Designing Impactful Science Learning Experiences for Underserved Youth

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Abstract

Out-of-school science experiences are an especially impactful way to learn for students who face barriers to science in the typical classroom environment. Authentic science experiences provide real world contexts which can make science learning more accessible. Programs with goals to support underserved student access to STEM degrees and careers are tasked with designing effective out-of-school science experiences. Instructional Design (ID) methods play an important role in guiding the design of learning experiences which meet both the needs of students and the desired program objectives. Using an instructional design model, this paper outlines the development of a watershed science curriculum that incorporates authentic science experiences to encourage students' connection to science and their intention to pursue STEM degrees/careers in the future. Included in the development of the program is the application of the ID model to each step of the process: characterizing the needs of learners, determining program objectives, identifying strategies to support learning, and assessment of learning. A model of learning was also used to guide the curriculum development.

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Significant gaps in college go-on rates persist for low-income, minority, and prospective first-generation to college (first-generation) students due to specific barriers such as decreased access to learning opportunities and fewer role models who have attended college (Engle & Tinto, 2008; Gibbons & Shoffner, 2004). There is strong evidence that for underrepresented students, out-of-school (also known as “supplementary”) science experiences increase science self-efficacy and science identity which in turn can contribute to persistence in science (Ballen, Wieman, Salehi, Searle & Zamudio, 2017; Chemers et al., 2010; Chemers, Zurbriggen, Syed, Goza & Bearman, 2011; Eccles & Barber, 1999; Estrada, Woodcock, Schultz et al., 2011; Hernandez, Schultz, Estrada, Woodcock & Chance, 2013; Hurtado, Cabrera, Lin, Arellano & Espinosa, 2009).

Authentic science learning experiences allow students to experience doing science the way scientists do in real world contexts. They are different from traditional science classroom experiences because they emphasize engaging in real world science practices rather than learning through textbooks (Carlone, Johnson, & Eisenhart, 2014; Chinn & Malhotra, 2002; Crawford, 2013; Woolnough, 2000). Authentic science experiences can provide a more accessible science learning environment for underrepresented students by connecting science to a context that has relevance and meaning for them in their everyday life, for example by investigating a local socio-scientific issue of concern to students, and sharing findings with local audiences (Ballard, Dixon, & Harris, 2017; Crawford, 2013). Authentic science experiences can develop students’ science identity (seeing oneself as a science person); science self-efficacy (feeling confident in science abilities), and science community values (believing in principles of science) (Ballen et al., 2017; Chemers et al., 2010; Chemers et al., 2011; Estrada et al., 2011; Hernandez et al., 2013; Hurtado et al., 2009).

In 1990 the Department of Education created the Upward Bound Math-Science (UBMS) program in order to address the need for specific supports in the fields of math and science for low-income and first-generation students, and to encourage students to pursue postsecondary degrees and careers in math and science (U.S. ED, 2009). UBMS works to meet these goals through a variety of programming, including summer programs with intensive math and science training, year-round counseling and advising, exposure to university settings and faculty research, and participant conducted research under the guidance of faculty or graduate students. In addition, the program works to improve financial and economic literacy, enhance college readiness, and otherwise meet the needs of the underserved students in the program. In 2018 there were 213 individual UBMS programs affiliated with institutions of higher learning, receiving an average of $319,281 in funding to support operations and programming (U.S. ED, 2009). While regulations govern the services UBMS projects can provide (34 C.F.R., §645.10-§645.14, 2010), the specifics of programming are left up to the individual UBMS program. Therefore program design is left to the individual UBMS sites, in compliance with federal rules and regulations.

The Upward Bound Math Science program at University of Idaho (UI) is called STEM Access (UBSA), and it works to connect a local population of students with college and careers, especially in the areas of science, technology, engineering and mathematics (STEM). Students in the program receive support through information, counseling services, field-trips and campus experiences to assist them on the path to college. Designing relevant and contemporary programs to ensure students are exposed to a variety of careers and STEM content and skills creates a challenge because designing and planning a program is a time-consuming and resource-intensive process. The purpose of this practice reflection is to clarify the design process for an UBSA watershed science summer program and distill design principles applicable to other programs with similar objectives.

Instructional Design Model

Instructional design is a systematic process to plan a learning experience in order to meet desired objectives, and can be aided by the use of models.

> Instructional design is a complex process that promotes creativity during development and results in instruction that is both effective and appealing to students. Instructional design models convey guiding principles for analyzing, producing, and revising intentional learning contexts (Branch & Dousay, 2015, p.15).

