



Integrating problem- and project-based learning into sustainability programs

A case study on the School of Sustainability at Arizona State University

Arnim Wiek, Angela Xiong, Katja Brundiars and Sander van der Leeuw

School of Sustainability, Arizona State University, Tempe, Arizona, USA

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Abstract

Purpose – The article aims to describe the problem- and project-based learning (PPBL) program and the institutional context at Arizona State University's School of Sustainability (SOS), with the goal of offering experience-based guidance for similar initiatives in sustainability programs around the world.

Design/methodology/approach – This case study presents the diverse PPBL activities that SOS offers on the undergraduate and the graduate levels and examines the institutional structures in place that support these activities. Data were collected through literature and document reviews, observations, interviews, student evaluations and faculty surveys.

Findings – The review of the PPBL program at SOS illustrates a case of successfully inaugurating a PPBL program in sustainability at a major university in the USA. Yet, a key challenge for this program and similar programs around the world is how to maintain the institutional momentum and make advances after the initial takeoff. SOS is attempting to address this issue by developing greater program cohesion and coordination, synthesizing past products and learning, monitoring and evaluating impacts, and developing PPBL training programs for faculty and graduate students.

Practical implications – The experiences and findings presented can help other programs to articulate the benefits of a PPBL initiative, anticipate implementation challenges and successfully support their own PPBL initiatives through adequate institutional structures. The review points to the fact that the major impact on both student learning and outcomes for partner organizations is achieved through a concerted effort by the organization as a whole. Successful PPBL programs require both top-down commitments from the administration and bottom-up drive from interested faculty and students.

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Originality/value – This case study discusses the PPBL program at SOS. The findings can inform and support the ongoing transformation in sustainability education with the ultimate objective to build students' capacities to address and solve wicked sustainability problems in the real world, competently collaborating with partners from government, business and civil society.

Keywords Project-based learning, Problem-based learning, Real-world learning, Sustainability competence, Sustainable solutions, Institutional change

Paper type Case study

Introduction

An idea has started to conquer academic sustainability programs – the idea of educating students in real-world settings, in which they work on “problems that were brought to higher education by cities, businesses, non-profit organizations and other institutions”, produce “workable contributions to solutions” and have “a positive impact on the world through their academic learning” (Rowe, 2007, p. 324). Over the past few years, this idea has developed into a guiding vision for education in sustainability science, an explicitly problem-driven and solution-oriented academic field (Kates *et al.*, 2001; Clark and Dickson, 2003; Lang *et al.*, 2012; Wiek *et al.*, 2011a; Wiek *et al.*, 2012). The key features of problem- and project-based learning (hereafter PPBL) are student-centered, self-directed and collaborative learning that focuses on real-world issues and may involve stakeholder engagement (Savery, 2006; Stauffacher *et al.*, 2006; Brundiens *et al.*, 2010; Brundiens and Wiek, 2011). In contrast to service learning, PPBL approaches engage students in inquiry-based research for complex problem solving.

There is some convergence that academic sustainability programs would benefit from using PPBL approaches in their curricula and courses and, indeed, universities have been exploring real-world learning opportunities and implementing PPBL components over the past ten years (Segalas *et al.*, 2010; Yasin and Rahman, 2011; Dobson and Tomkinson, 2012; Guerra, 2012; Brundiens *et al.*, 2013; Brundiens and Wiek, 2013). However, for many higher education institutions, it remains challenging to provide rigorous, curriculum-wide and cohesive PPBL opportunities in sustainability education. Whitmer *et al.* (2010) identify individual, disciplinary and institutional challenges. At the individual scholar level, a major challenge is the “relative lack of successful models [of engaged research and teaching] to follow when charting an academic career in this area” (p. 315). At the disciplinary level, peer review and evaluation systems undervalue engaged research, giving faculty little incentive to implement PPBL. Finally, the majority of institutional tenure and promotion structures do not recognize the additional efforts such as relationship-, trust- and network-building that engaged research and learning requires. Although some of these challenges require a fundamental shift in institutional values, there seems to be a potential for improvement by taking advantage of the PPBL experiences and achievements of other sustainability programs worldwide.

Since its inception in 2007, Arizona State University (ASU)'s School of Sustainability (hereafter SOS) – the first school of its kind in the USA with genuine undergraduate and graduate programs in sustainability – has incorporated PPBL opportunities for students into research and teaching practices (Brundiens *et al.*, 2010; Redman and Wiek, 2012; Wiek and Kay, 2013; Brundiens and Wiek, 2013). SOS faculty, students and staff have created various PPBL opportunities at the graduate and undergraduate levels, as well as international PPBL courses. The latter includes the undergraduate course “The Global Classroom” in collaboration with Leuphana University of Lüneburg (Lang and Wiek, 2012;

Wiek *et al.*, 2013). These PPBL opportunities present unique settings for students to build their professional capacity in collaboratively identifying, analyzing and developing solution options to sustainability problems, at local to international scales (Steinemann, 2003; Thomas, 2009; Wiek *et al.*, 2011b; Yasin and Rahman, 2011). In addition to curriculum development, SOS has developed different initiatives for international exchange and collaboration on PPBL in sustainability programs. For instance, in February 2011, an international workshop on “Problem- and Project-Based Learning in Sustainability Programs” at ASU brought together PPBL experts with representatives from academic programs that offer both undergraduate and graduate programs in sustainability worldwide.

