplant “isolated activities directed toward the building of conceptual representations about ready-made science” (p. 95). Yet, amidst a rising groundswell of calls to introduce more “research experiences” or “apprenticeship” learning opportunities in STEM is the concern that that the term “apprenticeship” has been and continues to be applied in indiscriminate ways. As Lave and Wenger admonish, “[the notion of learning through apprenticeship] has become yet another panacea for a broad spectrum of learning-research
problems” (p.30) and recognition that that the particular style, structure, relationships goals and context of the apprenticeship experience should be accounted for.

Similarly Baird, Deacon and Holland explain that apprenticeship learning is not merely about the insertion of more “hands-on” activities into existing educational systems. They argue that educators must exercise a more systematic shift: one that they describe as a shift away from developing active learning exercises to one that emphasizes learning from action. Indeed, the last two decades have seen an increase in scholarly research distinguishing apprenticeship from other forms of “active” or “experiential” learning in a variety of out-of-school or “informal” learning contexts much of which has been inspired by the papers produced by Lave and Wenger in the early ‘90s. Dissatisfied with the familiar models and existing definitions of apprenticeship-learning available at the time, Lave and Wenger departed from dominant assumptions about apprenticeship by problematizing the term and worked to develop a more rigorous analytic framework to distinguish apprenticeship from other models of “hands-on” “experiential”, “inquiry-based” or “active” learning. Moreover, to avoid conflations of “schooling” with other instances of learning and cognition in their analysis, they explored characteristics of apprenticeship across five different case studies in as many different socio-cultural settings distinguishing among qualities that are unique and site specific from those that they presumed to represent a core set of characteristics that could subsequently be used to define apprenticeship from other types of “experiential” learning. For example, they contrast the way that novice quartermasters in the U.S. Navy learn to work navigation instruments and navigate in the context of the actual operation of the ship with the way novice Liberian tailors to begin at the end, working on finishing touches first in order to observe the expert qualities of a finished piece. Common to both scenarios is the equal division and distribution of work shared between masters and apprentices alike. Moreover they observe that apprentices are treated as “legitimate” members of the community, not passive observers, in so far as they work side-by-side with experts and assume responsibilities that must be performed in the context of the ongoing work of the community. This contrasts strongly with other forms of experiential learning where some members, positioned as experts or teachers, demonstrate while learners observe or directly assist learners in practicing desirable skills or techniques. Lave & Wenger conclude that where apprenticeship is the prevailing mode, learning occurs as an “integral aspect of practice” rather than a separate activity that is “merely situated in practice” (p.35). Furthermore, they highlight how opportunities to learn are mainly improvised from the situation at hand - there are no rules dictating what should be learned, or when it should be learned.

Legitimate Peripheral Participation in a Community of Practice

Numerous papers have attempted to grapple with how learning is situated in socio-cultural contexts using a number of independent constructs (e.g. identity, sense of belonging, confidence or sense of self-efficacy, cultural or familial value systems) too explore how any one of these variables may influence cognitive engagement in specialized tasks (and presumably an individual’s ability to achieve mastery of content and process knowledge). Lave & Wenger take a different approach: rather than viewing learning through a lens focused on individual performances which can be enhanced through direct instruction, they view learning as occurring through “centripetal participation in the learning curriculum of the ambient community” (p.100).
Where other frameworks have focused on cognition as an isolated, independent, or innate developmental process (e.g. Jean Piaget’s treatises on cognitive development in children), Lave and Wenger pose questions that focus on social interactions among learning partners and the socio-cultural context of learning such as: What kinds of social engagements provide the proper context for learning to take place? What is the process of membership? Does the work of the apprentice promote the apprentice’s integration into the community? What is the relationship between work and learning? What concerns or priorities are shared by members of this community? And what is being done to resolve them?

The result of Lave and Wenger’s now widely recognized analysis of multiple forms of apprenticeship was the introduction of their analytic framework for “legitimate peripheral participation” which they use to show how changing participation in specialized “communities of practice” can account for a learner’s ability to gain new skills and knowledge. A community of practice is viewed as the cultural space where learners are continuously interacting with the different social and material aspects of their surroundings such that each mutually constitutes the other. For a community of practice to function, members need to mutually generate and appropriate a shared repertoire of ideas, commitments, values, ethics and memories. This corresponds to earlier observations by Brown et. al that learning communities are “bound by intricate, socially constructed webs of belief, which are essential to understanding what they do” (p.33). The co-generation of these shared practices and purposes motivates members to develop and use various resources such as tools, documents, routines, expectations, vocabulary or other symbol systems. As these resources are continuously shared back and forth among members they increasingly come to embody/represent and “carry” the accumulated knowledge of the community across different temporal, spatial and social realities.

Applied as an analytic framework, legitimate peripheral participation describes shifts in social structures that implicate a learner’s “evolving form of membership”: a continual process of engagement implicating shifts in identities and interpersonal relations as collaborators work towards implicit and explicit objectives shared by members of the community. It is the effort to organize around some particular area of knowledge and activity that gives members a sense of joint enterprise and identity. Peripheral participation does not refer to a geographic position nor does periphery connote any kind of system of binary or opposing extremes. For example, periphery is not conceived as the inverse of center and the framework does not support contrasts between legitimacy and illegitimacy. Instead, legitimate peripheral participation describes how learners can increasingly gain “mastery” of a core set of “knowledgeable skills” through the gradual transformation of their participation over time in organized learning communities even as their participation is transforming what is acknowledged as the core. Similarly mastery is not attributable to any particular master or seen as residing “in” the master, just as knowledge is not presumed to reside “in” an individual nor imprinted on individuals. Mastery is instead realized as a set of masterful practices that are distributed and coordinated throughout the community. The encompassing learning community is never defined in absolute or static terms but is also presumed to be constantly changing and emerging. In this sense, the community of practice and the relational identities of members within that community are mutually produced through the process of legitimate peripheral participation: “The community of practice provides identities of mastery and apprenticeship and simultaneously, the community of practice is defined and
validated by the participation of masters and apprentices”. Finally, Lave and Wenger are careful to clarify that their framework for articulating the defining characteristics of legitimate peripheral participation should not be mistaken as an instructional method: “[…it is not itself] an educational form, much less a pedagogical strategy or a teaching technique. It is an analytical viewpoint of learning, a way of understanding learning” (p. 40). It is most useful as a lens for viewing and understanding learning in new ways and understood as such, it can be applied to multiple settings for analysis.

