*Sustainability* **2013**, *5*, 1725-1746; doi:10.3390/su5041725

OPEN ACCESS

*sustainability*

**ISSN 2071-1050**

www.mdpi.com/journal/sustainability

*Article*

# Do We Teach What We Preach? An International Comparison of Problem- and Project-Based Learning Courses in Sustainability

**Katja Brundiers * and Arnim Wiek**

School of Sustainability, Arizona State University, PO Box 875502, Tempe, AZ 85287-5502, USA

* Author to whom correspondence should be addressed; E-Mail: katja.brundiers@asu.edu; Tel.: +1-480-965-1304; Fax: +1-480-965-8087.

*Received: 11 February 2013; in revised form: 10 April 2013 / Accepted: 11 April 2013 / Published: 23 April 2013*

---

**Abstract:** Problem- and project-based learning (PPBL) courses in sustainability address real-world sustainability problems. They are considered powerful educational settings for building students' sustainability expertise. In practice, however, these courses often fail to fully incorporate sustainability competencies, participatory research education, and experiential learning. Only few studies exist that compare and appraise PPBL courses internationally against a synthesized body of the literature to create an evidence base for designing PPBL courses. This article introduces a framework for PPBL courses in sustainability and reviews PPBL practice in six programs around the world (Europe, North America, Australia). Data was collected through semi-structured qualitative interviews with course instructors and program officers, as well as document analysis. Findings indicate that the reviewed PPBL courses are of high quality and carefully designed. Each PPBL course features innovative approaches to partnerships between the university and private organizations, extended peer-review, and the role of knowledge brokers. Yet, the findings also indicate weaknesses including paucity of critical learning objectives, solution-oriented research methodology, and follow-up research on implementation. Through the comparative design, the study reveals improvement strategies for the identified challenges and provides guidance for design and redesign of PPBL courses.

**Keywords:** sustainability science; sustainability education; evaluation; problem-based learning; project-based learning; transdisciplinary research

---

## 1. Introduction

The field of sustainability science is at an important junction having reached a first stage of consolidation as an academic field [1–3]. The consolidation is indicated by the number of established sustainability degree programs, academic journals, conferences, as well as scientific and professional associations. Recent literature shares the conviction that contextual, constructivist, and collaborative learning approaches on developing solution options to real-world sustainability problems involving stakeholders are best suited to building students' sustainability expertise [4–7]. Accordingly, sustainability and other programs around the world have begun to offer problem- and project-based learning (PPBL) courses that often involve collaboration with stakeholders [8–12]. We use the term PPBL "course" in a broad sense including various teaching-learning settings that comply with basic principles of PPBL, including seminars, workshops, case studies, and studios. PPBL courses are considered important educational settings not only for students as:

> "Students, researchers and practitioners […] work together closely in order to find an appropriate answer to the leading question […] In a complex, dynamic and knowledge-based society, researchers and/or teachers, students and practitioners need these core skills in order to meet their responsibility to contribute to the sustainable development of society. Hence, the concept leads to benefits for all participants ([13], p. 889)."

Such claims and promises trigger the question: "Do we teach what we preach?" In other words, do current PPBL courses in sustainability comply with the design criteria suggested in the literature? A compliance appraisal is timely and can provide important insights for redesigning existing PPBL courses and developing new ones. The importance of such appraisals is highlighted by a review of the state of problem-based learning at Maastricht University in the Netherlands, which identified subtle implementation flaws:

> "Lack of funding, poor understanding of the underlying principles by both staff and students, misguided attempts to 'make the approach more efficient', a focus on content at the expense of process, all contribute to the erosion of the set of intertwined principles that make the problem-based approach work. […] These often subtle changes, taken together, may lead in the long run to the collapse of the innovation, simply because more and more staff and students become dissatisfied with an inconsistent and failing educational framework ([14], p. 681)".

Similar challenges have been recognized for PPBL courses in sustainability [10,15–17]. Hence, it is critical to regularly review how PPBL principles are being implemented in sustainability courses and programs.

Building on previous international comparative studies that touch upon sustainability-oriented learning settings similar to PPBL, e.g., [18,19], the present study pursues the following objectives:

(1). Provide a coherent design framework for PPBL courses in sustainability, derived from disperse strands of literature (e.g., educational science, sustainability science, participatory research).

