PAPER

The *Synergies* research-practice partnership project: A *2020 Vision* case study

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Abstract

This paper, describes *Synergies*, an on-going longitudinal study and design effort, being conducted in a diverse, under-resourced community in Portland, Oregon, with the goal of measurably improving STEM learning, interest and participation by early adolescents, both in school and out of school. Authors examine how the work of this particular research-practice partnership is attempting to accommodate the six principles outlined in this issue: (1) more accurately reflect learning as a lifelong process occurring across settings, situations and time frames; (2) consider what STEM content is worth learning; (3) examine learning as a cultural process, involving varied repertoires of practice across learners' everyday lives; (4) directly involve practitioners (and learners) in the research process; (5) document how existing and emerging technologies and new media are, and will continue, to shape and redefine the content and practice of STEM learning research; and, (6) take into account the broader socio-cultural-political contexts of the needs and concerns of the larger global society.

The early part of the 21st Century has witnessed significant social, economic and political upheaval. Across much of the world, particularly within developed countries, historically homogeneous communities are becoming more diverse socially, racially, ethnically, even politically. Changing technologies are disrupting traditional lifestyles and ways of doing business. Meanwhile, an increasing number of large-scale challenges to human health and economic well-being, e.g., climate change, resource disparities and scarcities, and global conflict, threaten to further unsettle people's lives, even amongst those living within relatively stable and affluent countries. As the many authors in this special issue have made abundantly clear, these changes are reflected in the world of science learning as well.

The science learning landscape is also in the throes of major changes; changes that have implications for both science learning research and practice. Worldwide, individuals have unprecedented access to science education opportunities from cradle to grave, 24/7, through an ever-growing network of educational opportunities in school and beyond. Focusing just on early adolescents, today's youth live and learn within a variety of settings and configurations that include the home, schools, informal/free-choice learning organizations and institutions, and a range of virtual environments, all shaped by a continuous stream of emerging scientific and technological innovations and mediated by rapidly evolving digital media.

As a consequence of these, as well as other changes, there is increasing evidence that individuals develop their understandings of the world, including knowledge and interest in science, not only in school, but increasingly in out of school contexts, using a variety of community resources and networks across their lifetime (re 2013; National Research Council 2015). New technologies and new media are radically reshaping not only when, but how and why people learn. The boundaries of when, where, why, how and with whom people can and do engage in science learning experiences are increasingly blurring. Ideally, these myriad, distributed resources could be used by individuals to support continuous, personalized, high-level learning. However reality often falls far short of the potential, since many people, particularly those living in communities of color and poverty, lack awareness of available resources and the social capital necessary to effectively navigate this increasingly complex learning ecosystem.

Despite decades of investment, indicators suggest that advances in the public's science understanding, interest and engagement, particularly amongst those in poor, under-resourced communities have been at best modest; most citizens are only marginally interested or engaged with science across their life spans, and most evidence little understanding of key science concepts and processes (Carnegie Corporation of New York 2009; PCAST 2010). Yet most science education policy makers (and many researchers) continue to advocate for conventional remediation approaches focused on school curriculum reform and enhanced professional development for school science teachers. Given both the lack of valid evidence for the overall effectiveness of these traditional remedies, and the fact that the world, and as a result, science learning is rapidly changing, there is a critical need for new approaches and frameworks. A similar assessment could be made about science learning research.

Most science learning research continues to focus on limited temporal and spatial contexts, often failing to fully account for or value the significant funds of knowledge that learners bring with them to each and every learning situation, including schooling. Often research studies vastly underestimate the significant differences that exist, socially, economically and culturally within subject populations, and the consequences these differences can have on science learning. Many researchers persist in maintaining counter-productive, traditional hierarchical relationships between those they “study” and themselves. And all too frequently, research designs fail to fully incorporate the opportunities afforded by new technologies. As outlined in this special issue, leading researchers have argued for a comprehensive shift in the nature of science learning research. Their collective conclusion is that 21st Century science learning research should incorporate six key principles:

1) Rethink the coordination and integration of STEM content and pedagogy in ways that more accurately reflect learning as a lifelong process that occurs across settings (e.g., early childhood, K-12, higher education, informal), situations (school, work and leisure time) and time frames.

2) Given the vastness of STEM *what* STEM content is actually worth learning, is it possible or even worthwhile for an individual to have a working understanding of all STEM topics.

3) Examine learning as a cultural process involving varied repertoires of practice across learners' everyday lives, particularly non-dominant communities, seeing how these connect with practices in STEM disciplines.

4) Examine how and why to meaningfully engage practitioners from across the learning landscape in the research enterprise.

5) Describe how existing and emerging technologies and new media are and will continue to shape and redefine the content and practice of STEM learning research.

6) Frame STEM learning research within the broader social-cultural-political contexts of the needs and concerns of the larger global society.

In this paper we present the *Synergies* project as a case study for how we are attempting to comprehensively integrate these six research principles into a single science learning research-practice investigation.

Synergies Project: An Overview

Beginning with a planning year in 2010, initially with support from the Noyce and Lemelson Foundations, and most recently, the National Science Foundation (NSF), a research team based at Oregon State University (OSU) initiated the *Synergies* research-practice partnership in the under-resourced Parkrose neighborhood of Portland, Oregon, with the overarching goal of helping to create a more effective and synergistic community-wide educational system.