Extensive research by Rogoff and colleagues\textsuperscript{6,21,22} is demonstrative of work that uses a learning community as a “supra-individual” unit of analysis\textsuperscript{24} to compare different learning activities and outcomes: for example, Rogoff and her colleagues use a supra-individual lens to investigate how children integrate into established community structures and have gathered evidence demonstrating how different cultural paradigms and community structures lend themselves to distinct forms of collaborative learning. Rogoff describes the different ways that children from middle-class European heritage and Indigenous heritage (Mayan, Guadalajara) learn to collaborate and how these differences can facilitate or inhibit learning in formal classroom settings which may or may not align well with the repertoires learned at home. In the Mayan Indigenous heritage, children often share responsibilities, watch, contribute, pitch-in, and engage in the household work, conceptualizing work as a responsibility of everyone for a collective goal. In contrast, middle-class European heritage often divide labor, children conduct chores independently, working together involves dividing things up, and adults need to be aware of and supervise children. Schooling often feature middle-class European heritage practices and cultivates a type of collaboration defined by taking turns, dividing up tasks, teaching others, and that ideas need to confront each other. Through careful empirical analysis of how children learn to collaborate in different communities, Rogoff and colleagues identify functional differences in the shared repertoires that these children carry with them into new situations and contribute to a more complex understanding of how learning occurs.

\textbf{Cognitive Apprenticeship}

Evidence for assertions that learning is situated in practice and cannot be considered in isolation or analyzed apart from the social relations that shape participation is perhaps one of the important outcomes of Lave & Wenger’s careful analyses of apprenticeship learning. Descriptions of craft and professional apprenticeships that illustrate how apprenticeship begins through piecemeal participation and graduate to mastery of practical skills in a material world, can also be associated with mastery of domain-specific cognitive skills. The term 	extit{cognitive apprenticeship}\textsuperscript{2,12} has been used to describe how learners extend cognitive reasoning skills and gain mastery of symbol systems through their changing participation in collaborative meaning-making activities while maintaining “inherent content-dependent, situated, and enculturating nature of learning” (p.39)\textsuperscript{12}. This extends the premise that cognition, understanding and knowledge are not isolated within the individual but treated an outcome of a total system of actions, by actors, acting in their environment.

As Collins, Brown and Holum\textsuperscript{14} were careful to point out nearly two decades ago, a major implication of this work is that more attention needs to be paid to “the cognitive strategies [that]
are central to integrating skills and knowledge in order to accomplish meaningful tasks”. We have yet to transform pedagogical practices in schools which have been consistent in successfully “conveying large bodies of conceptual and factual knowledge” but largely ineffective in “making observable” or revealing to learners “the reasoning and strategies that experts employ when they acquire knowledge or put it to work to solve complex or real-life problems.” A further implication is that many of the assessment instruments developed for assessments of classroom instruction are not appropriate for the assessment of learning activity when it is conceived as cognitive apprenticeship. Assessment instruments and methods developed for classroom instruction are misleading because they tend to focus on knowledge as a “byproduct” of learning activity and do not reliably capture or account for incremental changes in participant structures or reasoning strategies linked to participatory actions that are crucial to understanding whether an apprenticeship model is working well or not.

**Apprenticeships in Science and Engineering Design**

*Apprenticeships in Science and Engineering Design (ASCEND)* is a program designed to create active learning communities that reinforce productive roles for a range of contributing members from expert professionals to apprentices and newcomers. The overarching goal of this program is to successfully prepare underserved or “at-risk” youth to pursue STEM-based careers in the expanding green-tech economy. Many of the participants in the target audience, teenagers ages 15 to 19, are from diverse backgrounds and struggling to achieve social, interpersonal and academic success in other formal educational settings. These youth face a variety of challenges in their personal lives: they may live in precarious housing situations, be separated from family members, or are dependent on family members battling addiction or disease. Some have been diagnosed with learning disabilities while others simply have found the regular public education system to be unresponsive to their diverse needs and as a result are themselves highly suspect of what formal education can offer them. These “at-risk” youth were recruited to participate in ASCEND through local service learning organizations or were already enrolled in alternative education programs at vocational training centers that rely on state funding to support Career Technical Education. For more information on these CTE programs visit the California Department of Education which can be found here: [http://www.cde.ca.gov/ci/ct/tp/](http://www.cde.ca.gov/ci/ct/tp/).

ASCEND was motivated by the understanding that in order to promote learning through legitimate peripheral participation, mentors must do more than expose “would-be” apprentices to exciting projects through menial task assignments – they must involve them as authentic collaborators working side-by-side with experts who should also identify as members of a community working to achieve mutually shared goals. At its core, the ASCEND program is organized around a selection of engineering-design projects that use innovations in “green-technology” to develop and promote local solutions for communities interested in mitigating environmental impacts. Examples of recent projects include the installation and assessment of a vertical axis wind turbine on the municipal wharf, the re-design of the shipping crates used to transport all-electric Zero Motorcycles (http://www.zeromotorcycles.com/) overseas, the design and installation of a linked rainwater catchment and smart irrigation system that uses a data-
driven sensor network to deliver water on demand and most recently, a net energy analysis of a recently commissioned plastic-to-fuel conversion machine.

Interdisciplinary teams of undergraduates lead the projects while working closely with local experts including university researchers, elected municipal officials and staff, industry and non-profit professionals, activists, entrepreneurs, and philanthropists to define project topics and develop detailed project plans. As undergraduate teams move sustainable design projects forward from planning towards implementation, they are compelled to make short presentations to small groups of “at-risk” youth affiliated with local community service organizations or enrolled at one of the vocational training centers mentioned above. Youth are encouraged to get involved in two different ways: they can assist in the actual “hands-on” implementation, maintenance and monitoring of a sustainable system designs (e.g. build water conduits and install storage tanks for rainwater catchment) or join undergraduate “digital-storytelling” teams. These storytelling teams are mentored by professional videographers and digital artists and tasked with following and documenting the overall progress of featured sustainable design projects in order to create compelling audio-visual narratives that portray the incremental challenges, success and outcomes of these projects.