The Kemp, Morrison, and Ross (1998) model was chosen for instructional design of the UBSA summer program because of the learner-centered approach which aligns best with the participant-centered approach of UBSA. Kemp, Morrison, and Ross (1998) identified four fundamental planning elements for systematic instructional planning through the following questions (p.4):

1. For whom is the program developed? (learners)
2. What do you want the learners or trainees to learn or demonstrate? (objectives)
3. How is the subject content or skill best learned? (methods)
4. How do you determine the extent to which learning is achieved? (evaluation)

Questions 1-3 will guide the description of this program design.

Learner Characteristics

The Upward Bound program requires that two-thirds of the participants in a project must be both low-income and potential first-generation college students. The remaining one-third must be either low-income, first-generation college students, or students who have a high risk for academic failure. Federal TRiO programs define a low-income individual as “an individual whose family's taxable income for the preceding year did not exceed 150 percent of the poverty level amount” (U.S. ED, 2019). A potential first-generation college student is

> an individual neither of whose natural or adoptive parents received a baccalaureate degree; or a student who, prior to the age of 18, regularly resided with and received support from only one natural or adoptive parent and whose supporting parent did not receive a baccalaureate degree (U.S. ED, 2009).

Low-income and potential first-generation to college students have unique characteristics that must be considered in relation to academic preparation, preparation for college life, navigating college without parental experience, and navigating different cultural worlds.

Academic Preparation

Low-income, first-generation students are more likely to enter college with less academic preparation than their peers, and therefore to take remedial courses (Engle & Tinto, 2008). There is a direct effect of secondary school academic preparation on postsecondary science and engineering persistence and completion (Seymour & Hewitt, 1997). Therefore, inadequate academic preparation of low-income and first-generation college students presents a significant barrier to both college and STEM persistence (Gibbons & Shoffner, 2004).

Preparation for College Life

According to Engle and Tinto (2008), low-income, first-generation college students are more likely than wealthier peers to:

- delay entry into postsecondary education after high school;
- attend college closer to home;
- live off-campus;
- attend part-time; and
- work full-time while enrolled.

These characteristics are risk factors for failing to earn a college degree (Engle & Tinto, 2008). Because of their work requirements, first-generation and low-income students may have more difficulties in connecting with college life (Gibbons & Shoffner, 2004).

Navigating College Without Parental Experience

Parental educational involvement is strongly related to student educational success (Benner, Boyle, & Sadler, 2016). Students whose parents didn't go to college may not have the benefit of active parental involvement or assistance in navigating information about college, preparing college applications, and may perceive a lack of family support in their decision to go to college (Gibbons & Shoffner, 2004).

Navigating Different Cultural Worlds

College campuses are not likely to provide an easy cultural transition for first-generation youth (Grimard & Maddus, 2004). A longitudinal survey revealed that universities' social norm of independence undermines first-generation students' more interdependent motives for attending college, resulting in lower grades (Stephens et al., 2012). First-generation students often find themselves navigating the margin of two cultures - negotiating relationships at college and at home and managing the tension between the two (Grimard & Maddus, 2004). Facing obstacles to cultural adaptation in the form of differences between the norms, values, and expectations of their home communities and the culture of college campuses, students may lack a sense of belonging in either world (Engle & Tinto, 2008).

Program Objectives

Two primary program objectives guided the design of the program:

1. Encourage Upward Bound students to persist in science, i.e. to continue studying science or to develop an interest in science.

2. Engage students in authentic science experiences in order to increase their persistence in science.

1. Persistence in Science for Disadvantaged Populations

The goal of “science for all” espoused by science education reform in the 1990’s (AAAS, 1990; NRC, 1996) has highlighted inequalities in achievement and success in science (Carlone, Johnson, & Eisenhart, 2014). Minority and female students continue to be underrepresented in science fields, as evidenced by their low participation in professional positions and college majors (Kim, 2011; NSF, 2017). Although there are many complex factors influencing a student’s trajectory into the sciences (Tytler, 2014), researchers have cited the failure of classroom science education to accurately represent what scientists do as a factor of critical concern (Chinn & Malhotra, 2002; Crawford, 2013; Packard, 2015). Students from underrepresented groups are best able to succeed with curricula that incorporates aspects of their everyday experiences (Buxton, 2006). Science teaching that fails to incorporate the cultural experiences of underrepresented groups will likely fail to recruit or increase the interest of underrepresented students (Lee & Luykx, 2006). Although science curriculum is a critical component in preparing students to succeed in science, student persistence in science is dependent on learning environments that attend to psychosocial variables such as recognition of science skills by self and others, identification with science, and connection to personal and community life.