We selected Parkrose as a study site because it is a small, relatively self-contained community with many of the educational resources found in any U.S. city – schools, museums, afterschool programs, libraries, and parks, as well as the socio-economic challenges found in such urban communities. Although technically a "neighborhood" in Portland, the Parkrose community is unique in many ways. Historically Parkrose was not in Portland proper and it continues to be served by a single, independent public school district, although a few private, faith-based schools also serve the area. The Parkrose School District has four elementary schools that feed into a single middle school and then into one high school. In terms of informal STEM resources in the community, Portland has a number of quality informal STEM-related education institutions/organizations (e.g., science center, zoo, and children's museum), but these resources require extensive travel to reach, are poorly served by public transportation from the Parkrose neighborhood and have admission fees. Parkrose does have a branch library and parks. In addition, at the beginning of the project, a small number of community-based organizations offered some form of STEM-related after-school and summer programming, although primarily for elementary-aged children.

Parkrose is a geographically bound, cut off from the rest of Portland on three of its four boundaries (by two major freeways, the municipal airport and the Columbia River). The fourth boundary is not a physical border but a socio-economic one; Parkrose is in northeastern Portland, the area of the city with the highest poverty, unemployment, drug use and crime. Although Portland proper is primarily white, Parkrose is a majority, minority community. According to U.S. Census statistics (U.S. Census, 2012), Parkrose residents fall within the following broad demographic categories: 38% White; 24% Latino/a: 18% Asian; 12% African American; 5% Native American; and, 3% of Pacific Island origin. The majority of Parkrose residents are low income (e.g., 75% of children in the public schools qualify for free or reduced meals).

But these statistics belie the true diversity of the community. For example, although nearly 40% of Parkrose residents are classified as "white non-Hispanic, over half of these are recent immigrants from Eastern Europe, and the "Asian" category is roughly equally represented by immigrants from Vietnam, Korea, Thailand and several parts of China. In fact, Portland has one of the largest Vietnamese populations in America per capita. Similar diversity can be found within the "Latino/a" category as well. Evidence of this diversity is the fact that over 50 languages are spoken in the school district of about 1200 children and many of these children live in homes in which English is not the first language. Although a small community by many standards, Parkrose is large enough to mirror the majority of the complex social and economic dynamics of major urban areas, yet small enough from a research and practice perspective to be manageable in both scope and scale for a project of this nature. In many ways, Parkrose is a microcosm of urban America.

Beyond its physical and socio-cultural characteristics, Parkrose is an ideal study site for one other critically important reason – the Parkrose community has welcomed our research team from the start. We spent the first planning year identifying key educational partners, certainly Parkrose School District, but also other educational partners, including Oregon MESA (Mathematics, Engineering, Science Achievement), Mt. Hood Community College, Metro Portland 4-H Youth Development, Port of Portland (Portland Airport Authority), Girls, Inc. (national STEM education provider), Metropolitan Family Services (regional social services agency), Oregon Museum of Science & Industry (OMSI) and Metro (regional parks and recreation). All community members and partners have been uniformly open to change, excited about the prospect of being a community-based research laboratory and committed to improving the lives of their community's children.

In order to take a learner-centered perspective and build an empirical foundation for a community-wide system, over the first five years of the project we collected STEM interest and participation data from all youth in the cohort, as well as developed in-depth case studies for a subsample of 15 youth and their families. We also convened community meetings with partners and initiated planning for community-wide "interventions." The goal of this work was for *Synergies* project staff to directly engage as many of the education players in the community, as well as parents, community leaders, and youth themselves in the redesign of the Parkrose STEM learning ecosystem. The major product of these efforts is a draft Parkrose STEM Education Plan which will be collaboratively implemented with a recently funded NSF grant. This new funding enables us to leverage the research findings from the on-going longitudinal study in support of a systematic and systemic design phase. Meanwhile, basic data collection to monitor youth interest and participation in STEM will continue. Our research questions are:

- What is the nature of the STEM-related interests of 11-14 year old youth living in a single urban community and what factors seem to influence whether STEM interest increases, stays the same or diminishes over time?
- What STEM-related activities do 11-14 year old youth living in a single urban community participate in and what factors seem to influence whether participation in these activities increase, stay the same or diminish over time?
- Are there significant differences in the STEM interest and participation profiles for youth as a function of socio-cultural background factors (gender, race/ethnicity, economic circumstances); support and encouragement by parents, teachers, and peers; participation in out-of-school STEM activities; STEM understanding; perceptions of the value of STEM; perceptions of youths' self-efficacy in STEM; or parent/youth aspirations in STEM?
- Do STEM education interventions that are customized to take into account specific STEM interest profiles appear promising for sustaining STEM interest and participation outcomes?

- In convening a wide variety of informal and formal educators to collaborate over time on developing an integrated, ecosystem approach to fostering youth STEM interest and participation, what challenges were encountered, what was perceived as working well, and what was perceived as not being effective?

As we designed and are implementing *Synergies*, we have attempted to reflect the spirit, if not the letter of the six key research principles. We describe these efforts in the rest of this paper.