Youth apprentices concentrating on the digital media track are trained by collaborating professionals through a series of demonstrations and introductory workshops, to use audio-visual production equipment and editing / post-production software. Subsequent to the initial training period, ASCEND provides continuing opportunities over approximately the next six months for these youth apprentices to work closely with undergraduate digital media and film majors who are in turn receiving technical guidance from professionals in the field. Interactions between “design-build” and “digital storytelling” teams are necessary in order for each side to stay informed about the plans, decision-making and progress of other and are useful in keeping each group accountable for completing their work. These interactions create added layers of transparency while incentivizing team members and youth apprentices on each side of the equation to keep their projects moving forward. Digital-storytelling teams have the added responsibility of finding ways to translate technical science and engineering content into appealing presentations that will engage public audiences. These “hybrid” stories must simultaneously be appealing, entertaining and provocative for public audiences and yet maintain standards of accuracy and validity in regard to the science, engineering and technical content they feature. At the end of each production cycle, youth-produced media are presented to community members during leisure events, which are hosted by ASCEND in partnership with local organizations including science museums, and any other community centers that agree to act as event venues. In either case, whether youth become involved in the “design-build” aspects of a project or in the production and exposition of “digital stories” highlighting these projects, the expectation is that youth will become legitimate peripheral participants in emerging communities of practice where they can make meaningful contributions to sophisticated technological projects that they might not otherwise access to.
Research Agenda

As educational researchers working with ASCEND, we have been investigating and evaluating educational strategies to incentivize the legitimate participation of CTE youth that would otherwise be considered “STEM-outsiders” in a collection of STEM-linked sustainable design projects moving forward in their community. More specifically we are exploring the efficacy of apprenticeship (a.k.a. legitimate peripheral participation) through digital-storytelling as a possible alternative to more familiar “hands-on” apprenticeship models. We are additionally interested in evaluating when and how museums can work with other informal or “out of school” learning organizations to create lasting community forums and lifelong learning opportunities that reposition hard-to-reach target audiences and renegotiate normative practices that threaten to exclude or alienate members of these audiences from STEM-linked endeavors.

Assessment of learning outcomes demonstrated by youth participating in the pilot study was initially focused on a particular cognitive engineering reasoning skill: the ability to formulate and articulate problem statements that implicate specific constraints and requirements for design-solutions. Our research plan was to compare evidence of learner proficiency in demonstrating cognitive skills involved in problem definition with evidence of a number of attitudinal outcomes. We were additionally interested in capturing differences among learning outcomes achieved by the youth apprentices involved in digital-storytelling and those achieved by apprentices involved in the “hands-on” design and construction of featured green technologies and sustainable systems. However, we quickly recognized that evidence of learning outcomes must be interpreted through a further investigation of the extent to which these apprentices were accepted as contributing members of the surrounding learning community (including undergraduates, researchers, community mentors and other project stakeholders) to begin with. Furthermore, we recognized, the legitimacy of these apprentices’ peripheral participation in sustainable design projects was predicated on the overall success of ASCEND in disrupting and transforming existing normative (school-based) educational practices to create an authentic learning community. In other words, in addition to collecting evidence of individual learning outcomes we needed evidence of whether the participants believed collectively that they were part of an emerging coalition working collaboratively with others to achieve commonly shared goals and where each participant was assumed to have an important role to play and potential to contribute towards accomplishing those goals.

Introduction to Research Methodology

Early observations of learning activity in ASCEND led to the formation of the working hypothesis that continues to inform our research agenda. We hypothesize that evidence of the extent to which STEM domain-experts (a.k.a. “masters”) are providing learners (a.k.a “newcomers”) with engaging and authentic opportunities to contribute and work collaboratively towards a common goal will be correlative to greater participation in and improved performance of targeted learning outcomes including: a) STEM reasoning skills involved in scientific argumentation and b) understanding of technical STEM content implicated in sustainable engineering and ecological design projects and correlative to measureable changes in a) learner appreciation for the role and applications of STEM in larger problem-solving contexts and b)
greater awareness of the possibilities for continuing membership and advancement in communities of practice using STEM to solve local and societal problems and c) greater confidence in their own ability to pursue pathways into those communities.

To test this hypothesis we set out to make comparisons between evidence of target learning outcomes with evidence of changes in the ways 16 youth-apprentices seized (or did not seize) opportunities to participate and contribute to a selection of engineering-design projects presented by undergraduate teams. As an initial attempt to measure the overall success of ASCEND as an educational intervention in creating opportunities for participation and membership, we used exit interviews to ask participants’ about their assumptions regarding the relevance of STEM to sustainability, their interest and confidence in pursuing STEM-linked careers, and their overall sense of agency, ownership or efficacy as contributors able to “pitch in” and move a project forward. We soon realized that these summative self-report methods were insufficient for understanding how the context of the learning activity impacted learning outcomes and that the fulfillment of our research agenda required development of new assessment instruments and methods. Our research agenda called for instruments that would not only allow researchers to observe transitions in the social organization of learning activity and interpersonal relations (i.e. group dynamics) over time, but also allow researchers to explore potential correlations between these third-party observations of changes in participation over time with evidence of changes in participants’ comprehension and reasoning skills. In the following sections we describe some of the assessment instruments, data collection protocols and analytic methods that were used in the pilot, how we plan to continue using them to testing our working hypothesis in the future and provide some illustrative examples of the kinds of evidence these instruments can generate. To clarify, the examples that follow do not represent the final results of a full study – but rather are presented as illustrations of the type of data generated by instruments used in the pilot. Following these examples we propose and discuss the rationale for a new third-party observation tool: the Participatory Learning Observation Protocol (PLOP) and how it could be used to triangulate data collected through an adaptation of self-report data collected through audio diaries.

Methodology: Assessment of learner ability to formulate and articulate problem statements for “wicked sustainability problems”

Preliminary work on instruments used to assess youth-apprentices’ abilities to formulate and articulate problem statements for wicked sustainability problems was completed in 2015 as part of an NSF-AISL Pathways award (NSF-AISL award no. 1323804; $250K, PI Isaacsion). The six month study was designed collaboratively by the first and second author authors, with the former acting as project director and the latter as project evaluator. Both authors have formal training as educational researchers. The first author, Ball, received her Ph.D. in educational research in 2009 with an emphasis in policy and social context of STEM education. Her prior work has focused on STEM education in informal or “out of school” settings and recent work has focused on the development of reasoning skills in the context of research apprenticeships sponsored by the Center for Adaptive Optics, and NSF Science and Technology Center in adaptive optics for astronomy and vision science. The second author, Beckett, is a doctoral candidate in education, with an emphasis in feminist studies, and served as an evaluator on
ASCEND. Her dissertation examines learning within a multimodal school reform effort. Beckett worked closely with an undergraduate student-researcher who was employed to help solicit and collect bi-weekly audio recordings (see below), interview youth participants, and analyze data. The undergraduate student-researcher was selected for her familiarity with the site and participants after having spent the better part of the prior academic term implementing a senior thesis for environmental studies that involved the youth at the same site in designing and planning a solar tube installation— a passive solar lighting technology in their classroom. The student-researcher was trained over the preceding summer months, using trial data sets collected the year prior, to conduct educational research by the project evaluator who also visited the site periodically to observe participant interaction and monitor data collection.