There is strong evidence that for underrepresented students, supplementary science experiences increase science self-efficacy and science identity which in turn can contribute to persistence in science (Ballen et al., 2017; Chemers et al., 2010; Chemers et al., 2011; Eccles & Barber, 1999; Estrada et al., 2011; Hernandez et al., 2013; Hurtado et al., 2009). Large scale, nationwide surveys using quantitative measures have developed models to understand how supplemental science experiences impact underrepresented students’ persistence in science. These models provide strong evidence that science self-efficacy and identity as a scientist are psychological mediators of persistence in science (Ballen et al., 2017; Chemers et al., 2010; Chemers et al., 2011; Eccles & Barber, 1999; Estrada et al., 2011; Hernandez et al., 2013; Hurtado et al., 2009). Chemers et al. (2011) modeled the effect of supplementary science experiences on science self-efficacy and science identity and leading to student persistence in science (Figure 1). Science self-efficacy and science identity are therefore important variables for programs or supplemental science experiences aimed at increasing the persistence of underrepresented students in STEM.

2. Authentic Science Experiences

Authentic science experiences simulate “real” science experiences - that is, practiced by scientists, while taking into account the differences between the classroom community and the scientific community (Schwartz & Crawford, 2006). Science education researchers interested in authentic science experiences believe that students should have experience *doing* science to *learn* science, especially if we want them to be interested and engaged (Woolnough, 2000). It is also important for researchers and educators that authentic science experiences be relevant to students’ lives in order to be engaging (Crawford, 2013). Recent Next Generation Science Standards have called for educators to "provide students with engaging opportunities to experience how science is actually done" (NRC, 2012, p.1). Given this perspective, the meaning of *authentic science experiences* is therefore an adaptation of *authentic science practice* to function within the bounds of the learning environment and meet the goals of science education.

Buxton (2006) argues that rather than focusing on the degree of authenticity that students can or should emulate, the learners' interests and needs should be the starting point, what he calls "youth-centered authentic science" (p. 702). This student-centered approach is aligned with constructivist views of learning (Vygotsky, 1978), and positions learners in "collaborative social contexts to explore their own scientific questions" (Rivera Maulucci et al., 2014, p. 1121). In this sense, authenticity can be viewed as a property emerging from the shared meaning-making of scientists, teachers, and students engaged in science projects (Rahm et al., 2003). Indeed, social learning and communities of practice have been highly influential concepts in authentic science literature, with most publications citing Lave and Wenger's *Situated Learning* (1991). Ideas of social learning within communities of practice have deeply influenced ideas of authentic science, framing our understanding of both classroom science and actual science as taking place in a social context where learning happens among a group rather than individuals.

Process

I was hired as a summer instructor for Upward Bound in April, 2018. The position description specified that I work closely with the UBSA team to create an intentionally integrated summer learning experience with student-relevant results. My specific responsibilities were to design the course curriculum in coordination with the director, identify and organize the necessary materials for course delivery, construct specific lessons with objectives and goals serving the overall expected course outcomes, identify appropriate locations for lessons, and plan for assessment. Five key steps guided the development of the summer program:

1. Identifying teaching and learning strategies to support Upward Bound students in science learning.

2. Identifying a learning model which supports science learning through authentic science experiences.

3. Developing key program elements.

4. Developing curriculum guided by steps 1-3.

Step 1. Strategies for Supporting Upward Bound Student Success

Research suggests a number of strategies for supporting low-income and potential first-generation students in high school and college success. This section answers the question: How does knowledge of the student population inform summer program design? Examples of how the strategies can be implemented through summer program design are provided.

Honoring Culture and Bridging Cultural Divides

Culture shapes our attitudes, values, and behaviors, and therefore how we learn. Culture also presents barriers to academic achievement for students from nondominant cultures (Gay, 2002). Those students must negotiate the borders between their everyday culture and the culture of Western science and/or college, requiring they go back and forth between the respective domains of knowledge, a kind of "border crossing" (McKinley & Gan, 2014). Making these border crossings explicit is a strategy that allows students to become consciously aware of their beliefs and life experiences in relation to their identities, and effectively builds a bridge between different ways of knowing. To facilitate such bridge building in the context of science education, Aikenhead (2006) suggests promoting discourse whereby:

- Students are talking science,
- Students' ways of knowing are legitimized and connected to science learning, and
- Values of Western science are taught in the context of society.