The purpose of this case study is to describe the PPBL initiatives and the institutional context at SOS, with the goal to provide experience-based guidance for problem- and project-based activities in sustainability programs elsewhere. The article begins with a brief summary of the key features of PPBL and describes how the two approaches are synthesized at SOS. Next, the authors present the diverse PPBL activities that SOS offers on the undergraduate and the graduate levels. The authors then examine the institutional structures in place that support these activities. Based on literature and document reviews, observations, interviews, student evaluations and faculty surveys, the authors derived key lessons learned and challenges. The empirical material is mostly used anecdotally; systematic analyses are pending. Finally, the authors conclude with an outlook on strategies for the further development of PPBL in sustainability programs that have gotten off the ground, yet need to consolidate and sustain their institutional momentum.

PPBL in sustainability programs

PPBL approaches have a rich history in the fields of health sciences, engineering, architecture and business, among others (Savery, 2006). In addition to providing experiential learning opportunities that are effective in all educational fields, there are several reasons that make PPBL necessary for sustainability education. Sustainability science is distinct from other disciplines because it develops solution options to specific types of complex societal problems (Wiek *et al.*, 2012; Wiek and Lang, 2013). Developing solution options to these problems requires in-depth exploration, as well as collaboration across different types of expertise. Thus, sustainability programs must equip students not only with content knowledge and analytical skills but also with interpersonal competencies and transdisciplinary/transacademic work experience. These skills cannot be developed through lecture-based activities alone, but require hands-on practice, teamwork and community engagement opportunities.

While problem- and project-based learning approaches have a great deal in common and are often combined into hybrids, they are two distinct educational approaches (Savery, 2006; Sipos *et al.*, 2008). At SOS, both models serve as reference points for a spectrum of educational opportunities that, combined with experiential learning (Kolb and Kolb, 2005), offer self-directed, constructivist and real-world learning experiences to undergraduate and graduate students (Figure 1).

The commonalities of the two approaches are that students engage with a real-world sustainability issue while working in small student teams, simulating professional environments. The self-directed learning approach requires instructors to adopt the role of a facilitator/coach and to include formative assessments to support students in

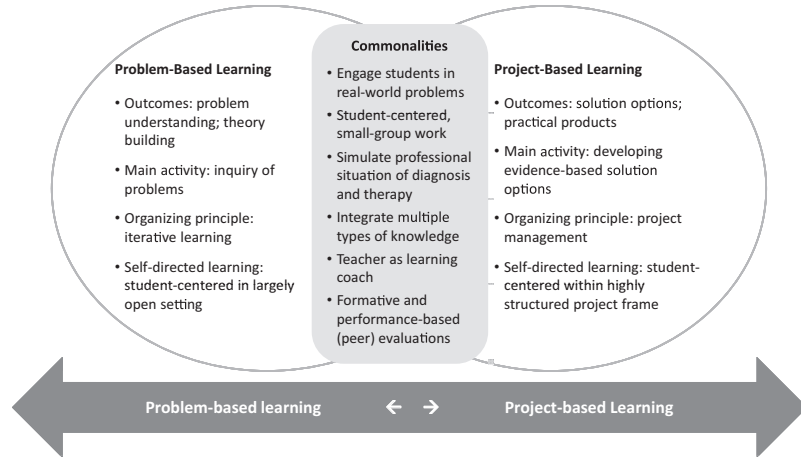


Figure 1.
The spectrum of PPBL
approaches

Source: Brundiers and Wick (2013, p. 1,727)

reflecting upon and improving their individual and collaborative learning strategies (Donnelly and Fitzmaurice, 2005; Hmelo-Silver, 2004). Hence, PPBL approaches emphasize a practice in which students engage in peer- and self-evaluations and reflect on their activities, critical thinking abilities and quality of outputs. In sustainability programs, project clients might also be invited to evaluate students' work from a professional perspective.

Problem-based learning centers on complex problems and adopts an inductive and contextual approach to hypotheses building and testing to develop a deeper understanding of such problems (Barrows and Tamblyn, 1980; Hmelo-Silver, 2004). To structure learning, students engage in an iterative process that includes identifying problems, deconstructing problem frames, reframing the problem, analyzing problem facets and integrating findings (Moust *et al.*, 2005; Jerneck and Olsson, 2011). In sustainability programs, the problems addressed are real-world sustainability challenges. These problems are complex and "wicked", with no simple solution. In fact, most "solutions" to wicked problems (Brown *et al.*, 2010) create other, additional problems. The focus of inquiry translates into a rich exploration of sustainability challenges; to a minor extent, the study of existing solution options (and their success or failure) is pursued as well. Emphasis is put on critical and deep understanding and less on constructing and testing feasible solution options (Thomas, 2009; Sipos *et al.*, 2008).