(2). Review an international sample of PPBL courses in sustainability against the guidelines of this framework in order to exemplarily appraise the current state of implementation.

(3). Summarize strengths and weaknesses of current PPBL courses in sustainability (using the analyzed cases) and highlight innovative solutions to overcome the weaknesses.

In pursuit of these objectives, we reviewed literature on PPBL in sustainability (Section 2); selected and characterized six PPBL courses in sustainability from around the world, namely Europe (Spain, Switzerland), North America (Canada (2), USA), and Australia (Section 3); conducted semi-structured qualitative interviews with the course instructors and program officers (Section 4); and supplemented the findings through an analysis of course and program documents (Section 5).

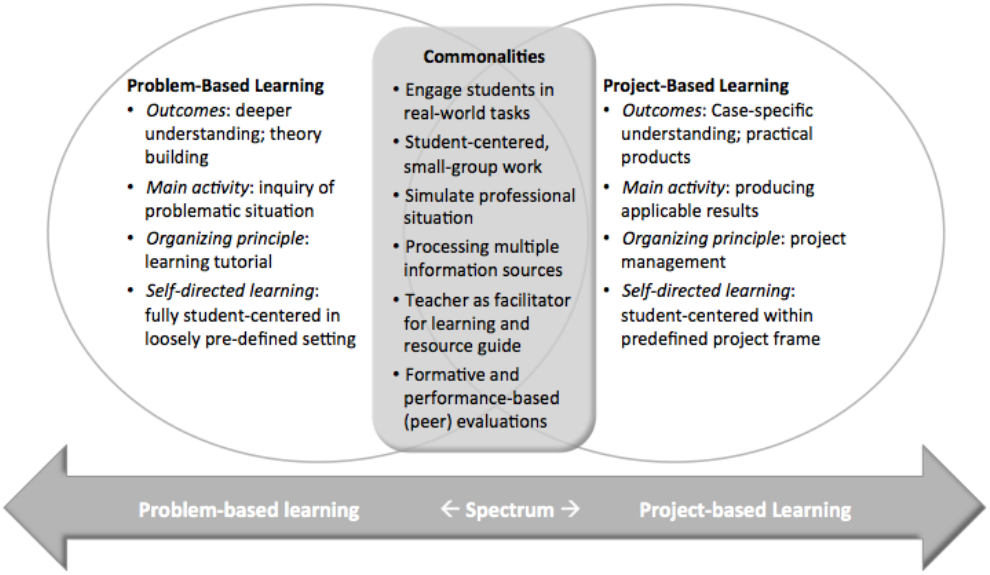
The article aims to provide evidence-based guidance to faculty, staff, and students, interested in designing, evaluating, and redesigning PPBL courses in sustainability. We hope to facilitate learning among sustainability and other programs for making progress towards high quality PPBL courses in sustainability that inspire students, faculty, and external partners.

## 2. Key Features of Problem- and Project-Based Learning in Sustainability

Problem- and project-based learning courses in sustainability are characterized by a set of key features. These courses might follow slightly different learning formats and might be labeled differently (e.g., seminars, workshops, case studies, studios); yet, they center on similar design features. Problem-based and project-based learning approaches display many commonalities; yet, they put different emphasis on some of the key features such as product-orientation, reflexivity, and learner-centered pedagogy. Figure 1 illustrates commonalities and differences between both approaches.

PPBL courses employ constructivist and experiential learning approaches [20], in particular approaches of *problem-based learning* [21–23] and *project-based learning* [24,25]. In these settings, learning shifts from passive (instructor delivers, students receive) to active (students deliver, instructor receives and provides feedback) [26]. Students investigate a real-world problem and work on *solution options* to this problem by engaging in *small-group work* (ideally in an interdisciplinary team) to which instructors contribute as *coaches* for the teams.

**Figure 1.** Problem- and project-based learning (PPBL) as a continuum of constructivist, experiential learning approaches (Adapted from [23,27,28]).