Youth-apprentices working with interdisciplinary undergraduate teams on either digital storytelling or design-build projects were asked to complete weekly “audio diary” entries responding to discursive verbal prompts posed to them during bi-weekly visits by a student-researcher. Youth apprentices were given control of the recording devices, and each recorded “audio-diary” session lasted three to five minutes taking place one-on-one, away from the rest of the group. Individual sessions were organized around a selected “set” of prompts (see Table 1.). The student-researcher was able to complete between two and five sessions per visit. Prompts were generally organized around three types themes 1) comprehension of sustainability and/or wicked sustainability problem contexts 2) perspectives on learning (hands-on, schooling, group activities, etc.) and 3) interest in or perceived relevance of STEM to future educational or career plans. Three sets of prompts were designed to solicit evidence of apprentices’ changing understanding and ability to articulate the problem context associated with the project they were most familiar with and how that related to their larger understanding of sustainability as an overarching goal. Questions for each set are included in Table 1. The student-researcher used conversational follow-up questions to solicit further evidence of the youth-apprentices’ “definition of sustainability” and their ability to describe the premise for the sustainable design project they were most involved with or the problems/impacts that project was trying to mitigate. The research plan called for learners to record responses to prompts in each of the three sets at least twice, and ideally more than twice in order to reveal changes in their thinking over time.

Table 1. Discursive Prompts used to solicit audio-diary recordings in ASCEND.

<table>
<thead>
<tr>
<th>SET 1: Perspectives on/ Comprehension of Sustainability</th>
</tr>
</thead>
<tbody>
<tr>
<td>• How would you define sustainability?</td>
</tr>
<tr>
<td>• Remember our very first question when we were coming up with a definition for sustainability. Do you think your definition has changed at all? Or developed in any way?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SET 2: Project Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>• What project are you working on right now with [the undergraduates]?</td>
</tr>
<tr>
<td>• Has anything happened lately that is important or something you haven’t thought of before?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SET 3: Problem Statements for Sustainable Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Taking it back to the [sustainable design] project, what project are you working on?</td>
</tr>
<tr>
<td>• And what problem is [this project] trying to solve?</td>
</tr>
<tr>
<td>• What is important about this project or problem? Is it making you think about anything you haven’t thought about before?</td>
</tr>
</tbody>
</table>

Due to various logistics (e.g. absences, schedule conflicts), the student-researcher was only able to compile a full archive of recorded responses (two responses for questions in each set of prompts) for 11 out of 16 youth-apprentices. Others recorded partial files with responses to a
more limited number of questions) Recorded audio files (a.k.a. “audio-diary entries”) were archived and accessed through free online software offered by Sound Cloud (https://soundcloud.com/). The rational for the coding scheme summarized in Table 2. below was developed using ideas from the literature on how engineers use backwards design to develop solutions to design problems and literature on “wicked sustainability problems” and is described in more detail in an earlier publication.\(^{18}\) Generally, Wicked sustainability problems\(^{19}\) have been described as problems that are ill-defined or cannot be clearly formulated because any single formulation of the issue(s) at stake leads to further debate about the premises for logic that is inclusive of some issues but not of others. Unilateral cause and effect relationships are impossible to trace because these problems consist of highly contingent and often radically changing relationships that exist between multiple factors. Solutions to wicked sustainability, by definition, are always partial solutions in so far as no single solution can fully resolve the multiple contrasting and often competing issues at stake. Furthermore ratification of solutions is highly subjective in so far as the criteria prioritized by one set of stakeholders may not meet the criteria framed by another.

For this study, the lead researcher and undergraduate student-researcher conducted independent coding trials to establish inter-rater reliability using an earlier iteration of the coding scheme presented in Table 2. After refining the scheme together, the undergraduate student-researcher coded the remaining audio-diary entries independently and submitted the results to the lead researcher for review. On the whole, the coding scheme in Table 2. represents a subset of elicited (or “made observable”) cognitive practices related to problem definition and problem contexting that can be considered evidence of “mastery” in a learning community focused on developing sustainable designs to solve wicked problems. Given the weak definitions of sustainability and lack of comprehensive problem statements recorded by youth apprentices in the pilot, we should clarify that some of the actual codes were derived, inductively, from the data rather than from the literature. For example comparisons of the conventional technologies with innovative “green” technologies emerged from the data as a robust qualitative code in so far as it appeared reliably across cases.

**Table 2. Coding Scheme for Wicked Sustainability Problems in Audio Diary Entries**

<table>
<thead>
<tr>
<th>Code</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uses terms to describe or qualify the meaning of sustainability</td>
<td>“Like <strong>taking care of the environment</strong>. Not littering and stuff.”</td>
</tr>
<tr>
<td>(1 pt per qualification)</td>
<td>“The ability <strong>to produce something and keep it going not just for your lifetime but lifetime of future generations</strong>, I guess.&quot; -- &quot;Like plants or agriculture. Sustainable agriculture, I guess.&quot;</td>
</tr>
<tr>
<td>Compares conventional technology or systems to green technology</td>
<td>“...zero motorcycles like its electric so <strong>its not gas</strong> so its <strong>not polluting the air and having global warming</strong>. It's like reducing it and it helps. I feel like that would be a skill like making or inventing something that would make the world more sustainable... in a natural way.&quot;</td>
</tr>
<tr>
<td>or systems (1 pt per comparison)</td>
<td></td>
</tr>
<tr>
<td>Demonstrates recognition or identification of a design problem</td>
<td>&quot;Basically it's kind of like solar power. Except <strong>what they are trying to fix is they don't know if the lanterns are 100% sustainable and recyclable. And also they don't recycle</strong> them. In Kenya, they just burn them. So they kind of want to change that...&quot;</td>
</tr>
<tr>
<td>(1pt per mention)</td>
<td></td>
</tr>
<tr>
<td>Makes inferences linking attributes of a problem to either</td>
<td>&quot;We are trying to make the lanterns less hard to get open and easier to dispos of because people there are just burning them to get rid of them...and, ya, it is something I haven't really thought of either just burning trash. Like yeah, it gets rid of it, but it's not going to do good for the air. It's like all the trash pretty much stays unless we burn it.&quot;</td>
</tr>
<tr>
<td>a broader context or other problems (1 pt per link between two</td>
<td></td>
</tr>
<tr>
<td>attributes)</td>
<td></td>
</tr>
</tbody>
</table>
Recognizes implications of problem statement for requirements or constraints on design-solutions. (1pt per implied constraint or requirement)

None found

Identifies tradeoffs, contingencies, or limitations of a proposed solution. (1pt per reference to tradeoff, contingency etc.)