Project-based learning models focus on developing case-specific problem understanding to create feasible solution options. A professional project-management approach provides steps and tools to structure and support students' work. As in problem-based learning, instructors act as facilitators, yet their role extends to include proactive guidance of students in the challenging process of constructing not only new understandings but also developing feasible solution options (Blumenfeld *et al.*, 1991; Roessingh and Chambers, 2011). Applied to sustainability programs, students work on a real-world sustainability challenge, focusing on solution-oriented outcomes or

products that can be applied in professional practice. To this end, students engage with a partner from the practice (client). This situation mimics what students might encounter if they were sustainability practitioners in professional fields. Instructors support student teams in knowledge acquisition, methodology, project management, teamwork and collaboration with clients.

The School of Sustainability at Arizona State University offers problem-based learning opportunities, project-based learning opportunities, and hybrids thereof. The opportunities are intended to build students' sustainability competencies (Wiek *et al.*, 2011a and 2011b) and ease their way into professional practice. Based on a broad literature review, Wiek *et al.* (2011a) synthesized the following key competencies in sustainability:

- systems-thinking competence;
- anticipatory competence;
- normative competence;
- strategic competence; and
- interpersonal competence.

Each competence is a “functionally linked complex of knowledge, skills, and attitudes that enable successful task performance and problem solving with respect to real-world sustainability problems, challenges, and opportunities” (p. 204). These competencies are transferable across cultures, locations and scales – thus, place-based work does not limit students but provides a practical setting to learn universally applicable skills.

Compared with lecture-style learning that is mostly based on knowledge transmission and focused on cognitive development, PPBL opportunities *require* students to actively and self-responsibly develop knowledge, skills and attitudes, while being supported in reflecting on and deepening their learning experience and strategies. Furthermore, the outcomes expand beyond rich learning experiences by engaging cognitive, procedural and affective knowledge domains and also include policy-relevant reports, intervention manuals and project proposals for submission to funding organizations (Wiek and Kay, 2013).

PPBL activities at the School of Sustainability

PPBL at SOS began in the academic year 2008/2009. Until academic year 2012/2013, the program has grown quickly and developed at both the undergraduate and graduate levels. In total, there have been 82 PPBL courses at SOS (this number counts each course individually, even if it was taught in multiple semesters) that have involved 46 distinct faculty members and 2,746 students. Table I shows the number of courses, faculty and students involved in PPBL in each academic year and gives an indication of how the program has grown.

Several workshop-courses are cross-listed so that both graduate and undergraduate students can participate, which allows for greater peer mentorship and teacher training opportunities for graduate students. These courses are counted as graduate program workshop courses, although the numbers of undergraduate and graduate students involved have been separated into the two programs.

At both the undergraduate and graduate levels, SOS uses PPBL in regular courses, workshop-courses, individual student capstone projects and academic theses. For PPBL

Table I.
Number of PPBL
opportunities in SOS'
undergraduate and
graduate programs during
the academic years 2008-
2013

Academic Year (fall, spring, summer)	In regular courses		Undergraduate program		Capstones		In regular courses		Graduate program		Thesis work	
	Number of courses	Number of faculty students	Number of courses	Number of students	Number of courses	Number of faculty students	Number of courses	Number of faculty students	Number of courses	Number of faculty students	Number of faculty students	Number of students
2008-2009	2	39	-	-	2	1	2	2	-	-	-	-
2009-2010	6	221	0	36	4	4	2	2	4	5	4	2
2010-2011	6	493	0	15	5	4	3	3	2	4	2	1
2011-2012	5	534	2	7	4	3	2	2	7	8	41	3
2012-2013	6	705	2	10	3	3	2	7	11	11	53	2

in regular courses, the courses themselves are not entirely problem- or project-driven; yet, students may spend a few weeks applying learned material in a team project centered on a specific issue, or there may be field trips or students organize a panel with community representatives, professionals and city staff (Brundiens *et al.*, 2010). Workshop-courses, which often combine undergraduate and graduate students, are thoroughly based on the PPBL model, where students spend the entire semester working in teams on a project – often with an outside project partner or client.

Undergraduate program

As detailed by Brundiens *et al.* (2010), the undergraduate PPBL program is based on a model that progressively exposes students to four levels of PPBL over their four-year degree program (Figure 2). PPBL becomes more challenging in upper division courses: projects become more student-driven than faculty-led, students shift from individual to team-working approaches and increase their abilities to engage with stakeholders from one-time and one-way communication to collaborative interactions. The progressive model emphasizes three major points:

- (1) The model distinguishes four basic PPBL components (Brundiens *et al.*, 2010): bringing the world in; visiting the world; simulating the world; and engaging with the world. These terms are metaphorical and they are meant to emphasize the potential of outside-classroom settings as a learning laboratory for students. While students are always “in the world”, they do not always engage with it meaningfully in educational settings.
- (2) These PPBL components help students strengthen their individual and collaborative learning capacities and build communication, collaboration and project-management skills across disciplines and with practitioners.
- (3) When structured in a meaningful progression, PPBL components strengthen the skills necessary for building sustainability problem-solving competence in students (Wiek *et al.*, 2011a and 2011b).