Learning as a Lifelong Process Occurring across Settings, Situations and Time Frames

Two decades ago, in the context of improving the evaluation of informal/free-choice STEM learning experiences, St. John and Perry (1994) proposed a reconceptualization of education resources in a community, arguing that in addition to schools and universities, there are myriad learning resources – libraries, community-based organizations, museums, parks, print and broadcast media and the Internet – all components of a single, complex educational infrastructure. More recently, the idea of an educational infrastructure has been reframed by STEM education researchers using the ecological concept of an ecosystem (cf., National Research Council 2015), but the basic ideas are the same – learning happens across a wide range of settings and situations across the day and over a lifetime. The notion of an ecosystem has also been expanded to include not only material resources, but social ones: social networks, peers, educators (in school and out of school), friends and family.

This concept has implications for both science education research and practice. In terms of practice, a recently published report on the STEM learning ecosystem (Traphagen & Traill, 2014), proposes more strategic, integrated approaches to STEM education across learning spaces (schools, community settings such as after-school and summer programs, informal experiences at home and in other free-choice learning environments, designed spaces such as science centers and museums, and the ever important social networks of peers, family and significant adults) which would enable youth to become engaged, knowledgeable and skilled in STEM across their lifespan.

The *Synergies* project is committed to improving the quality of STEM learning in Parkrose, and we have argued (along with others described earlier), that a key reason for the current challenges within STEM education is a failure to recognize that quality STEM learning is best supported through a healthy and robust community-wide ecosystem. In most communities, certainly in the U.S, there is a lack of coordination and cooperation between STEM education providers, in school and out of school, resulting in a fragmented and inefficient collection of STEM education efforts and resources. Concomitantly, residents often do not fully appreciate the myriad resources for engaging with STEM that already exist within their community, nor completely understand their potential. Additionally, there may be a lack of social capital and/or agency for doing so more regularly and effectively. Unfortunately, this is the case in many diverse, under-resourced communities with high numbers of immigrant families, such as is the case in Parkrose.

This view of STEM learning requires significant re-thinking of STEM learning research as well. As outlined in the introduction to this issue, if STEM learning is truly a lifelong, life-wide and life-deep process, research designs must cut across diverse settings and investigate multiple contexts and media, rather than the historical approaches that have viewed learning within limited temporal, spatial and socio-cultural contexts (e.g., the 3rd grade classroom, the introductory college physics course or 5th grade school field trip to a science center). Research designs need to fully accommodate the complexities of learning across time and space and acknowledge that rarely, if ever, is it totally valid to assume that "learning" exclusively took place in just one particular, narrowly defined and delineated context or situation (e.g., over the course of this school unit or after participating in this particular afterschool robotics program). In short, STEM learning research needs to be designed with the view that STEM learning is an on-going cumulative and continuous process, rather than individual and delineated events.

In conceptualizing *Synergies*, the goal has been to determine to what extent we could design a research study that would provide both fundamental understandings about how diverse youth in an under-resourced community become interested and engaged in STEM (or not), across the settings, situations and time frames they traverse, but also whether these data could be used to engage a community in rethinking and redesigning the education system, writ large. In line with this ecosystem approach, the context for the investigation is the Parkrose STEM learning ecosystem; an educational system that includes the schools, as well as informal STEM learning resources. These resources include not only physical resources such as the school classrooms, afterschool programs, libraries, parks and museums described earlier, but also the digital resources youth engage with, Mine Craft and digital search engines such as Google, which vastly expand the STEM ecosystem's boundaries.

In order to take a learner-centered approach, we first investigated STEM learning through the lens of a single cohort of early adolescent youth as they moved across and through their own personal STEM ecosystem. We sought to study the collective learning ecologies of these youth; an ecology that includes siblings, friends, teachers (in school and outside of school) and parents, and that crosses multiple institutional boundaries and STEM content areas throughout the day and over the years. In the design phase we have just begun we will be adding other cohorts to study the development and implementation of interventions in a systematic manner, all built on the research foundations of the initial 5 years of the project.

To study the collective learning ecologies of the initial cohort of youth and build an empirical foundation for a community-wide system, in 2011 *Synergies* staff began longitudinally tracking the STEM interest and participation pathways (both in school and out of school) of a single cohort of approximately 200 youth for whom we have parental consent and assent forms. The youth were in fifth grade (aged 10/11 years); this initial cohort is now entering high school. We used two data collection strategies: 1) a primarily closed-ended questionnaire administered annually to every youth in the cohort; and 2) intensive, in-depth case study data collected roughly monthly with a subsample of 15 youth from the cohort.

We developed the questionnaire for this aspect of the study through an iterative process in which we drew upon a large body of research on interest development (particularly in science or STEM), existing instruments, research on youth participation in STEM, reviews by project advisors, several of whom are experts in the field of science and STEM interest development, input from eight youth researchers whom we hired explicitly for this purpose, and cognitive interviews with five 10/11 year old youth living outside the study area but comparable in background (for details on instrument construction and content see Falk, et al. in press).

An initial sample of 20 youth and their families were recruited to participate in on-going case study data collection; five families either left the study or moved out of the neighborhood so we have a final sample of fifteen youth. These individuals were selected on the basis of gender, race/ethnicity, income and geography to be broadly representative of the broader population in Parkrose.

As of the writing of this paper, we now have four years of quantitative and qualitative data. The quantitative data provides a detailed record of the year-by-year STEM-related interests and behaviors of the vast majority of youth in our cohort (limited only by the details of our instrument and the realities of Institutional Review Board policies requiring parental consent and youth assent). We also have detailed qualitative data from the subsample of youth included in the case studies; highlights of their contribution to the study are described in a later section of the paper. Collectively, these data form the empirical foundation for an understanding of the STEM learning ecologies of this single cohort of youth and provide a rough outline of the boundaries and nature of the STEM learning ecosystem youth in Parkrose currently interact within.