I think it's like along the lines of how [solar lanterns are] getting out to [local communities in Africa] because there are minimal resources there and they're dealing with a lot of other problems. And so the main problem is getting the resources to them and so like since solar is expensive. The initial start of it is expensive but it pays off later."

Results: Understanding Wicked Sustainability Problems

On a basic level, analysis of audio diary entries provided evidence that apprentices involved in ASCEND were being exposed to and could identify problems that they would not have otherwise considered. For example Gabe, a youth-apprentice who was peripherally involved in the production of a digital-story about off-grid solar lanterns being distributed to impoverished communities in Africa that are otherwise dependent on kerosene for illumination at night, recognized a gap in his awareness of how other people live and the challenges they face:

"I never realized that lanterns were such a big deal over there. But I mean since they don't have electricity it makes sense. I just never put it together that that's a main source of their light is their lanterns."

Another apprentice, John, working with the same group had a new appreciation of problems with waste management that solar lanterns introduce into the same communities where they are supposed to be solving problems:

"I didn't really think solar power was becoming a bigger thing in Africa and other countries in Africa. And something that kind of made me think was - I didn't know they burned them instead of disposing of them properly... but they can't [dispose of them properly]."

Analysis of individual apprentice’s audio diary entries using the coding scheme described above was also useful in generating weak evidence of what youth-apprentices understood about the “wicked” or multifaceted nature of the problems motivating the sustainable design projects featured in ASCEND. More importantly analysis of successive audio diary entries recorded over time can potentially allow researchers to see changes in understanding over time. Youth-apprentices became increasingly aware of not only a greater number of factors in multiple domains (economic, environmental, social), that impact sustainability but were slowly coming to realize the importance of considering these multiple factors together, all at once. Arguably, this can be interpreted as evidence of their emerging ability to consider these problems from a systems-thinking perspective. For example, Gabe’s peripheral involvement in the production of the story about off-grid solar lanterns helped him gain a greater appreciation of the inevitable tradeoffs complicating solutions to wicked sustainability problems in general. Here he expresses his understanding that any long-term benefits of solar lanterns must be weighed against the expense of an initial investment:
"I think we are working on the off-grid solar lanterns in Africa and how they are disposing of the regular [kerosene] ones and how they want to get the solar ones that are off-grid. "I think it's like along the lines of how it's getting out to them because there is minimal resources there and [they are] dealing with a lot of other problems. And so the main problem is getting the resources to [the local people] and so like since solar is expensive. The initial start of it is expensive but it pays off later."

Self-report data corroborates our interpretation of the increasing sophistication of Gabe’s thinking over time: when asked to reflect on whether his “definition of sustainability” had changed or developed as a result of his involvement with ASCEND, Gabe confirmed that he thought it had and then tried to offer a statement that captured his more mature understanding of sustainability as involving more that just “going green”. Specifically he tried to articulate the importance balancing society’s different needs including those pertaining to current generations, and future generations, and all of which are contingent on the state of the natural environment:

"Ya I think it has [developed]." --- "Just the ability to produce something and keep it going; not just provide it for you, for your lifetime but for the future generations and it's kind of just like uhm I have realized how important it is; a sustainable environment is a healthy environment."

It was interesting that nearly half of the youth recorded, used their developing understanding of the problem context they were working within as a mechanism to express the increasing sophistication of their “definitions” of sustainability. For example John’s comments, illustrate how his involvement with the project on the disposal of solar-lanterns helped him to recognize the importance of considering the full (“cradle-to-grave”) life cycle of a commodity in deciding whether it was “eco-friendly”:

"Yeah, at this point I know that something that's sustainable has to be 100% eco-friendly instead of before, anything that kind of didn't completely harm the environment was sustainable." -- "I mean that depending what it is it's not causing damage to the environment and when it is being disposed of, it's not caused damage to the environment."

Comments recorded by Daniel, illustrate how his involvement with ASCEND helped him expand and translate his understanding of initiatives to solve a local issue (beach clean-ups) into a more generalized perspective on waste management that included an awareness of the multiple tradeoffs that complicate sustainability problems. In this instance he describes his new appreciation for the relationship between waste management and air quality:

“...and, ya, it is something I haven't really thought of either just burning trash. Like yeah, it gets rid of it, but it's not going to do good for the air. It's like all the trash pretty much stays unless we burn it...There's not just trash on the beaches, but there's other places and other worse things in other countries. So ya, you guys got us thinking more about other places other than just here at home.”
Overall we found that using audio devices to record audible responses to verbal prompts was more efficacious as a mechanism for data collection than asking youth to provide written responses (i.e. survey or short answer formats) and more conducive to collecting new responses to iterations on the same prompts repeatedly, over time. Moreover these examples illustrate the potential of using successive recordings in audio-diaries as a mechanism to track developments in a participant’s understanding of key topics over time as a function of their peripheral participation in a collaborative project.

**Developing an instrument to observe systemic changes in participation**

While we did find weak evidence in audio-diary entries that the sophistication of the way that youth-apprentices peripherally involved in digital storytelling projects were understanding the kinds of contingencies and tradeoffs that complicate sustainable design projects was more robust than that of youth-apprentices involved in design-build activities intuitively we suspected - and anecdotally we observed - that the apprentices who demonstrated the greatest sophistication in their thinking were those who were more authentically engaged as peripheral participants because the opportunities to actually contribute to digital media production projects were greater than the opportunities to actually contribute to design-build tasks which often took place of site or required specialized knowledge and skills. While anecdotal observations and interpretations of these associations were grounded in neo-Vygotskian theories of situated cognition and informed by Lave & Wenger’s analytic framework for learning apprenticeship, we were acutely aware that we did not have the specific data collection or analytic tools we needed to support our suppositions with evidence. Indeed, developing assessment tools to reliably record and measure changes in participant participation became the next order of business.

The coding scheme that was used in the pilot analyze audio-diary entries (see Table 2.) is one way that we sought to “make observable” some of the cognitive practices associated with mastery of digital storytelling about solutions to wicked sustainability problems. These data however, did not reveal much about whether or to what degree these youth were actually being integrated into the production of a digital story to begin with. Ideally first-hand observations of apprentices working together with mentors would provide additional evidence and allow us to triangulate data. We also realized that our investigation was further complicated by the fact that the entire learning community was itself in transition: ASCEND was intentionally designed to disrupt the normative “assembly-line” or “schooling” practices already evident at the site. The importance of developing this kind of instrument was reinforced by participant reflections on their overall experience in ASCEND, as revealed through focus group exit-interviews. These comments provided weak or anecdotal evidence of a learning community in transition and hinted at suggestions for what could be done in the future to support a stronger transition to an apprenticeship-learning model. For example, focus groups suggested that participants felt their ability to learn was limited by their overly peripheral positions in the project as compared to undergraduates who they saw as having more ownership and direction of the projects in both tracks. For example, youth participants reported that the irregularity of meetings with the undergraduate film and digital media undergraduate team leaders and their exclusion from the
work that happened off site in between those meetings restricted their ability to contribute in legitimate ways. Participants also reported that the time instructors and mentors spent demonstrating or explaining how to execute different media production skills would have been better spent supporting the youth in working collaboratively with their peers and undergraduate counterparts on the decision-making, production and post-production tasks involved in actually producing the final digital story. Overall, these focus groups communicated participants’ desires to be involved in the type of apprenticeship-style learning that ASCEND was offering but that the program was only minimally successful in implementing.