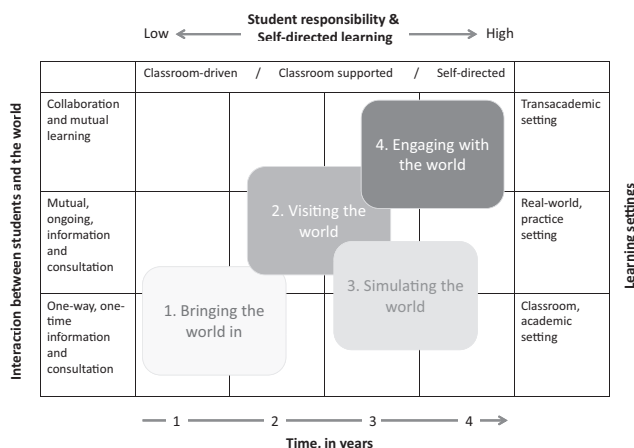


Figure 2. Progressive model for PPBL in SOS' undergraduate program

Source: Adapted from Brundiens *et al.* (2010, p. 314)

Currently, the model has informed individual course design at all levels (100-level courses to 400-level courses), but the progressive model has not yet been fully realized through a coordination across the curriculum for a real progression to emerge.

PPBL as components of regular courses. SOS has offered between academic years 2008/2009 and 2012/2013 > 20 regular undergraduate courses with PPBL opportunities on topics ranging from urban development, food and water to international development. For example, as part of a regular course, students investigated the case of Jackson Street rezoning and development in Phoenix from a broad sustainability perspective, referring to academic articles and project material such as letters to the City Council, meeting minutes and development proposals (SOS 320: Society and Sustainability; Summer 2009) [course number and semester for reference purposes]. The students role-played a city council meeting to bring the problem to life through real-world simulation. Another example was a course that integrated a PPBL activity on identifying ways to increase community participation in drought management, addressed in collaboration with the Arizona Department of Water Resources for their drought monitoring and preparedness program (SOS 321: Policy and Governance in Sustainable Systems; Spring 2011).

PPBL as workshop-courses. SOS has offered eight undergraduate workshop-courses on topics ranging from urban composting systems and transit-oriented development to economic justice and job quality. Some workshop-courses address a sustainability challenge on-campus, such as ASU's food waste problem, where student teams worked with campus management staff and other stakeholders. They identified three key areas for exploration (legal framework, appropriate technologies and organizational and behavioral change approaches) and used interviews, participant observation and waste audits to develop a strategy for sustainable food waste management that closes the gap in ASU's Zero Waste Program (SOS 494/594: Urban Composting Systems – Applied Case Studies for ASU; Spring 2011). Other workshop-courses build on a local or regional problem, such as environmental justice in low-income neighborhoods in South Phoenix (SOS 494/594: Economic Justice, Job Quality, and Sustainability; Spring 2010). After engaging with the history of environmental injustice in Phoenix, students investigated the dynamics that reproduce patterns of injustice. Drawing on a variety of sources, including interviews with citizens and municipal staff, historic documents, statistics and empirical studies, students wove their findings into a documentary juxtaposing dominant and marginal perspectives on the causes and effects of environmental justice. A public viewing, where the documentary's protagonists discussed questions with the audience, closed the project.

PPBL as capstone-project. Another type of PPBL at the undergraduate level is the required senior capstone project that allows students to work with a community partner to develop solution options to an existing problem through research, an internship, or a collaborative project. For instance, two students researched the technical and political opportunities and barriers to ground water recharge across municipalities sharing the same watershed. Their internship mentor provided access to data, high-level meetings of regional water managers and critical feedback to their research (SOS 484: Internship Capstone; Spring 2010). An example of a collaborative research project is the collaboration between a local neighborhood association and three students, who performed a sustainability appraisal, focusing on childhood obesity, homelessness and community development. Reviewing the appraisal findings with the students, the neighborhood association decided to

initiate a community garden by applying for funding through the city. In their application, they used research results from the students (SOS 394: Sustainable Mitchell Park Neighborhood; Spring 2011). A professor supported students' academic dimensions of the research, while a staff member (community-university liaison – explained below) helped facilitate the collaborative process with the community.

The PPBL activities in the undergraduate program are subject to current restructuring efforts to create synergies among them, better coordinate them within the curriculum and better align them with the needs of the internal and external partners. The ultimate goal is to fully realize the progressive model (Figure 2) by coordinating PPBL course offerings across the curriculum so that a number of different pathways exist for building students' sustainability competencies over the course of the undergraduate program.

Additionally, an introductory course has been established to better prepare students for the experiences in the upper division courses by introducing undergraduates to the concepts and skills required to succeed in self-directed and team-based learning as well as in engaging in meaningful stakeholder interactions (SOS 230: Professional Skills in Sustainability; Fall 2013).

Finally, SOS has partnered with "Global Resolve", a social entrepreneurship program where ASU students and faculty collaborate with international universities, rural villages, governments, financial institutions and non-governmental organizations to develop sustainable programs and technologies in collaboration with partners from the developing world. Adding to these international opportunities, SOS is developing study-abroad courses that include PPBL opportunities and focus on analyzing solution-options and exploring their transferability to Phoenix. Similarly, the "Global Classroom" is a collaborative international pilot project between SOS, other units of ASU and Leuphana University of Lüneburg in Germany that entails a PPBL stream for students interested in comparatively investigating solutions to urban sustainability challenges (Lang and Wiek, 2012).