Donnelly and Fitzmaurice ([27], p. 89) speak of problem-based and project-based learning as a continuum: "in practice, it is likely that the line between project- and problem-based learning is frequently blurred and that the two are used in combination and play complementary roles". Similarly, Bereiter and Scardamalia [28] found that today's modified forms of problem-based and project-based learning overlap in important areas. Additional arguments speak for hybrid forms of problem- *and* project-based learning (PPBL) in the context of sustainability education [29]. First, PPBL courses in sustainability adopt the problem inquiry as in problem-based learning and, in order to develop solution options, the product-orientation from project-based learning. Combining both approaches aims at avoiding both the risk of getting caught in the "knowledge-first" trap by endlessly analyzing problems [30], as well as jumping prematurely to solutions without sufficient problem framing and analysis [31]. Second, PPBL expands the engagement structure of the broader public of problem-based learning as it involves stakeholders in a collaborative process of knowledge generation and critical reflection [11,15,32]. Problem-based learning courses often do not involve stakeholders, or only in a consultative way [33].

PPBL courses in sustainability offer students the opportunity to engage with real-world sustainability problems. Sustainability problems are so-called "wicked" problems that are life-threatening and urgent, have long-term impacts, are highly complex (systemic), and cannot be solved by simple remedies [2,34]. As *real-world problems,* they pose actual challenges relevant to stakeholders and decision makers "now", as opposed to re-constructed problems as presented in textbooks. Real-world problems offer the advantage of the "pedagogy of place" where students' exposure to their research topics in real-time is utilized to enhance learning and empathy [35,36].

PPBL courses put emphasis on research. The research feature demarcates them from other experiential learning settings with stakeholder engagement, such as service learning and internships. The focus is on *generating knowledge* in form of novel solution options to sustainability problems. Thereby, research happens in participatory (also called, "transdisciplinary" or "transacademic") settings [11], where "scientists and persons from business, administration, government and public […] interact intentionally and purposefully to generate socially robust and scientifically reliable knowledge" ([37], p. 52). Such research collaborations provide a series of benefits, including *substantive* (e.g., accounting for multiple perspectives for improving problem understanding and developing solution options); *normative* (e.g., eliciting and negotiating values and preferences), and *instrumental benefits* (e.g., developing legitimate processes and linking knowledge to action) [38–40]. With adequate coaching, students acquire interpersonal competence in participatory settings, that is the ability to motivate, enable and facilitate outcome-oriented collaboration among diverse stakeholder groups [7]. In advanced PPBL courses, participatory settings are initiated and supported by a transacademic interface manager, who facilitates the collaboration between students, faculty, and stakeholders [11,13].

Here and in the following, we use the term "instructor" in the meaning of PPBL, where instructors switch roles from knowledge-providers to facilitators and coaches [15]. The term "stakeholders" refers to people operating in the "real-world", who contribute problem awareness and/or relevant professional expertise to the PPBL course. Stakeholders are usually representatives from business, government, or civic society. University staff can participate as stakeholders representing campus units

such as operations, maintenance, facilities, and management. These collaborations strive to advance the public good through student-centered research and to disseminate research results widely.

## 3. Profiles of Selected PPBL Courses in Sustainability

Based on an initially broad review of potential courses, we selected six PPBL courses in sustainability. The courses comply with the basic features outlined above; represent programs from different parts of the world, namely Europe (Spain, Switzerland), North America (Canada (2), USA), and Australia; are well documented; and are regarded exemplary in the academic sustainability community. We provide here comparative descriptions of the courses' organizational structure and context (Table 1).

**Table 1.** Organizational context and structure of the six reviewed problem- and project-based courses in sustainability.

| **Country** | **Canada (East)** | **Australia** | **Canada (West)** | **USA** | **Spain** | **Switzerland** |
|---|---|---|---|---|---|---|
| University | Dalhousie University | Australian National University | University of British Columbia | Arizona State University | Universitat Politechnica de Catalunya | ETH Zurich |
| Program | Environmental Sciences | Human-Ecology Program | All programs | Sustainability | Engineering | Environmental Sciences |
| Pedagogy of place | Off-campus and On-campus | On-campus | Off-campus and On-campus | Off-campus and On-campus | Off-campus and On-campus | Off-campus |
| Level | 3rd year undergraduate students | 3rd year undergraduate students | Typically 4th year undergraduate students; open to graduate students | Combined undergraduate (4th year) and graduate students (2nd year) | Graduate students in 1st year | Graduate students in 1st year |
| Credits (per semester) | 3 credit points | 3 credit points | Credit varies | 3 credit points 135 h/student | 10 credit points 300 h/student | 10 credit points 300 h/student |
| Format | Hybrid course incorporating a PPBL project | Hybrid course incorporating a PPBL project | Directed study, graduate thesis, workshop, etc. | Workshop | Workshop | Workshop |
| Number of projects (p/a) | 12 | 6 | 80 (145 individual sub-projects) | 1 (split into 3 sub- projects) | 4 | 1 (split into 3 sub-projects) |