In order to develop an instrument that would allow us to gather more robust evidence of qualitative changes in participation and membership over time and transitions in participatory structures at play during an intervention period we began by asking question about the types of behaviors and interactions we would expect to see in a collaborative community of practice conducive to learning through apprenticeship versus one more reminiscent of normative practices associated with “assembly line” instruction as described by Rogoff and colleagues. The result was the development of the third-party observation tool and protocol detailed below.

**Participatory Learning Observation Protocol (PLOP)**

The *Participatory Learning Observation Protocol* (PLOP) detailed in Table 3. below is designed for analysis of learning communities presumed to be in transition out of a predominantly didactic model (assembly-line instruction) into a participatory model (apprenticeship). PLOP calls for two types of data entries: short descriptions characterizing particular aspects of the immediate context and scalar rankings associated with provided descriptions of observational cues organized in relation to three major themes (Social Organization, Motivation for Learning and Focus of Attention, Tools-in-use) and two types of learning systems (Assembly-line instruction and Apprenticeship). Short open-ended descriptions of the setting, goals, set-up, participants, and tools-in-use should be repeatedly noted as they first become evident to the observer in order to qualify how the overall educational program is being introduced and organized. While short descriptions of the introduction and organization (a.k.a. “set up”) of the learning activity should be noted early on and as they first become evident; summative notations indicating the dominance of interactive cues relative to other cues should be recorded at the close of the targeted learning activity. Observers may choose to take field notes as the activity progresses and use these to make decisions about how to complete the PLOP at the end of their visit. Third party observational cues are intended characterize interactions among members of the learning community and specified features of the learning environment. The weighted 3-point scale uses a simplified system of a check, minus or plus symbol in order to allow observers to make inferences about the predominance of each set of cues articulated in PLOP. A check mark indicates that cues for the participatory patterns associated with each category in PLOP are evident, a plus sign indicates that participatory cues were dominant and a minus sign indicates that a set of cues was minimal or absent.

To be clear, this instrument has yet to be used in practice to gather data and we expect that it will undergo substantial revision after pilot trials. It will be important to pilot the instrument across a variety of learning contexts to learn how it is working, what it is able to capture, what it misses, and where it becomes redundant. As a disclaimer, the observational cues
listed in PLOP do not represent what we would consider to be a comprehensive list of all the types of interactions that could distinguish apprenticeship from assembly-line instruction. Rather, the observational cues included represent only a select subset of a larger set that we hope to establish as sufficient to support conclusions about the transitory nature of a learning system and/or the relative success of an educational intervention in disrupting practices associated with the ethos of schooling. PLOP is not intended for isolated use; it should be used together with other self-report instruments (i.e. such as the coding scheme designed to analyze audio recordings for evidence of participants’ emerging ability to identify and define wicked sustainability problems as described above or with instruments that generate evidence of discipline-specific learning outcomes (i.e. understanding the difference between power and energy, or the ability to articulate a valid problem statement) and attitudinal learning outcomes (i.e. self-efficacy). Ultimately the goal is to be able to compare or corroborate evidence of global transitions in the organizational structure with evidence of individual learning outcomes. Triangulation will allow researcher to either corroborate third-party observations of participatory transitions or to explore possible correlations between these transitions with evidence of individual participant learning outcomes.

PLOP is not intended to support statistical findings; rather it is intended to provide greater rigor to observations and qualitative assessments of transitional learning communities. The number of visits required to make PLOP useful to any analysis should ultimately be determined by the researcher or evaluator using the instrument based on their understanding of the organization of the program in question and their own research goals. Observers/evaluators should select activities that are likely to be repeated or connected to other planned activities throughout the program period. Repeated observations of connected learning activities over the program period will allow evaluators to assess changes over time in the overall structure of the participatory model and the quality of participation exhibited by newcomers. All of the items included in the instrument, should be completed for repeat visits. A systematic coding scheme for analyzing the data collected using PLOP has yet to be developed and will be contingent on pilot testing of this data collection instrument in the field.
### Table 3. Participatory Learning Observation Protocol (PLOP)

**Instructions: Provide a short description of the following:**

<table>
<thead>
<tr>
<th>Physical setting:</th>
<th>Describe the physical setting e.g. outside in a school garden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Institutional setting:</td>
<td>Describe the institutional setting e.g. student-run club chartered to grow produce for weekly farmstand OR continuing education for senior citizens OR K-12 science/life lab class.</td>
</tr>
<tr>
<td>Activity Goal:</td>
<td>Describe the organizing goal of the activity e.g. learn to use new technology-based and urban gardening techniques a.k.a aquaponics OR &quot;harvest produce to sell for profit&quot;</td>
</tr>
<tr>
<td>Set up:</td>
<td>Describe how the activity began or how it was introduced e.g. &quot;group launched directly into the work - participants were familiar with their task&quot;</td>
</tr>
<tr>
<td>Participants:</td>
<td>Describe and distinguish newcomers from experts, provide information about the group composition ratio of newcomers to experts</td>
</tr>
<tr>
<td>Tools-in-use:</td>
<td>Describe the tools, equipment, and other materials that seem central to the main activity</td>
</tr>
</tbody>
</table>

**Instructions: Use a check (+) plus (+) or minus (−) sign to indicate the prevalence of any of the "cues" for each of the themes in the table below. If a set of cues does not apply to the situation under observation use (N/A) to indicate "not applicable".**