Supporting students of different cultural backgrounds also requires attention to social dynamics, including building positive, caring, meaningful relationships, creating a safe atmosphere, and promoting a culture of acceptance. An emotionally safe space creates a positive learning environment where students feel safe to make mistakes without being made fun of (Izard, 2016).

Empowerment

Many students from disadvantaged populations are in need of a sense of control in their lives. For example, students in poverty may have limited choices for nutrition and entertainment (Izard, 2016). Macias (2013) urges educators and institutions to move beyond a deficit mentality in supporting first-generation students, through a focus on empowerment. Empowerment can encompass a sense of competence, a sense of self-determination, a sense of meaning, and a sense of impact (Macias, 2013). A sense of competence is also known as self-efficacy, or the conviction that one can successfully execute a behavior to produce an outcome (Bandura, 1977).

Students who have higher self-efficacy are more likely to persist in the face of difficulty (Zimmerman, 2000; Usher & Pajares, 2008). Research has shown that for college students, perceived competence in STEM predicts achievement in a STEM course and lessened intention to leave their STEM major, especially for underrepresented students (Hilts, Part & Bernacki, 2018). There is strong evidence that for underrepresented students, supplementary science experiences increase science self-efficacy, which in turn can contribute to persistence in science (Ballen et al., 2017; Chemers et al., 2010; Chemers et al., 2011; Eccles & Barber, 1999; Estrada et al., 2011; Hernandez et al., 2013; Hurtado et al., 2009).

In addition, specific strategies contributing to student empowerment include teaching emotional skills such as gratitude and acknowledgement of others (Izard, 2016) and service learning experiences. Service learning experiences can help students "develop many of the kinds of cultural and social capital valued in higher education, as well as the coping skills to persist despite difficult circumstances" (Yeh, 2010, p. 60).

Step 2. A Learning Model for Authentic Science Experiences

Recently, citizen science, or the public participation in science, has emerged as a type of authentic learning experience in science education, as it allows students the opportunity to contribute to scientific research by engaging in scientific practices and interacting with scientists conducting investigations (Jordan, Ballard, & Phillips, 2012). Citizen science is becoming increasingly accepted in both the scientific community and the classroom community as a method for achieving goals of science and science education (Bonney, Phillips, Ballard, & Enck, 2016). Ballard and colleagues (2017) adapted Critical Science Agency from Basu and Barton (2010) to propose Environmental Science Agency, which is specific to the learning context of citizen science. Environmental Science Agency identifies student learning processes which include: Deepening understanding of environmental science content and practice, identifying an area of expertise, and using experiences in youth-supported citizen science as foundation for change. Ballard et al. (2017) also identified key student practices such as rigorous data collection, disseminating scientific findings to authentic external audiences, and investigating complex social-ecological systems, suggesting that when learning experiences provide opportunity for youth to engage in these practices, they can lead to outcomes such as participation in conservation actions, and capacity for future conservation actions. The model of Environmental Science Agency has been developed through case studies to understand the processes and outcomes of student learning during participation in citizen science and is therefore an appropriate learning model for this program.

Step 3. Develop Program Elements

Key program features and learning objectives are described in Table 2. The key program elements were developed based on the learning model as well as the learning strategies identified to support the participants.

Key Program Elements

1. Watershed investigations in the local community - Students actively engage in science practices through field experiences.

2. Alternative engagement with science through art and writing - Field sketching, and reflective writing in journals.

3. Mentorship Component - Connections with scientists and science students are formed through field experiences, as well as mentoring on student research project.

4. Student Research Projects- Students work on a research question related to water/community individually or in groups and present on their project proposals.

5. Service Learning - Students will learn about and volunteer in a local community garden, and at a lake celebration, teaching younger students about water quality.

Step 4. Develop Curriculum

Curriculum was designed in collaboration with scientist partners. Together we identified program activities, selected appropriate learning objectives, and planned logistics. Therefore it is important that I acknowledge the willingness of these collaborators to not only dedicate time and energy to facilitate an enriching science learning opportunity for students, but their commitment to the process of developing meaningful lesson plans. A brief description of four of the lesson plans is included in Table 1.