**Table 1.** *Cont.*

| **Country** | **Canada (East)** | **Australia** | **Canada (West)** | **USA** | **Spain** | **Switzerland** |
|---|---|---|---|---|---|---|
| Number of students, stakeholders, faculty (p/a) | 60 students, 1 faculty or sustainability manager and 2 tutors, 12 stakeholders | 30 students, 1 faculty, 6 stakeholders | 480 students, 360 faculty, 3 staff as program managers, 77 stakeholders | 22 students, 2 faculty, 3 core and 20 related stake-holders | 24 students, 2 faculty, 4 staff, 4 stakeholders | 18 students, 1 faculty and 3 tutors, 1 staff as program manager, 8 core and 100 related stakeholders |
| Prerequisites | Yes | Yes | No | No | No | No |
| Project Structure | Highly pre-structured timeline and course | Highly pre-structured timeline and course | Not pre-structured | Low-level of pre-structure, apart from timeline | Low-level of pre-structure, apart from the first weeks | Highly pre-structured course |
| Duration | Since 2001 | Since 1998 | Since 1997, with interruptions | Since 2008 | 2008–2011 | Since 1994 |

This overview indicates that PPBL courses are happening on all academic program *levels*, namely on upper division undergraduate and graduate levels. While almost all cases offer PPBL courses as a regular component of their degree program, few have designed their degree program to prepare students for this culminating experience or require students to have completed prerequisites [17]. PPBL courses are occurring in all *formats*, ranging from hybrid courses combining lecturing with student-centered project work; to workshops and studios, focusing on student-centered project work with minimal lecture time; to individually directed studies and graduate theses as part of larger team efforts. Almost all cases structure the projects prior to offering them to students. For instance, instructors—often in collaboration with the stakeholders—scan projects regarding their suitability for educational purposes, develop a general timeline for students, and set up contacts with stakeholders. Few cases allow project teams to organize the project and timelines entirely on their own.

The organization of PPBL courses illustrates institutional diversity: courses are led by instructors, ranging from full professors to faculty associates; or by faculty *and* senior staff; or by senior staff being in charge of coordinating the entire course. While each student team is expected to engage stakeholders in a collaborative way, few PPBL courses deliver on the expectation that researchers and stakeholders join projects on "equal footing" (e.g., as co-leaders) and that student are being *trained* in stakeholder collaboration. Hence, the collaborations vary from simple to sophisticated organizational structures and roles. The *size* of PPBL courses ranges from self-contained small courses (2–6 students, 1 stakeholder), to large courses with more than 20 students who are split into sub-projects. While the core course duration is one to two semesters, the project sometimes extends over several years. The specific course topics vary, as they depend on the selected projects. Most cases recognize the campus as a source of projects for PPBL courses in sustainability and have developed a partnership with the

university's sustainability office as project provider and participant. Some cases engage stakeholders from neighborhoods, municipalities, cities, or regions in PPBL courses.

One of the Canadian cases presents an interesting exception: a university-wide service provides a PPBL program rather than one specific course in order to offer opportunities to all students and faculty of the university. The idea is that the PPBL experience enriches a regular course, because students link their project to a course they are enrolled in, or instructors incorporate a project into their course [41]. In this case, we applied the framework to appraise the design of the PPBL *program*, and not the individual projects themselves.

## 4. Framework for PPBL Courses in Sustainability

The selected PPBL courses are being analyzed through the framework for transformational sustainability research, proposed by Talwar *et al.* [42] and elaborated in Wiek and Lang [43]. Figure 2 illustrates the four phases: *Orienting*, *Framing*, and *Doing* the research, as well as *Implementing* the solution options. Each phase entails specific *steps* and *outcomes*, as well as combinations of project participants. The PPBL approach offers different learning opportunities depending on the constellation of project participants.