<table>
<thead>
<tr>
<th>Assembly-line Instruction</th>
<th>Apprenticeship Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Social Organization (interactions between members)</strong></td>
<td></td>
</tr>
<tr>
<td>Peripheral</td>
<td>Full</td>
</tr>
<tr>
<td>Experts rely on close-ended questions and evaluative statements to affirm or evaluate. Newcomers refrain from volunteering information in response to expert prompts</td>
<td>Experts rely on close-ended questions and evaluative statements to affirm or evaluate; newcomers regularly volunteer information in response to instructional prompts</td>
</tr>
<tr>
<td>Expert dictates opportunities for engagement and contribution; Newcomers resist or are oblivious to the dictates of the expert</td>
<td>The expert dictates opportunities for engagement and contribution; Newcomers take turns, raising hands, ask for help or direction.</td>
</tr>
<tr>
<td>Newcomers default to unsolicited interactions with their peers which expert-authority figures discourage.</td>
<td>Newcomers refrain from unsolicited interaction with peers as discouraged by expert/authority figures</td>
</tr>
</tbody>
</table>

**Tools-in-use**

<table>
<thead>
<tr>
<th>Tools and materials are predominantly used for the purpose of either instructional demonstrations or in evaluations of learner proficiency.</th>
<th>Tools, resources and materials are predominantly being used to accomplish an immediate practical goal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>peripheral</td>
<td>full</td>
</tr>
<tr>
<td>Experts control access to resources, tools, and materials and expect that newcomers do not have proficiency to use them independently. Experts predominantly handle tools and materials for purposes of demonstration</td>
<td>Experts control access to resources, tools, and materials but expect that newcomers can use them independently and proficiently. Experts handle tools and materials for purposes of demonstration.</td>
</tr>
<tr>
<td>Newcomer access and use of tools, resources and materials is restricted or limited as newcomers use tools with minimal proficiency under the close supervision of experts. Newcomers are minimally responsive to expert corrections.</td>
<td>Access to tools, resources and materials is restricted. Newcomers use tools with proficiency under the close supervision of experts and respond to corrections.</td>
</tr>
</tbody>
</table>
In practice this tool will need to be adapted to particular learning communities under observation. For example, our efforts to develop an observation instrument that would allow us to record changes in participation and organizing participatory structure began with attempts to define the community of practice that would be the focus of our research. In this instance the learning community we were investigating was organized around the creation, production, and presentation of digital stories about sustainable design and the impacts of green-tech innovation. Attempts to define this community quickly led us back to questions about what cognitive practices were central to this community and what “mastery” of those practices would look like. Identifying what mastery looks like in cognitive apprenticeships is akin to defining the kinds of learning outcomes that are used to organize and assess the success of educational designs in formal settings. For us it was a necessary step in preparing to next identify legitimate forms of peripheral to full participation in the ASCEND community of learners. For example, in ASCEND, mastery of the ability to produce the kinds of hybridized digital stories that accurately characterize the “wicked” sustainability problems motivating these projects, involves the ability to understand and blend technical accuracy with narrative appeal. We reasoned that mastery of technical accuracy would reiterate many of the best practices developed for the field of science communication and science news reporting but would additionally allow audiences to see the multiple issues implicated, identify and explore the tradeoffs among them, realize some unintended consequences and problematize solution-impacts. Technical accuracy also requires the inclusion of content that in any solution-process. Narrative appeal, in this context, should involve aesthetic techniques that not only amuse or entertain audiences but also motivate their empathy for different groups of stakeholders and persuade them to get involved with ongoing projects or propose new projects.

In the next section we describe how the prompts for “audio-diaries” developed to collect data on participants’ ability to recognize and articulate problems motivating featured sustainable
design projects in ASCEND can be adapted to collect data characterizing transitional participation in any learning activity.

**Soliciting self-report observations of changing participation and participatory structures through recorded audio-diary entries.**

In our discussion above we included examples of audio-diary prompts that were used to solicit evidence of their ability to formulate and articulate an understanding of the problem context for “wicked sustainability problems”. Here we provide three additional sets of prompts for audio-diary recordings that can be used to solicit evidence of the changing qualities of learner participation as well as more global changes in the participatory structures that characterize the encompassing learning community. These prompts are organized around the same three analytic themes included in PLOP but have been designed to reposition learners as participant-observers of their own experience and provide a system they can use to document aspects of their own learning activity at regular intervals.

**Social Organization**
- How did you spend your time? What was your group working on?
- Who did most of the work [on this occasion]? What were you responsible for doing? What were others responsible for doing?
- Who did most of the talking [on this occasion]? Who did you talk to? What did you talk about?
- Were you able to make creative suggestions and offer new ideas.
- Were things working well? Were people collaborating to get things done? What should people do more of? What should they do less of?

**Motivation for Participation**
- What were you trying to accomplish? What was the goal of the activity?
- What were you learning about?
- Were you interested in what you were doing or learning about today? What was interesting to you about it?
- Was it relevant to anything else? What was it relevant to?

**Interactions with Tools-in-use**
- What kinds of tools, equipment or materials were you / your group working with [on this occasion]?
- Did you personally have opportunities to use these tools or were you observing others?
- Were you familiar with these tools and materials? What was familiar or unfamiliar about them?

A coding scheme for the analysis of audio-diary entries recorded in response to the prompts listed above can be generated using the following criterion:
- (social organization: interpersonal relations )
  - apprentice-learners were accepted and treated as collaborating members of a joint-venture
○ apprentice-learners observed as “on-lookers” but were not accepted or treated as collaborating members
○ apprentice-learners were treated as pupils and the main objective of the activity was to impart knowledge or skills
● (motivation to participate and focus of attention)
  ○ apprentice-learners are working to carry out self-initiated tasks
  ○ all members are working synchronously to carry out collaborative task and all members have important responsibilities and roles
  ○ apprentice-learners working to carry out assigned task or procedure
  ○ apprentice-learners understood the activity as useful and interesting
  ○ all participants understood the activity as situated within and relevant to a shared goal
  ○ activity organized around instructional goals rather than shared goal
● (tools-in-use)
  ○ apprentice-learners had open access to the tools and materials and were using them to perform essential tasks or partial tasks
  ○ access to tools and materials was restricted by the approval or direction of an authority figure
  ○ use of tools was regulated by instructional directions
  ○ apprentice-learners were on-lookers as experts primarily handle tools

Through our prior experience with ASCEND, we learned that prompts for audio-diaries work best if they are initially presented in a discursive manner (i.e. a researcher, research assistant or educational aid is available on-site to deliver each prompt and ask follow-up questions as part of a reflective discussion with individual or pairs of participants). Over time, after repeat sessions, and as respondents become familiar with each set of prompts, respondents may become able to work more independently recording entries on their own time following a handout with written prompts enclosed. Analysis of recorded responses to these prompts should be used to supplement, corroborate or challenge analysis of the third-party observations documented through PLOP. For that reason, thematic redundancies with the observational cues provided in PLOP are intentional.