Reconsidering the central role of STEM content

It has become widely accepted that successful citizenship in the 21st Century increasingly requires a foundation of interest, facility and comfort with STEM ideas, practices and fields (NRC, 2011). Some individuals will build on this foundation to pursue STEM academically and professionally, while others will pursue STEM-related hobbies and pursuits. All will require this foundation to make informed political, social and economic decisions. Accordingly to ensure the strongest possible science literacy platform, it is essential to broaden and deepen access to, and participation in quality STEM education for all young people, and especially young people from communities or social groups (e.g., low income, minorities, females) who historically have not been fully represented in STEM fields and/or STEM-related hobbies/pursuits.

In light of these goals, a growing number of STEM educators have become focused on the dual areas of STEM interest and participation as evidence mounts that these areas, rather than content, may hold the key to future STEM literacy (DeWitt et al. 2011; Tai, Qi Liu, Maltese and Fan 2006). Evidence exists (cf., Osborne, Simon and Collins 2003) that youth interest in, and participation with STEM consistently declines during adolescence, both in the U.S. and internationally, with fewer and fewer young people choosing to major in scientific fields or even take science coursework at the high school and university level. Clearly, declining numbers of youth pursuing further STEM education and careers translates into fewer STEM professionals, leading to negative economic effects related to a lack of qualified workers available to fill the increasing number of STEM-related jobs. However, it also results in citizens with a declining capacity to function successfully in an increasingly scientific and technological world.

Policy makers, practitioners and researchers have increasingly focused attention on the early-adolescent years as a time that is critical to engage and excite young people, recommending that individual and group experiences inside and outside the classroom be created for youth to inspire their interest in STEM. For example, STEM interest during early adolescence, particularly between ages 10 to 14 years, has been shown to be a key variable in predicting involvement in further science education and careers (Maltese and Tai 2011). Children who have an interest in STEM are more likely to be motivated learners in STEM; they are more likely to seek out challenge and difficulty, use effective learning strategies, make use of feedback, persist in tasks over time and expend effort to master them, particularly when they experience feelings of enjoyment and value for the activities in which they are engaged (Renninger and Hidi 2016).

As a result of these findings, from the outset *Synergies* focused on the issue of adolescent interest and participation in STEM, rather than content. However, our focus on interest was predicated on an understanding that interest and knowledge are tightly inter-related, each developing over time through engagement in STEM learning activities. Children whose interest in STEM is developed and sustained are likely to become adults who pursue STEM interests at home and at work. Of course in addition to needing to operationalize what we meant by interest and participation (cf. Falk et al in press) we also needed to operationalize what we meant by STEM within these contexts.

STEM is an acronym for science, technology, engineering, and mathematics, originally coined by the education-related programs of the National Science Foundation (NSF), though not explicitly defined by NSF. Implicit in the concept of STEM was that problems within the real world are often not easily divisible into the separate disciplines traditionally defined by the academy, e.g., physics, biochemistry, molecular biology, structural engineering, electronics, algebra and calculus. Some have even called STEM a meta-discipline, an integrated discipline that is a new ‘whole’ (Morrison 2006).

The concrete embodiment of this practice-focused move to think more broadly about the content of STEM, to perhaps even integrate the disciplines within it more fully, is seen in the new U.S. Next Generation Science Standards (NGSS), in which every standard includes “three dimensions: disciplinary core ideas (content), scientific and engineering practices, and cross-cutting concepts” (Achieve, 2013, p. 1). Reinforcing the notion of STEM integration, the National Academy of Engineering (NAE) and the Board on Science Education of the National Research Council (NRC) formed the Committee on Integrated STEM Education, a group of experts on diverse subjects who conducted a two-year study to develop a research agenda for determining the approaches and conditions most likely to lead to positive outcomes for integrated STEM education at the K–12 level in the United States. The committee's charge was to identify and characterize existing approaches to integrated STEM education, in both formal and after-school/informal settings. The report, *STEM integration in K-12 education: Status, prospects, and an agenda for research*, was published in 2014 (NRC 2014).

As NGSS becomes adopted in the U.S. and the findings of the aforementioned NAE/NRC study are disseminated, there will undoubtedly be increased pressure to measure various dimensions of children and youth's understanding, interest, attitudes and practices in STEM, despite the challenges inherent in measuring such a complex, ill-defined construct. A recent review of STEM-focused assessments (Minner, Ericson, Wu and Martinez, 2012) found that 69% measured cognitive dimensions of STEM, and within these, 53% had an exclusively science focus, 26% exclusively a math focus, and only 21% attempted to measure science and mathematics in an integrated manner, as well as other content domains including literacy. Among the instruments surveyed that attempted to measure both content knowledge and reasoning skills, only a quarter (26%) covered multiple domains. Currently few existing instruments fully capture the breadth and extent of STEM disciplines. This is not surprising, given the significant challenges of incorporating all of the multiple content areas that STEM, writ large, theoretically embraces, within a single instrument. This is particularly true for any instrument that hopes to generically capture youth understanding, interest or participation in STEM, as opposed to measuring a more targeted aspect of STEM.