Graduate program

At the graduate level, PPBL is incorporated into few regular courses, but primarily into workshop-courses. International PPBL opportunities are under development to deepen students' capacity for international engagements.

Initially, the two required introductory courses for graduate students (SOS 510: Perspectives in Sustainability/SOS 511: Sustainability Methodology) also served as pilots to explore and test different formats of PPBL through illustrative case studies and group projects focused on real-world sustainability problems. Acknowledging the necessary scope of PPBL endeavors, the group project has now been separated and made into an entire workshop-course, generally taken in the following semester (Wiek and Kay, 2013). Graduate-level workshop-courses are an example of how SOS can create useful products for community partners, while providing a high-quality PPBL environment for its students. Doctoral students are required to take at least two workshop-courses as part of their degree program. They are offered every semester, and faculty and students partner with businesses, government organizations and community partners to work on urgent sustainability challenges.

PPBL as components of regular courses. Similar to the undergraduate program, a variety of graduate courses incorporate bringing the world in (e.g. through documentaries and guest speakers), visiting the world (e.g. through field trips) and simulating the world (e.g. through interactive negotiation games). In a course titled “Sustainable Ecosystems” (SOS 535: Sustainable Ecosystems; Fall 2011), students took a virtual field trip to the Okavango Delta region in Africa, where a unique wetland ecosystem supports the livelihoods of > 120,000 people. Students split into four focus groups to analyze the current state with regard to the ecological issues, economy, transboundary issues and culture. In the second half of the semester, students recombined into synthesis groups, composed of a member from each focus group. This allowed for greater peer learning, teamwork and self-direction. Finally, synthesis groups were tasked with creating a plan for a sustainable Okavango Delta through visioning and backcasting. A large portion of the evaluation for this class was based on peer evaluation and feedback.

PPBL as workshop-courses. Workshop-courses at the graduate level have a heavy focus on problem- and solution-oriented research strategies, where students work collaboratively in their teams and with project partners to produce relevant and useful outputs. Such projects include addressing the future of water use in Arizona agriculture (SOS 594: Future Scenarios for Agriculture and Water in Arizona; Fall 2009), creating a comprehensive sustainability policy for the City of Mesa (SOS 494/594: Urban Public Policy and Sustainability; Fall, 2011) and working closely with three different neighborhoods to create actionable interventions for sustainability (SOS 594: Sustainable Solution Options for Phoenix – Intervention Research on Walkability, Health and Water Quality; Spring 2012). In the sustainable solution options for Phoenix workshop-course, students organized in three self-directed teams with instructor support. The instructors worked closely with student teams to introduce initial stakeholder contacts, review methodology and provide feedback and resources. Each team tackled a different real-world sustainability problem in local neighborhoods by building on existing relationships with external stakeholders, conducting interviews, attending neighborhood association meetings and facilitating their own community workshops to create intervention strategies. In addition to instructor and student learning, course outcomes included detailed intervention manuals produced by each team tailored specifically to their community. In 2013, one of these interventions on a neighborhood tree and shade plan received external funding and is on its way to implementation (Bernstein *et al.*, 2014).

PPBL approaches in thesis work. PPBL is also emerging in students’ thesis work. Different team-theses projects have been explored or realized since 2010. In one case, two graduate students adopted a PPBL research approach to study food insecurity in a low-income neighborhood in Phoenix and developed solution options (Talbot, 2012). They worked with children using “photovoice” to visually document their perspectives on the food environment, and conducted stakeholder workshops to explore solution options to food insecurity. In another case, a workshop-course triggered collaborative thesis research among six graduate students on urban sustainability issues in Phoenix and other US cities (Baty, 2010; Wiek *et al.*, 2012). In a third case, students explored thesis projects with faculty in a PPBL course on climate change mitigation strategies.

The course was conducted in collaboration with a stakeholder alliance in Sonoma County (CA), and the thesis work continued in participatory research settings.

In addition to the practice of PPBL in courses and projects, students are also conducting research on improving PPBL pedagogy and institutional arrangements. Currently, PhD and master's thesis research is being undertaken to understand how PPBL designs and assessments can enhance sustainability science education in K-12 schools [Kindergarten through 12th grade, a school system designation commonly used in the U.S. for children from age 4-6 through 18-19 year-olds] and in higher education, respectively (Frisk and Larson, 2011).

Finally, graduate students have been involved in international PPBL summer schools, for instance, the Intensive Program on Sustainability (IPoS) in Asia (www.ipos.k.u-tokyo.ac.jp), organized by the Sustainability Science Program at the University of Tokyo.

A yearlong International Sustainability Studio for Graduate Students is under development between the University of Tokyo and ASU. The studio is planned to become part of the University of Tokyo's "Global Leadership Initiative" and builds on the "Global Classroom" project (Wiek *et al.*, 2013). The studio is planned to engage collaborating teams of graduate students and faculty in a global dialogue about place-based sustainability challenges and solution options. By implementing a PPBL model in an international setting, the International Sustainability Studio will use virtual technologies to educate graduate students on ways to engage sustainability challenges and sustainability solutions in the urban environment, for example, with a focus on urban food systems.