Conclusion and Implications for Practice

Research on the ASCEND pilot program provided weak evidence that peripheral participation in sustainable engineering projects through the practice of digital storytelling was conducive to participants’ abilities to recognize and articulate the problem context for wicked sustainability problems. On a larger scale, the pilot also provided insights into the potential for apprenticeship models of learning to disrupt normative practices associated with “assembly-line instruction” by supporting opportunities for legitimate peripheral participation. However, the pilot also revealed that the challenge of overcoming long-standing institutional practices, embedded interpersonal relationships or power structures associated with assembly-line instruction are formidable and additional resources and strategies for supporting robust transitions towards practices and norms associated with apprenticeship models of learning are still needed.

The results of this pilot, and more generally of cross-cultural research on apprenticeship learning that is responsive the framework and insights offered by Lave and Wenger pose significant challenges to
the existing literature on learner “engagement” which remains influential in cognitive science and throughout the learning sciences. Research that uses evidence of learner engagement to evaluate the efficacy of educational programs or learning activities typically relies on prescribed conventions such as “time on task”. However the criteria used to differentiate and benchmark “on task” behavior (including observable and interpreted (cognitive) behaviors) from “off task” behavior are questionable and the underlying assumptions they invoke need further scrutiny. For example, Engle and Conant25 define engagement in terms of “high levels of on-task behavior” which include a learner actively speaking, listening, or [verbally] responding. Herrenkohl and Guerra36 take a slightly different approach suggesting that evidence of “disciplinary engagement” should reference a number of metacognitive strategies: for example, incidences where students are publicly and openly “challenging other’s perspective or claims” or “asking questions to be sure that they fully understand perspectives posed by other students” are taken as evidence that the learners exhibiting these behaviors are “monitoring [their own] comprehension” which tacitly implies that learners who are not exhibiting these behaviors are not monitoring comprehension. Where “asking questions” or “making assertions” might be the dominant way of showing engagement in some communities this kind of assertiveness might be frowned upon in another. Moreover, these kind of underlying assumptions can be problematic for assessments of apprenticeship learning where the apprentice might be silently observing a master perform a task in anticipation of doing it themselves, proactive and fully engaged in the task at hand, but without asking questions or demonstrating other verbal signs of engagement. One advantage of developing and using an assessment tool like PLOP, is in framing learner behaviors relative to the predominate repertoires of practice that are constitutive of different learning communities or that may prevail at different times in the same community. Rather than measuring individual performances against a pre-established set of standard or idealized performance-based criteria PLOP provides a practical way to observe and account for the normative transitions that can shape and reshape the collective action and interactions among members of a group.

Methodologically, ASCEND was useful in establishing that audio-diaries can function as a strong alternative to summative data collection methods that rely on self-report measures such as exit interviews or on written responses such as surveys. Audio diaries offered a number of practical and interpersonal advantages, not the least of which was the flexibility of recording responses, as time allowed, using smart phones or other hand-held recording devices. This approach can be particularly advantageous for studies involving underserved populations. Youth–apprentices involved in ASCEND were struggling to earn their GEDs, and for various reasons, were suspect of the normative practices and pathways they associated with schooling. This population in particular was reputed to be unlikely to maintain the focus required to complete written reflections, which are more time consuming and can be reminiscent of school-based evaluation activities. We found that participants were more receptive to having recorded discussions in response to semi-structured auditory prompts dictated by an impartial yet friendly and familiar third-party observer. These recordings were useful for assessing what apprentices were learning as a result of their participation ASCEND in so far as they revealed emergent changes in the way participants were articulating their understanding of sustainability as an organizing framework and how they were relating the specifics of an immediate situation to a larger (global) problem context. Reciprocally, they were able to speak to the implications of a larger problem context for the immediate decision-making and work on sustainable solutions in the “here and now”. The further significance of this work is its potential contribution to the literature on scientific argumentation, which has to date primarily focused on the formal
argumentation practices associated with scientific inquiry and given less attention to the parallel set of formal argumentation practices implicated in engineering-design, much less the pedagogy conducive to scaffolding learner participation in those practices.

Next steps and Future work

This paper reports on the outcomes of a pilot study that employed a new instrument, “audio-diaries”, to collect evidence of changes in the way that youth-apprentices were reasoning about sustainable design problems over time. If implemented on a schedule, successive audio-diary entries show promise as a useful method for documenting incremental changes in learning learner comprehension and learner attitudes regarding their participation in STEM-linked activities over time. In the future, using audio-diaries as an instrument to collect evidence of what participants are learning about the tradeoffs, complexities and imposed constraints on solutions for design problems will require greater repetition of prompts included in each of the response sets and more in-depth follow-up questions. Furthermore, while the pilot was useful in establishing an initial set of criterion for qualifying some key reasoning practices implicated in emergent problem definition, future studies will require a rubric or ranking system that can be used to validate and compare the acuity and sophistication of observed practices relative to practices established as indicative of mastery. This will be especially challenging given our interest in the kinds of complex and emergent problems that characterize fieldwork in sustainable development and in evaluating the efficacy of pedagogical scaffolds that support participation in tackling ill-defined problems. Future studies may also be used to evaluate how audio diaries can be used for more purposes other than assessment. For instance, audio diaries may also prove useful as a strategy for making reasoning skills visible to newcomers – a process that is imperative for cognitive apprenticeships to fully function.

In addition to reporting on the outcomes of a pilot case study, this paper also proposes an adaptation of the audio diary approach as well as a new data collection instrument that has yet to be tested in the field. Obvious next steps should include pilot testing of PLOP and development of methods to compare data collected by different instruments. More specifically, methods and metrics for establishing correlations between a) evidence of proficiencies in STEM-reasoning skills (e.g. scientific argumentation) and b) affective and attitudinal learning outcomes (e.g. self-efficacy) with data collected using PLOP still require further development. Additional pilot studies will also be essential for determining how to use multiple instruments in concert with each other and for making informed recommendations on the applications of these instruments to other researchers. For example in ASCEND focus group interviews were conducted in advance of the exit survey and in hindsight, focus group interviews would have been more useful as an opportunity to probe themes emerging from survey data.

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References


We use the term “participation” within the framework of situated cognition, however many researchers have made efforts to monitor and evaluate learners “engagement.” As of yet there is still no clear consensus on what constitutes evidence of learner engagement, much less changes in engagement over time. However we believe that the framework developed by Lave and Wenger holds great potential for developing reliable tools to record and account for a learner’s engagement by focusing on shifts in interaction (verbal and non-verbal) and participatory structures. Further discussion of this work can be found in recent publications by Ball, Isaacson and Beckett, 2015, presented at ASEE and FIE conferences.