Our approach was to operationalize STEM as a loose assemblage of youth-focused activities and/or practices (taking things apart, exploring outdoors, solving puzzles, etc.) in which we inferred a relationship to STEM disciplines, individually (and in some cases combined), and their associated practices which we conceptualized as concrete activities. From the myriad domains of science, technology, engineering and mathematics we could have selected, we chose to narrow our content areas to those the target cohort of youth were most likely to encounter in school (e.g., life and earth sciences) and out of school (e.g., gardening, consumer technology and topics commonly presented on youth-oriented media). After piloting several dozen items relating to activities/practices in STEM, the final questionnaire includes 16 items encompassing a diversity of STEM topics or activities that Parkrose youth were likely to be interested and participating in. This approach allowed us to avoid generic terms that might be a ‘turn-off’ to some youth (e.g. math), might not be understood (e.g., engineering) or may be interpreted in different ways (e.g., science), while still investigating the specific STEM topics and associated practices that youth enjoy learning about and engaging in. For example, rather than asking youth if they were interested in ‘technology’ as a general concept, we included specific items that were technology-related, and were likely to be within the everyday experience of this group of youth such as interest in ‘how computers or cell phones work.’ We chose science items that specifically related to the science curriculum of the public middle school attended by the vast majority of these youth. Thus, our final list of items was simultaneously broad enough to encompass a diversity of content/practice interests, and reasonably representative of the topics in science, technology, engineering and mathematics youth might encounter in their daily lives. At the same time, the list was sufficiently limited to accommodate the attention span of young research participants (recall only 10-11 at the beginning of the study) and the inevitable completion time and length constraints required of instruments of this kind (e.g., the need to obtain school administrator and teacher permission to administer the instrument during school time despite the research in question falling outside of on-going classroom or school district-mandated student assessments).

To iteratively, test and refine the questionnaire we utilized Principal Components Analysis (PCA). Although we initially had items that distinguished between technology and engineering, piloting showed that youth did not discriminate between these topics/activities; that is, youth who responded that they were interested in the technology-related items, were also interested in the engineering items, resulting in one factor, rather than two in the PCA, so we combined these into a technology/engineering dimension. Analysis of the first year survey data of youth 10/11 years old resulted in only three factors, plus one single mathematics item as an outlier. In the second year we added several more mathematics items and the PCA yielded four factors: earth/space science, life science, technology/engineering, and mathematics. After confirming reliability of each scale using Cronbach's alpha, we computed the mean score of the final items for each component to create four latent variables that correspond to the underlying dimensions of STEM interest for each youth responding. We also validated the four factors that had emerged with our STEM advisors. Given the reliability and validity results, we finalized the instrument and used it and the bottom up, youth-defined categories it contains, to track youth STEM interest and participation pathways over the four years of the project and will continue to use it as we follow the original cohort through high school, and add additional cohorts for the design work.

Examining learning as a cultural process involving varied repertoires of practice across learners' everyday lives

The *Synergies* investigation focuses on youth's STEM interests and practices. From the start, rather than using institutionally-defined outcome variables, the study has centered on how youth, themselves, define interest and participation in STEM-related topics. Although we had to limit the scope and scale of what constitutes STEM interest and practice in the questionnaire due to the practical necessities of reasonable length and time for administering, the more qualitative case studies are a vehicle for broadening the lens to include as much diversity in perspective and definition of STEM as possible. These data add richness and context to understandings about the varied repertoires of practice early adolescent learners engage in during a typical day, how and why children's STEM interests develop and change during this period of time, and which factors (e.g. family, friends, awareness, availability of and access to community resources, social capital, geography) contribute to changes in STEM interest and engagement. These data also validate and enrich the survey, modeling and community efforts of the project.

Case study data collection included an in-depth interview with youth every 6-8 weeks; most of these conducted in the home. Most interviews centered on a variety of activities in which we engaged the child and their family. For example, each family was given a digital camera to record family time, "days in the life" of the children, and STEM resources in the community. We also had youth create interest timelines in which they visually depicted how an interest had developed (or waned) over time and what the factors were that may have contributed. Youth made initial interest timelines in Year 1 when they were in 5th grade and these have been revisited, revised and discussed over time. We also worked with these youth to map their activities within Parkrose and the greater Portland Metro area.

After giving families time to complete their "assignments," we interviewed each child about his/her photos, interest timeline, etc., prompting them to describe their interest in the activity, where it took place, how they got there, the roles of others (family members, peers, teachers and other significant adults) in encouraging the activity, and/or participating in it with them, and how and why their interests have changed over time. Other times we merely interviewed the youth about current activities and interests in which they were participating, and the social and physical factors that might have influenced those activities and interests. These interviews were recorded and transcribed. In addition, we kept field notes that capture any contextual information that may not be recorded. We have used Dedoose, a coding software platform which enables the coding and analysis of qualitative data, including interview data transcripts, field notes, photos, etc. and have worked closely with colleagues at University of Colorado, Boulder (CU), in particular, William Penuel.

These data are revealing the "on the ground" realities of a subset of Parkrose families, and how income, social capital and race/ethnicity, influence youths' STEM interest and participation pathways, out of school, and in some cases, in school. For example, two of the fifteen case study youth live only one mile apart from one another, yet their lives in the first summer we interviewed them with their photos of family time, were very different. Their photos varied in terms of the activities they engaged in, the role their family played in seeking out and/or supporting their interests and the influence of peers. We also have observed the role of income, social capital and, race/ethnicity, on youths' perceptions of their STEM interest(s)-dis-interest; where activities related to STEM take place, and if outside the home, how youth get there; and, how and why their interests might have changed over time.