Institutional support structures for PPBL

Some of the most effective examples of PPBL are observed in schools where the institutional structure is closely aligned with the pedagogy, such as Expeditionary Learning Schools in the USA, where an explicit goal is to transform school culture (Expeditionary Learning, 2012). High Tech High, as another example from the USA, does not use textbooks, and instead teachers are given the flexibility and power to structure their curriculum around long-term projects. Classes are intentionally organized so that "pairs of core-subject teachers (one humanities, one science/math) share the same two classes of students so they can collaborate on cross-disciplinary projects and better support students and each other" (Rubenstein, 2008). Both examples are from K-12 schools, as adoption of PPBL approaches in the USA is more widely spread among K-12 schools compared to universities. However, worldwide, there are universities practicing PPBL across their academic programs such as Maastricht University in The Netherlands, Aalborg University in Denmark and McMaster University in Canada.

Institutional support is critical in providing expertise and funding, putting incentive systems in place and changing entrenched traditional structures to allow for greater flexibility (Whitmer *et al.*, 2010; Wiek *et al.*, 2011b). Much of the success of the SOS' PPBL program can be attributed to the substantial commitments made by SOS administration in implementing a PPBL program, dedicating resources and setting aside positions for students and staff to conceptualize and coordinate PPBL opportunities. SOS supports a community–university liaison (see below), a PPBL Research/Teaching Assistant and the *SustainabilityConnect* platform, as well as international collaboration. Additionally, SOS has established a PPBL Advisory Board.

Community–University liaison. The community–university liaison is a staff member who facilitates PPBL by connecting researchers (students, faculty) with experts and laypersons working outside of academia (community partners and stakeholders from business, public administration or civil society). The community–university liaison helps build effective teams of faculty, students and community partners; works with faculty to identify, design and implement PPBL experiences; supports collaboration among students, faculty and community partners by serving as facilitator, coach, project manager and co-instructor; and works with the leadership of SOS to develop the PPBL program. While students and faculty operate on an academic schedule, the community–university liaison can serve as a constant contact point for maintaining long-term relationships with community stakeholders (Brundiers, Wiek and Kay, 2013).

PPBL research assistant/teaching assistant. The research and teaching assistant furthers institutional knowledge and practice on PPBL in sustainability programs by cataloging and synthesizing PPBL practices, creating source lists and instructional material and showcasing PPBL products and processes.

SustainabilityConnect. This is an online platform (<https://sustainabilityconnect.asu.edu>) that helps individuals and organizations initialize, coordinate and document PPBL projects on real-world sustainability challenges. Any university student, faculty, staff or community partner can submit a project proposal or search the database for a project that they would like to participate in. The goal of the project-platform is to provide students with PPBL opportunities while fostering collaboration between academic and professional experts. In addition, the project-platform also serves as an institutional coordination-mechanism, as it brings together the leaders of related initiatives as conduits for students to real-world projects (e.g. sustainable cities initiative, university sustainability practices network).

International collaboration. International collaboration in the field of sustainability education is important to facilitate the development of the field through mutual learning and cross-cultural dialogue and integration. Hence, SOS supports efforts to exchange and coordinate educational experiences and research among leading sustainability programs worldwide. For example, SOS hosted an international workshop on “PPBL in Sustainability Programs” in 2011, with participation of the eight programs that offer both undergraduate and graduate programs in sustainability worldwide: Arizona State University (USA), the University of Tokyo (Japan), Maastricht University (The Netherlands), Lund University (Sweden), Stellenbosch University (South Africa), the Technical University of Catalonia, Barcelona, (Spain), Leuphana University of Lüneburg (Germany) and the Universidad Nacional Autónoma de México (Mexico City; Mexico).

PPBL advisory board. Introducing PPBL as a curricular dimension requires changes in individual, organizational and technical aspects. To support this process, SOS launched a PPBL advisory board, recognizing faculty participation as service to the university. The board is chaired by the Dean of SOS and comprises four teaching faculty with experience in PPBL, as well as three practitioners who are leaders or coordinators of sustainability initiatives, such as cities or businesses networks. The board is tasked with providing strategic and practical advice to the leadership and the faculty with respect to problem- and project-based curriculum and course building.

Incentives and rewards. SOS has created incentives and rewards for PPBL, including faculty stipends and funding for hourly student workers for problem- and project-based course development. These incentives complement award opportunities provided by the

president of the University, incentivizing PPBL efforts that achieve high-quality education and community impact.

Publications. To support institutional change and mutual learning within the local community and wider circles of interested educators and students, faculty and students have been encouraged to produce academic reports and peer-reviewed journal articles on PPBL in sustainability education based on empirical and theoretical research (Brundiers *et al.*, 2010; Frisk and Larson, 2011; Wiek *et al.*, 2011a and 2011b; Brundiers and Wiek, 2013). Additionally, these publications are testament to the idea that engaged research can have a great impact in both the academic world and through tangible outcomes in communities.

Challenges, successes and impacts

A major challenge with PPBL is the issue of community fatigue and even resentment. In a workshop course in Spring 2012, students experienced this at a neighborhood association meeting where a community member expressed frustration with the researchers they had worked with in the past, resulting in reports “that gather dust on the shelf”. Although SOS has had long-term relationships with community organizations over the past years, intermittent interactions, student turnover and the limitations of the academic schedule have been issues that can only be dealt with through careful relationship building, planning and impact orientation.