For each phase, we developed two sets of questions: (i) *analytical questions* to learn about the *process* (what was done and by whom?) and the *results* (what were the outputs and outcomes?); and (ii) *appraisal questions* (how do process and results relate to the quality criteria proposed in the literature?). The questions are summarized in Table 2.

**Figure 2.** Process model of PPBL courses—Steps, processes, actors involved, and outcomes.

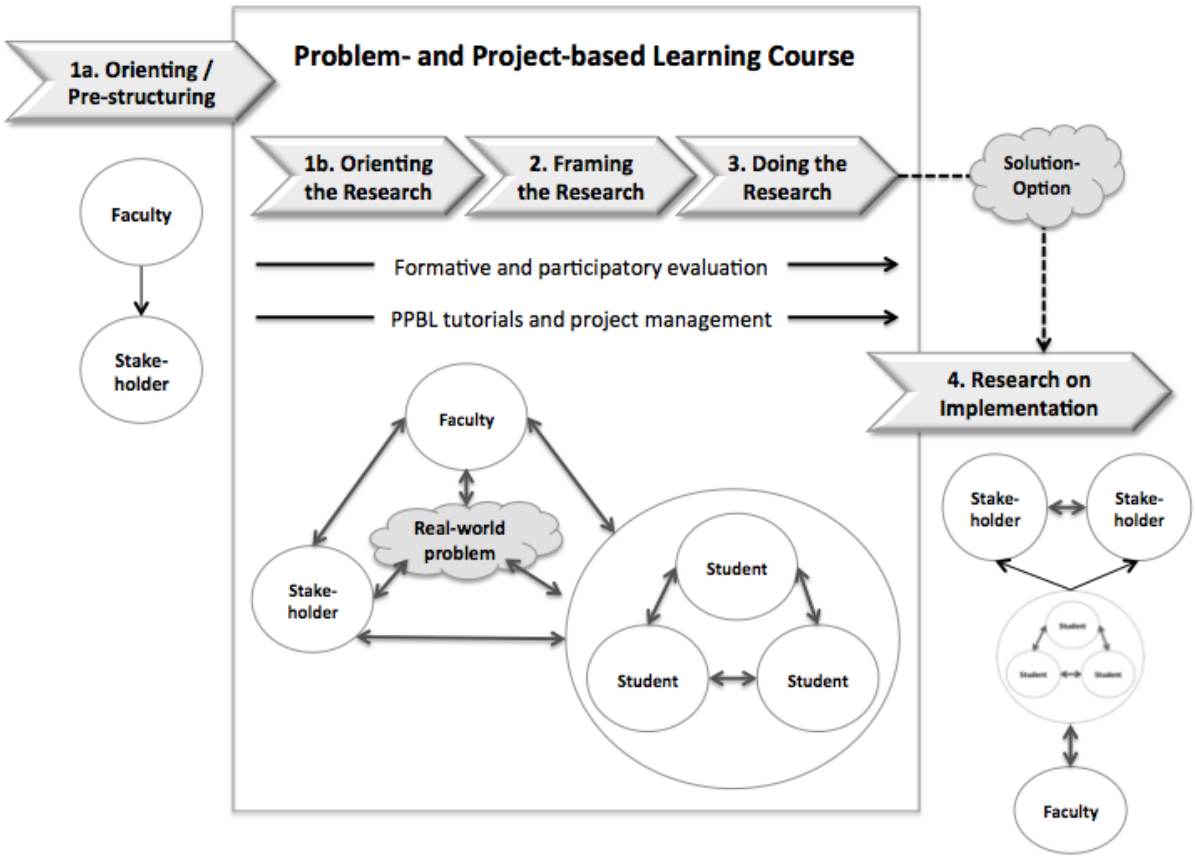


**Table 2.** Analytical-evaluative framework for problem- and project-based courses in sustainability.

| Analytical questions | Evaluative questions | Literature |
|---|---|---|
| 1. Orienting Phase | | |
| (1). Who is involved in the problem definition and result formulation? | (1). Do project partners equally agree on the relevance of the problem and the research objectives? | [40,44–46] |
| (2). What is the problem? | (2). Is the problem defined as a *sustainability* problem? | [2,34] |
| (3). What is the goal of the project? | (3). Is the goal to develop actionable solution options? | [2,30] |
| (4). What are the learning objectives of the PPBL course? | (4). Are the learning objectives linked to key competencies in sustainability? Are learning objectives individualized? | [7,11,30] |
| (5). How are teams composed? How is teambuilding organized? | (5). Do the teams account for expertise and interests? Are teambuilding techniques (e.g., code of cooperation) used? | [15] |
| (6). How is PPBL as a learning- and teaching environment introduced? | (6). Is there an explicit introductory PPBL tutorial with provision of resources, tools, and techniques? | [14,27,47] |
| 2. Framing Phase | | |
| (1). What research methods are selected and combined? | (1). Is a solution-oriented methodological framework adopted or developed? Is sufficient time allocated to each module? | [8,43] |
| (2). Are participatory settings determined? | (2). Do the participatory settings reflect the project objectives, as well as expertise and interest of the participants? | [39,40,42] |
| 3. Doing Research Phase | | |
| (1). How is the research conducted? | (1). Is research conducted according to the methodological framework created? Are all methods applied according to quality standards? | [2] |
| (2). What are the ultimate research results? | (2). Is a solution option developed based on the modular results? Does an extended peer-review inform credibility and saliency of the results? Are insights generalized beyond the specific case? | [2,38] |
| (3). Are process evaluations performed? | (3). Are formative evaluations conducted? Do students reflect on their experience and the quality of process and products? Do participants feel that agreed upon expectations were met? Are evaluation results implemented? | [22,48–50] |