Case studies also have shown some of the interplay between out-of-school and in-school activity. One case study youth was very interested in mathematics in fifth grade, sharing his "love" for the topic during the first interview. In fact, when asked during a subsequent interview if he had a weekend when he could do whatever he wanted, he said he would visit a math website, sharing that he started getting on math sites when he was in third grade, and by fifth, used them almost daily. Although he did not have strong parental support for his interest (his mother did not even know that math was his favorite subject), he independently sought out math websites and spent many hours after school, solving math problems on his computer that were not for school, most often alone, but sometimes with his cousin. However, by the end of sixth grade, his love of math was starting to wane and he was identified as Math Disinterested; this dis-interest persisted through 8^{th} grade, though he remained interested in science, technology and engineering. Case study analysis indicated that there were several factors that could be implicated in the decline of his STEM interest over time. Perhaps the lack of family support ultimately made a difference, or the fact that none of his peers participated with him. Another factor, identified both through the survey and case studies, was the role of self-efficacy or self-concept in STEM. This youth indicated he gradually lost interest largely because school math was becoming more difficult, particularly fractions which he said, "hurt him."

Although in this young man's case, it was likely some combination of these factors, case study findings suggest that a number of out-of-school factors, including parental and peer support and participation in out-of-school activities, were significant in explaining how STEM interest may develop or decline over time. In addition, to understand the varied repertoires of practice early adolescent learners engage in during a typical day, it is critical to take into account issues of income, social capital, geography and race-ethnicity. In the next five years, we plan to use these findings to inform the development of targeted intervention strategies that better support long-term youth interest and participation in STEM and that we hope may lead to life-long engagement in these fields.

Directly involving practitioners (and participants) in the research process

All along, a key principle of *Synergies* has been the desire to directly engage formal and informal practitioners, as well as parents, community leaders and youth, themselves, in the research process. As described earlier, project staff spent the first planning year meeting with key partners to engage in conversations about the project's goals, but also to discuss the nature of the data to collect; this approach was taken before collecting a single piece of data. We felt this was critically important since we were mindful that it was highly possible that the ways we as researchers, were thinking about constructs such as STEM interest and participation, and how we hypothesized these might develop (or wane) over time and across settings, were not likely to be the same as community partners, including educators, thought about these constructs.

This transcends whether practitioners are familiar with current research on interest and participation. Most practitioners utilize planning tools (e.g., curricula, grant proposals) that deal with these constructs in a very linear fashion; rarely are constructs like STEM interest and participation conceptualized as complex, multi-dimensional variables. Thus a key part of these early discussions with partners and stakeholders revolved around building a shared understanding of what was meant by youth STEM interest and participation.

We are conducting the project as a *research-practice partnership*, engaging practice colleagues from Parkrose, as well as from across other parts of the Portland STEM community. Although we began with a set of basic research questions, these have been modified through an iterative process with community members. Since one of our key goals is to improve collaboration between and amongst all of the different youth-serving organizations/ institutions within the STEM ecosystem, this input by practitioners into the empirical foundations and process are essential. We have facilitated theory- and model-building, collecting data on community theories and models, sharing data with participants, and facilitating the generation of strategies for improvement.

The first step in this process was to meet both individually and collectively with key stakeholders in order to develop a shared theory of change for the community. As suggested by the work of Connell and Kubisch (1999), this activity clarifies for all parties – researchers and practitioners alike – areas of consensus and differences in beliefs about key mechanisms for improving community outcomes. We have also engaged practitioners in a multi-step process resulting in the development of a comprehensive *Parkrose STEM Community Education Plan*. To create this plan we assembled senior leadership from all sixteen of our existing partners – Parkrose School District, Metro (regional parks and recreation), Multnomah County Libraries, Oregon MESA, Oregon Zoo, Intertwine Alliance (a regional consortium of environmental organizations), Mt. Hood Community College, 4-H Youth Development, nConnect (non-profit focused on STEM mentoring), Saturday Academy (regional informal STEM education provider), Port of Portland, Girls, Inc., OMSI, Portland Children's Museum, Metropolitan Family Services and Portland State University; 28 individuals. The meetings were structured so that the OSU team could share research findings to date, build consensus around strategies, and organize working groups to develop the Parkrose Education Plan. Subsequent to this meeting, smaller working groups created specific research-based plans around specific "challenges" highlighted by the research. These separate plans were ultimately assembled by *Synergies* staff into a single document. The resulting Plan was circulated amongst all partners for comments and edits; a final version was approved by all sixteen participating organizations. With new funding from the NSF, efforts to implement this plan will begin in 2016.

In addition to working with practitioners, at critical junctures in *Synergies* we also have involved "youth researchers," who have helped us better understand, from a youth and local Parkrose perspective, the issues and realities of the system we are studying. Youth have been shown to be effective informants and co-researchers in collaborative community change initiatives (Kirshner, O'Donoghue and McLaughlin 2005).