Table 1

Lesson Plan Descriptions

Lesson	Description	Instructional Objectives
Creek Investigation	Students learn about the connections between water quality, food availability, and habitat quality to understand the impacts on native fish populations. They will test various water quality parameters, collect and identify macroinvertebrates, and snorkel for fish and other aquatic life.	Students will be able to... 1) Observe how fish behavior changes in response to the environment 2) Identify fish in Lapwai Creek 3) Collect and assess water quality data 4) Collect and identify macroinvertebrates and make assessments of water quality based on the assemblage
Wetland Investigation	This lesson takes students on a nature hike through the Nature Trail to learn about the role of the native and culturally important plants in wetland restoration. Differences in soils are related to hydrology and plant composition, and students have the opportunity to engage in an observation and plant identification activity.	Students will be able to... 1) Identify socially significant plants 2) Discuss the differences between natives and invasives 3) Identify elements of project management for natural resource management
Metal Contamination in the Chain Lakes	This lesson takes students on a bicycle tour of the chain lakes to learn about metal contamination in the Coeur d'Alene (CdA) Basin from a socio-ecological perspective. This place-based lesson is intended to broaden the students' awareness of the primary water quality issue facing the CdA Basin from a biophysical, historical, and cultural perspective.	Students will be able to... 1) Define toxic metals. 2) Diagram the biogeochemical cycling of metals within riverine and lake systems. 3) Explain (via journal entry and class discussion) the impact of toxic metals on water resources from a socio-ecological perspective.

		4) Develop solutions to disseminate the implications of toxic metal exposure from a public health perspective.
Field Sketching Art and Science	This lesson introduces students to the role of field sketching in science. Students learn about how field sketching is used in bird research. In the process, they learn about bird identification.	Students will be able to... 1) Use art as observation of bird characteristics 2) Identify a bird through observation

Assessment

Student learning was assessed formatively through reflective questions at the end of every field experience. Student research posters were assessed summatively using a rubric developed by the Stanford Center for Assessment, Learning, and Equity. The rubric was designed to align with the Next Generation Science Standards to assess students' ability to articulate a science-related issue, make a claim, identify evidence, justify a claim, and evaluate an argument. The rubric uses a scale from "developing" to "advanced."

Observation of student engagement was also used to assess programming. Program evaluation included baseline and post-program assessment of students' confidence in their science skills, intention to pursue science in college or as a career, and their identification as a science person. Previously developed and validated scales were used to measure each variable (see Estrada et al., 2011).

Conclusion and Design Reflection

Many programs are tasked with meeting goals through the design of an intervention, without clarity in the process of how to do so, especially when many design considerations specific to the learners, the type of intervention, and overall program objectives must be taken into account. Here I have used an instructional design model to facilitate the process of translating theory and research into practice. While confusing at times, I found the use of an instructional design model helped to clarify the sometimes messy process. In particular, aligning the various design considerations in table one helped to facilitate the selection of appropriate learning activities and to design curriculum. Five design principles emerged from my experience designing this course. The design principles drew on the literature on persistence in science for underrepresented students, the environmental science agency learning model, and the STEM curriculum framework. The five design principles are student-centered and specific to the needs of low-income and first-generation students, and may be useful for other programs with similar goals and student populations (Table 2).

Table 2

Design Principles Supporting Integration into STEM in Summer Program

Design Principle	**Integration Variable**	**Enactment in Summer Program**
(1) Students actively engage in science practices (Ballen et al., 2017; Freeman et al., 2014)	Self-Efficacy Science Identity	Students participate in scientific research through authentic field experiences including water quality testing, analysis, sampling, comparison, and reporting.
(2) Students investigate complex social-ecological systems in the context of community (Ballard, Dixon, & Harris, 2017)	Science Community Values	Authentic science field experiences take place in the local community and are connected to local social issues
(3) Students' feelings of belonging are supported (Freeman, Anderman, & Jensen, 2007; Trujillo, & Tanner, 2014)	Science Identity Science Community Values	Team building, attention to emotional and intellectual safety, small group work, and opportunities to get to know scientists both personally and professionally
(4) Students' ways of knowing are legitimized and connected to science learning (Buxton, 2006; Lee & Luykx, 2006)	Science Identity Self-Efficacy	Students design their own community-based research project (mastery experience), receive mentoring (process feedback), but no summative evaluation of their projects
(5) Students share their newly acquired science knowledge and skills to authentic external audiences (Ballard et al., 2017; Crawford, 2013).	Self-Efficacy Science Identity	Students teach younger students at a service learning event, students share their research projects with a larger audience.

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