| (4). How is the acquisition of sustainability competencies ensured? | (4). Are students provided adequate support in developing sustainability competencies? | [11] |
| 4. Implementation Phase | | |
| (1). What happens after the main research is completed? | (1). Is implementation of the research results moving forward? Is research on implementation lined up? | [46,51,52] |
| (2). Who is involved in the implementation? | (2). Are students involved as part of their overall PPBL experience? | [4] |

### *4.1. Orienting the Research Phase*

Orienting the research is broken down into two steps (1a and 1b in Figure 2). Prior to the involvement of students, instructors explore and pre-structure the problem and the project objectives together with stakeholders, similar to regular participatory research projects [40,42]. Thereby, jointly clarifying the question of who initiates and leads the project is important to ensure equal ownership of the project between researchers and external partners [11,44]. "The question of who takes the lead is significant because it is typically the initiator who has the greatest say in how the engagement is structured and, consequently, how power is shared ([45], p. 466)".

The involvement of students starts with reviewing the learning objectives and sustainability competencies to be conveyed and acquired in the PPBL course. As PPBL courses strive to develop life-long learning skills, it is important to allow students to determine and negotiate (facilitated by the instructor) which of the competencies the student wants to focus on individually [23]. It also allows the teams to assess the sets of competencies required for the project.

The initial activity is followed by an orientation about the PPBL approach employed in the course (provided by instructors), forming student teams, getting organized (logistics), building the teams (code of cooperation; clarifying expectations; building trust), and formalizing the partnership with stakeholders (memorandum of understanding) [15,22,27,46]. Explicitly introducing students into the philosophy and process of PPBL and providing PPBL resources, tools, and techniques enables students' to succeed in this novel teaching and learning environment [14,47].

Content-wise, the teams review the initial problem identification and result expectations. Students do additional structuring of the problem as a *sustainability* problem and anticipating the results (*i.e.*, solution options as changes towards sustainability) in collaboration with the instructors and stakeholders [31,43]. Both problem identification and anticipated results are finally formulated by means of research objectives and research questions; it is ensured that all participants agree on these important reference points [40].