Drawn from the Parkrose community, at two strategic points in the process, the project hired a team of high school-aged youth to provide "ground truth" for the assumptions and specifics of our proposed research. In the first research year, the first thing we did was to hire ten youth researchers at an hourly wage to help us understand the range of choices, venues and conditions with which Parkrose middle-school-aged youth operate, as well as their views of

STEM. With the help of our CU colleagues, we adapted a youth-led participatory research (YPAR) curriculum, to teach youth researchers a variety of skills including how to conduct open-ended interviews, create videos and critique research materials. Youth researchers reflected upon their own STEM experiences and conducted interviews with Parkrose youth within the study's age range (10-14). These data provided a foundation for initial choices of what types of STEM-related activities and practices Parkrose youth might possibly be engaging in.

We also "piloted" the initial versions of the questionnaire with this group, asking them to critically assess the questions, for both content and wording. Their feedback proved invaluable in helping to craft an instrument that was perceived as both relevant and comprehensible to our diverse sample. This group of youth researchers also created video-documentation of what STEM meant to them, sharing these at a public meeting attended by parents, community leaders, including local Council members, school and informal educators and school administrators and the press.

We hired a second set of youth researchers, including a few from the original group, during implementation planning when we were working with the community on the development of the Parkrose Education Plan. Under the direction of the *Synergies* Community Coordinator, these youth learned how to do field work and identify and contact potential STEM resources and assets in the community, who might be able to play a role in supporting and sustaining youth interest and participation in STEM, based on the six top interests that emerged from the survey data (Astronomy, Building and Construction, Creativity and the Arts, Nature and the Outdoors, Animal Care and Fitness). The *Synergies* Asset Mapping team met for 6 weeks and during that time, youth canvassed the community, interviewed neighbors, local business owners and community members in public places. This work culminated in the creation of a large Excel database including all of the necessary data points for each asset that we plan to update and make into an interactive tool, for example, a smartphone app that can be used by youth, parents and/or educators in Parkrose.

Utilizing existing and emerging technologies and new media

As suggested above, the *Synergies* project has attempted to accommodate the rapidly changing STEM learning landscape of the 21st Century by acknowledging the role that digital media such as games and search tools play on youths' ability to access and participate with STEM. One example of a focused study in this area is a recent dissertation completed by a doctoral student on the *Synergies* team interested in the Maker movement and new media (Wyld 2015). Jennifer Wyld explored the contributions of a nine-week new media Maker experience offered in an afterschool program at Parkrose Middle School, in which a group of diverse youth learned how to design interactive, on-line computer games. Wyld was interested in whether, and if so how, such experiences might support or sustain youths' understanding of technology, and their relationship to it, as well as offer opportunities for youth to explore STEM interest and identity, as well as their personal identity.

Utilizing observations of the activities, interactions and conversations between and among participating youth, near peer mentors, and adult facilitators, the completion of an interest questionnaire at the start and end of the experience, and Personal Meaning Mapping, in-depth interviews, pronoun usage and artifact analyses, Wyld found that the synergy of the Personal, Socio-Cultural and Physical dimensions of the experience provided a space/place in which youth interested in technology could identify more personally with the tools and practices of technology, broaden and deepen their interest, and as a result, transform their relationship to technology. Critical components that seemed to support youth agency, interest development and identity exploration around technology, were the intentional use of a non-hierarchical facilitation style, engagement with authentic tools and practices, collaboration, and a focus on interest-driven activity and choice. In addition to technology-based interventions, we also anticipate the need to create digital tools that become a part of a mix of educational intervention strategies we envision the Parkrose community using to support and sustain youths' interest and participation in STEM.

However our use of new technologies has not been limited to educational practice. We have attempted to incorporate new technologies into the research design of the study as well. As said many times already in this paper, from the outset we envisioned this study occurring within a complex setting. We use *complexity* here in a very specific way – not 'complicated,' but rather characterized by properties and dynamics observed in a wide variety of adaptive biological and social systems (Gell-Man, 1994). This study seeks to investigate the STEM learning of youth within a community as a complex system; where the learning that occurs is greater than the sum of its parts. Conventional approaches to studying STEM learning often describe interactions at only one level of the organization (e.g., between a teacher and a learner, or between an institution such as a museum and its visitors); these approaches are unable to provide data that depict levels of learning and interaction simultaneously. This is problematic when trying to understand complex systems such as cells, economies or communities, since individual components interact with each other through complex networks of interactions that are neither totally regular, nor entirely random (Parrott, 2002). Complexity theory provides a framework in which the relationships between constructs at different hierarchical levels can be accommodated and optimizes important clues hidden within the system's structure about how it operates and evolves. Agent-based modeling (ABM) is a computer-based research tool specifically designed for this purpose.

Agent-based models are computational models following a relatively simple set of rules specified in the model, that simulate how the actions of individuals (agents) produce observable patterns at a macro-scale (Axelrod, 1997; Epstein & Axtell, 1996). Agent-based models have been used to develop insight into a variety of phenomena involving complex social interactions, such as the diffusion of innovations (Deffuant, Huet, & Amblard, 2005), the emergence of social norms (Epstein, 2001), the spread of infectious diseases (Segovia-Juarez, Ganguli, & Kirschner, 2004), and the performance of financial markets (Axtell, 2005).

In this research we are using agent-based modeling to help gain insight into youth interest pathways and the dynamic relationships that participation, adult involvement and peer relationships have with interest. We have found that the use of this tool has significantly enhanced our understanding of youth interest and participation pathways by: 1) "Forcing" us to explicitly articulate our own theories about what might be "causing" youth interest to increase or decline; 2) Illustrating the critical role of crossing the threshold from maintained situational interest to emerging individual interest (cf., Renninger and Hidi 2015); 3) Clarifying the importance of social encouragement by adults, particularly parents and guardians; and, 4) Clarifying the importance of friend co-participation in sustaining interest in STEM-related pursuits amongst early adolescence. Overall, the ABM process has helped to make a number of key mechanisms and dynamics of the complex system we are investigating both more visible and more intellectually accessible.