Anecdotal evidence and partial reviews of student course evaluations indicate positive educational experiences. Evaluations from two workshop courses (Fall 2012; Spring 2013) show that all students ($n = 18$) agreed that they “had learned important skills” from these courses. Students felt that the acquired skills helped them gain employment opportunities after graduation:

I developed many skills that helped me land a job right out of graduate school. Project management, leadership, stakeholder engagement, facilitation skills, and report writing are some of the invaluable tools I have added to my resume.

Additionally, students commented on the acquisition of sustainability competencies:

One of the most important skills I developed through this class was how to facilitate discussion around sensitive development topics in a positive, future-oriented way. I learned how to discuss aspects of sustainability in concrete terms with specific examples, which allowed community members to engage with complex ideas about the future.

Another common thread focused on the valuable collaborative experience. Students were not only able to contribute meaningfully to the project based on their backgrounds in sustainability, engineering, anthropology and more but they also felt respected by those from different backgrounds:

I can honestly say that while I was coming from a very different background than most of the other students in the course, I felt that my ideas and contributions were given the utmost respect.

Students gained team-building skills and noted that “conscious and deliberate team building is often overlooked in other courses, which comes at the expense of a strong final product and a pleasant work environment.” Finally, students felt motivated because they were working toward concrete and relevant objectives. One student asserted: “This is the vision for the new normal in the classroom that should be strived for”.

While there is the need for more systematic impact evaluation, initial indicators suggest positive impacts on the community too. One PPBL workshop-course (Spring 2010) resulted in five sustainability-oriented transition strategies for urban development in Phoenix (Wiek *et al.*, 2012). These strategies have been discussed in public hearings, coaching sessions and professional conferences, and have stimulated discussions among planners, politicians, business leaders and citizens, as well as in public schools in Phoenix. This PPBL course initiated the relationships with the City of Phoenix that eventually led to the acquisition of a major federal grant for community development in 2012 (“Reinvent Phoenix”). Another PPBL workshop-course (Spring, 2012) resulted in an actionable tree-and-shade manual for a neighborhood in Phoenix (Bernstein *et al.*, 2014). The student team continued working with the community after the course concluded and secured funding for implementing an initial tree and shade program.

Outlook on PPBL program advances after take-off

The initial insights presented above demonstrate a case of successfully inaugurating a PPBL program in sustainability at a major university in the USA. Yet, a key challenge for this program and similar programs around the world is how to maintain the institutional momentum and make advances after the initial take-off. Sterling and Thomas (2006) posit four stages in a transition toward strong sustainable education. The final stage is characterized by “a deep, conscious reordering of assumptions which leads to paradigm change” (Sterling and Thomas, 2006, p. 4). To consolidate and advance PPBL programs, SOS needs to:

- further enhance the cohesion and quality of the PPBL program across the curricula;
- further increase opportunities for national and international exchange and mutual learning about PPBL activities in sustainability programs;
- further increase program impact on local and regional sustainability issues; and
- build PPBL capacity in a critical mass of advanced graduate students and faculty across the school and the university.

First, there is wide agreement among PPBL scholars and practitioners that PPBL needs to be one of the guiding principles of the entire curriculum, not just of isolated course efforts (Savery, 2006; Sterling and Thomas, 2006). SOS has made good progress in offering a wide range of PPBL opportunities to undergraduate and graduate students; yet, the cohesion across the curricula still displays some weaknesses and offers opportunities for improvement. Second, over the years, students have participated in numerous PPBL projects, yet lack of capacity and resources to document these projects limits the opportunities to make those courses tangible and effectively share experiences with faculty and the broader community. Third, lack of monitoring and evaluation also makes it difficult to assess program impact in rigorous ways, both in terms of student learning, faculty development, and real-world community impact. Demonstration of evidence, however, is critical for funding opportunities and broader agreement on the importance of PPBL efforts in undergraduate and graduate sustainability education. Finally, although significant institutional support is in place and there is a consensus around the desirability of PPBL, major PPBL efforts are championed by a relatively small number of faculty and staff.

Creating a sustainable PPBL program requires further expanding the group of interested and knowledgeable faculty, students and staff.

In order to achieve these objectives, the authors propose the following approaches:

- *Develop greater program cohesion and coordination:* SOS plans on further developing an explicit framework for PPBL in the field of sustainability. On an institutional level, this framework will allow for greater synergy between PPBL courses, individual student work, faculty projects and internship opportunities (documented and coordinated on *SustainabilityConnect*). Planning and offering PPBL courses differ from preparing lecture-based courses in a few ways. First, they take longer for faculty to plan and require greater program coordination to allow for an institutionalized structure and timeline for PPBL course planning across the curricula for the next one to two academic years. Second, problem- and project-based courses require higher contact hours and credit-units than lecture-based courses because of the novel self-directed and team-based learning approach and the commitments made to project-partners with respect to outputs and process. Third, to allow students to take reasonable course-loads per semester, the school needs to balance the course offerings of lecture-based and PPBL course-workshops per semester.
- *Synthesize past products and learning:* To improve PPBL, past products and experiences must be catalogued, systematically analyzed and evaluated to tease out critical lessons learned (factors of success/failure), and to build upon these insights. To this end, a handbook for teaching PPBL in sustainability programs is being created, which incorporates lessons learned and lays out the basics of designing a successful PPBL course. This would provide an evidence-based resource to interested faculty, students and staff in support of their PPBL/teaching efforts.
- *Monitor and evaluate impacts:* Alongside the synthesis of past products, new evaluative schemes should be created, including formative and summative components to more systematically measure the impact of PPBL endeavors in terms of student learning (competence building) and faculty development, as well as community and stakeholder impacts. Student competency achievement was not assessed in the past due to lack of assessment tools. There is now an international working group composed of faculty and students that is developing and testing sustainability competency assessment tools.
- *Develop training programs for faculty and graduate students:* More formal capacity building on the part of the students and of faculty is critical for broadening and expanding the pool of interested and knowledgeable instructors capable of offering PPBL opportunities. In addition to a handbook and individual faculty training opportunities, one could train graduate students to develop and implement PPBL opportunities for a team of undergraduate students over the course of two semesters. Graduate students would be encouraged to seek out projects and project-partners that correspond to the research topics of their Master or PhD theses. Undergraduate students could take this course to fulfill their capstone requirement.

These approaches, implemented in conjunction, could contribute toward a fundamental shift in institutional values by building a critical mass of students and faculty who have capacity, are interested and see the value in PPBL for sustainability education.

Conclusions

Arizona State University's School of Sustainability has integrated a variety of PPBL opportunities in their undergraduate and graduate programs. This is one example of what higher education institutions can do in terms of curriculum development and aligning institutional structures with PPBL objectives. By sharing our experience and findings, other programs may be able to better articulate the benefits of PPBL initiatives, anticipate implementation challenges and successfully support their own PPBL initiatives through adequate institutional structures. In this article, the authors have presented examples of the variety of ways to incorporate PPBL opportunities into the curriculum, from components in classes to full workshop-courses, thesis work and international collaboration. The critical review of our experience points to the fact that the major impact on both student learning and outcomes for partner organizations is achieved through a concerted effort by the institution as a whole. Successful PPBL programs require both top-down commitment from the administration, bottom-up drive from interested faculty and students and openness on behalf of the project-partners. The findings can inform and support the ongoing transformation in sustainability education with the ultimate objective to build students' capacities to address and solve wicked sustainability problems in the real-world, competently collaborating with partners from government, business and civil society.

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About the authors

Arnim Wiek is an Associate Professor in the School of Sustainability at Arizona State University (USA). He is the head of the Sustainability Transition and Intervention Research Lab. His research group conducts sustainability research on emerging technologies, urban development, resource governance, climate change and public health in the USA, Canada, different European countries, Sri Lanka, Mexico and Costa Rica. The group's research pursues a transformational agenda and develops evidence-supported solutions to sustainability challenges. The group carries out research in close collaboration with government, businesses and community groups. Wiek had research and teaching engagements at the Swiss Federal Institute of Technology, Zurich; the University of British Columbia, Vancouver; and the University of Tokyo. Arnim Wiek is the corresponding author and can be contacted at: Arnim.Wiek@asu.edu

Angela Xiong obtained her master's degree from the School of Sustainability at Arizona State University in 2013 and is currently a Non-Profit Leadership Fellow at Strategic Energy Innovations, San Rafael, CA. Her research brings a sustainability lens to public health, working with health professionals, government and local residents in implementing sustainable, preventative health services. Her master's thesis investigated the role of well-designed playgrounds in providing access to recreation, improving safety perceptions and tackling childhood obesity. She has also supported the problem- and project-based learning program at the School of Sustainability. Xiong organized environmental education courses at the Franklin Park Zoo in Boston, MA, and at the Urban Ecology Institute in Cambridge, MA.

Katja Brundiers is the community–university liaison for the School of Sustainability at Arizona State University. In this role, she supports problem- and project-based sustainability research for students. She serves as a facilitator, coach, project manager and co-instructor to faculty, students and community partners. Before joining the School of Sustainability, Brundiers headed up a small boundary organization at the Swiss Federal Institute of Technology, Zurich, Switzerland, that facilitated collaborative sustainability research projects. Brundiers has worked as a sustainability consultant to the University of British Columbia and as a member of the Swiss UNESCO Committee on Education for Sustainable Development. She holds a master's degree in Geography and Anthropology from the University of Zurich and currently pursues her doctoral research at the School of Sustainability.

Sander van der Leeuw was trained as an archaeologist and historian at the University of Amsterdam, The Netherlands. After an academic career spent mostly in Europe, he is a Professor of Anthropology and Founding Director of the School of Human Evolution and Social Change at Arizona State University. He served as the Dean of the School of Sustainability between 2010 and 2013. During his tenure there, he devoted an important effort to structuring its curriculum and teaching approaches in the directions discussed in this article. His personal research is on complex systems approaches to the long-term evolution of socio-environmental systems and innovation. In 2012, he was awarded the UNEP "Champion of the Earth Award for Science and Innovation". He is also an External Professor at the Santa Fe Institute, New Mexico.