### *4.2. Framing the Research Phase*

In this phase, the participants collaboratively identify a framework that combines research methods in a way that fits the problem and allows producing actionable knowledge. Actionable knowledge provides evidence-based instructions for how to carry out sustainability-oriented interventions and transition processes. In order to achieve these goals, different methods need to be combined and sufficient time for all research modules and their synthesis needs to be allocated (avoiding the misbalance between rich analysis and poor intervention design). A methodological framework needs to be developed that combines methods from different "families" of methods: (i) *descriptive-analytical methods* that inform about the past, current, and future states of the problem from a systems perspective; (ii) *normative methods* to assess the extent of the problem and envision a sustainable future state eliciting relevant sets of values, norms, and thresholds; and (iii) *instructional methods* that design and test intervention and transition strategies intended to resolve or mitigate the identified problem [43]. In addition, participatory settings for each of the research modules are determined that adequately reflect stakes, expertise, and interest of stakeholders [40]. The methodological framework

guides the research process and helps integrating the results of the selected methods over the course of the project. Next, the required and available expertise is reviewed (specific to the methods selected), and a project-management plan is developed, including responsibilities, budget, and timeline [27]. The framing phase might pass through several iterations as students identify new learning issues and additional partners need to be recruited [21,47].

Another important task of the research framing is to define an approach for formatively evaluating the PPBL course as a research and learning endeavor [11,39]. A formative evaluation allows students to continuously review and revise learning objectives, insights, and assumptions, as well as to provide and receive feedback in interactions with peers, instructors, and stakeholders [48,49]. Such reflection and conscientious learning rarely happens without a facilitator. Thus, instructors support teams in setting aside time for regular reflections, for example, individually prepared through structured journals [22].

### *4.3. Doing the Research Phase*

Doing the research then is applying the identified methods (according to quality standards), which should result in evidence-based solution options able to realize the desired change toward sustainability. The participatory and formative evaluation in this phase provides a mechanism to ensure that stakeholders and instructors consider the outputs as credible, innovative, and impactful [38,42]. For students, the process should provide sufficient opportunities for their professional development and to acquire sustainability competencies. Ideally, all participants experience changes in their knowledge, attitude, or behavior toward sustainability [13]. To test the feasibility of the developed solution options, teams perform, among others, extended peer-reviews with stakeholders and experts and revise the solution options based on the review results [11,37,46]. Explicit self- and peer-evaluation of one's own and each team member's contributions at different stages during the phase and a final plenary reflection complement the PPBL process [14,50]. A working meeting with stakeholders, instructors, and students, towards the end should outline how students can continue the research in the implementation phase and help to avoid the well-known research-implementation gap [8,51].

### *4.4. Implementation Phase*

Implementation is the process of applying the research results and realizing the solution option, which is the domain and responsibility of the stakeholders [42]. The opportunities for students to be involved in the implementation phase include for students (1) to maintain their *role as researchers* and perform research on implementation, which expands the evidence base for the developed solution options and provides insights for necessary revisions and adjustments [46,52]. Ideally, this follow-up research on the implementation of the solution option should be a goal of the PPBL course from the outset as an integral part of the learning experience [4]. Another role would be that students enroll in an internship at the organization of the stakeholders and contribute to the implementation of the solution option through their internship experience.

## 5. Results

Considering the wealth of relevant material, we present results for selected criteria of each phase summarizing the findings across the six cases along two questions (for each criterion). Thereby, we selected those criteria that resonated most with all interviewees: (1) What is the current state of PPBL practice for this criterion and is there room for improving practice with respect to the compiled quality guidelines? (2) What are successfully applied and proposed approaches to make improvements in compliance with the quality guidelines?

### *5.1. Orienting the Research Phase*

#### 5.1.1. Is the Problem Defined as a Sustainability Problem?

Four of the six PPBL courses initially indicated that they define the problem as a sustainability problem using sustainability criteria. Yet, when presented with a set of criteria derived from the literature [2], they acknowledged not using explicit criteria—which is in line with previous evaluation results [11,39]. One case uses explicit sustainability criteria, yet reported on the need for re-labeling the problem in the participatory process: "Talking about sustainability can lead to negative reactions as [sustainability] became such a buzzword and people are tired talking about it" (ETH). Instructors and program officers support the suggestion to let students define and structure the problem along sustainability criteria as well as engaging stakeholders in this process (DAL, ANU). One case made good experience with using explicit criteria for capacity building in sustainability literacy: "Having students just to check off "this is a sustainability problem" and leave it at that—that would be insufficient" (ASU).

#### 5.1.2. Do the Teams Account for Expertise and Interests? Are Teambuilding Techniques (e.g., Code of Cooperation) Used?