Accounting for the needs and concerns of the larger society

Although at its heart the *Synergies* project is exceedingly place-based and local, this community like any other around the world is affected by, and responsive to events within the wider world. As pointed out by Barab and Kirshner (2001) communities are not mere “backdrops” for STEM learning, they are dynamic learning environments in which people engage, interact and make sense of the STEM they encounter in their daily lives, including economic disparities, climate change and pollution. Our research has attempted to be sensitive to these realities and our practice has sought to expressly address them.

An example of the latter is that a central tenant of the Parkrose Educational Plan is that the most likely path to educational transformation is the application of a systems approach, which effectively harnesses a community’s strengths and capacities by leveraging synergies between existing social, cultural, physical and technological resources. What this means in practice is focusing on systems-level topics as a vehicle for engaging youth in meaningful STEM experiences. For example, among the efforts currently being considered by the community are a range of projects involving PDX, the international airport that abuts Parkrose (in fact the land for the airport was “cut out” of the original Parkrose footprint. Historically despite being a major presence and employer of local residents, there was virtually no interaction between PDX and the broader community. Yet PDX, like all international airports, is the focal point for a host of economic, social and environmental challenges that plague most urban areas, including illegal immigration, crime, economic effects of globalization (e.g., reduction in jobs created by the consolidation of airlines), introduction of invasive plants and animals and air, water and noise pollution. *Synergies* project staff are working in collaboration with colleagues at PDX, Parkrose schools and a range of informal education partners, including SUN Schools, 4-H and MESA, to build real-world issues and solutions into in-school and out-of-school STEM programming, with a key focus on careers. This will be one of the interventions we will test over the next five years.

Meanwhile the research investigation is seeking ways to better understand how focusing on these types of “real-life” issues might enhance youth interest and participation in STEM. Currently research findings indicate that very few Parkrose youth perceive the real value of STEM to their lives, particularly in terms of their future prospects as STEM professionals. As we begin to manipulate the system we are studying through “interventions” such as the one just described, we hope to be able to determine whether we discern any real changes in outcomes based on interventions framed around broader social-cultural-political contexts and the needs and concerns of the local and larger global society. In particular, we are hoping to test interventions that actively engage youth in problem-based experiences, in school and outside of school, that give them opportunities to be active players in identifying and acting upon these problems.

Equally important, even without actually changing what youth learn about and do in STEM, our research will be attempting to predict what these kinds of interventions might achieve. One of the promises of technological tools like agent-based modeling is that it allows you to model and "predict" change, in other words, to investigate possible interventions, prior to developing them, to see whether they could be pivotal experiences for youth. As we refine the *Synergies* interest and participation agent-based model, we hope to "test" whether we can define and introduce a "relevance" variable into the model. Adding this variable will enable us to experiment with these kinds of interventions, prior to actual implementation, and determine both the costs and benefits of such interventions, but equally, how they might differentially affect diverse learners. As we tweak this model, and the other tools and processes we create in the next five years, the goal is to broadly disseminate these findings. For although place-based and local to the Parkrose STEM learning ecosystem, we always have envisioned that *Synergies* would provide insights, tools and strategies that both practitioners and researchers could broadly apply to other regional, national and international STEM ecosystems.

One other important comment as we close the discussion about framing research within broader social-cultural-political contexts, and the needs and concerns of the local and larger global society. Over the five years we have been privileged to work in Parkrose, we have observed the conditions and stresses of life in a diverse and under-resourced community, particularly through the lens of our case study research. Over the last decade, many Parkrose families, like those in other urban communities, have experienced the loss of homes and jobs and are struggling to make ends meet on a day-to-day basis. There also has been a continuous flow of immigrants into, and out of the community; many coming and leaving, not out of choice, but necessity. These circumstances present tremendous challenges to the families trying to make a life in Parkrose, and to the educational partners in the community, both in school and out of school, attempting to meet the needs of this diverse and under-resourced community. Our research cannot but be influenced by these challenges too.

Final Thoughts

For the past 100 years researchers and practitioners acted as if the words *learning*, *education* and *school* were synonymous – today public STEM learning does not just happen in school. Today's learners spend only a fraction of their lives in a classroom, and most learning is *free-choice*, driven by an individual's needs, interests and access to learning opportunities. If we are to better understand the nature of STEM learning, let alone achieve the oft-stated goals of creating a STEM engaged and literate public, we need to adopt approaches that embrace the six principles advocated in this issue. We need to understand and foster STEM learning experiences across settings, leverage community resources and partnerships and broker additional STEM learning opportunities across individual learners' lives, from cradle to grave. We need to utilize models that embrace complexity and move beyond one-size-fits-all solutions and descriptions.

As suggested within this issue, a range of investigators have begun integrating these research principles into their work, including the *Synergies* project in Portland, Oregon. The reality though, is that currently these efforts represent only a tiny fraction of activity within the larger STEM learning research community. Thus, we urge researchers in the future, to embrace models and approaches to STEM learning research, consistent with the new realities of the 21st Century.

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