In most PPBL courses, students self-select their teams based on topical interest, friendship, or previous collaboration. Teambuilding is discussed in class and fostered through special social events; yet, students often use informal and unstructured activities for teambuilding. In most cases there is paucity of activities that support structured teambuilding activities to prepare for small-group work and professional skill-development. Students mostly do not assess their skills in relation to problem features, anticipated outcomes, or sustainability competences in general. One case makes positive experiences with engaging students and stakeholders progressively in teambuilding and teamworking activities as they move through the phases of the course/project (ETH). Another case lets students self-select into their team, but asked them to assess their skill-sets against sustainability competencies (ASU). Progressive teambuilding approaches can help to compose teams more rigorously: students indicate team preference, and are then guided to conduct a self-assessment of skills and compare them with the problem features, anticipated results, and sustainability competencies. Teams are then composed based on aligning expertise, interest and project requirements [15].

### *5.2. Framing the Research Phase*

#### Is a Solution-Oriented Methodological Framework Adopted or Developed? Is Sufficient Time Allocated to Each Module?

Three of the six PPBL courses adopt a solution-oriented methodological framework to create sustainability solution options, drawing on intervention research or organizational change management methodologies (ANU, UPC, ASU). The other three PPBL courses organize synthesis activities either as part of the course, e.g., project presentations to synthesize results across groups through interactive discussions (DAL); or hire student research assistants or recruit a student team after the course ended to synthesize findings in a synthesis report (ETH, UBC). Students often perceive the synthesis activities as an additional, not an integral part of their work (ETH, UBC). Although the majority of PPBL courses stated sustainability problem-solving as explicit course objective, they allocate most of the time to the problem analysis, using predominantly descriptive-analytical methods. Two PPBL courses adopt a framework that combines all three families of methods in developing solution options (UPC, ASU). One PPBL course came up with a model for iteratively checking the feasibility of solution options. Students are expected to revise their proposed solution option stepwise to account for challenges and obstacles that professional experts were perceiving: "if they recommend an intervention, then they have to seriously assess the feasibility and cost of what they are recommending" (ANU).

Three PPBL courses (ANU, UPC, ASU) have students define the responsibilities of team-members in the workplan and structure the timeline of the project from the outset, so that all steps are building on each other and contribute to the development of solution options. One PPBL course uses a matrix organization to integrate each student-team's project topics (x-axis) with the three families of methods (y-axis) and allocate sufficient time to each module (ASU).

It seems advisable in the framing phase for student teams and instructors to reflect on and discuss different methodological frameworks and then make an informed choice in order to align desired project objectives with research methods and activities [43]. From a general PPBL perspective, it is critical to plan explicitly for linking case-specific and generic insights [11,25,28].

### *5.3. Doing the Research Phase*

#### 5.3.1. Does an Extended Peer-Review Inform Credibility and Saliency of the Results?

The typical outputs of PPBL courses are final reports and presentations either for the course participants, fellow students, the broader public, or other stakeholder groups considered instrumental for implementing the results. While the outputs are shared with stakeholders, the majority of PPBL courses do not entail a formal request and process for extended peer-review. Despite strong efforts to encourage *collaboration* among students and stakeholders, one-way/one-time interactions often prevail due to a paucity of structured opportunities for mutual learning throughout the project. The lack of extended peer-review as standard practice in PPBL courses is also due to a general hesitation among students to actively elicit feedback (that might impact grades), combined with additional logistical efforts and a lack of experience with this procedure. Nevertheless, two PPBL courses organize

extended peer-reviews of selected documents, such as reports for the public, after instructors had reviewed the public report and students had an opportunity to revise it (ASU, ETH). An important element of organizing an extended peer-review-process is to clarify with students and stakeholders the evaluative criteria based on negotiated expectations, anticipated results, learning objectives, and quality standards. Additionally, inviting stakeholders directly to convey particular knowledge or skills through collaboration, tutorials, and regular feedback to students helps create a culture of constructive critique (ETH, UPC). Such ongoing formative assessment is a key element of general PPBL practice as it helps build students' capacity to account for and integrate various perspectives, to think critically, and improve learning strategies [49].

#### 5.3.2. Are Participatory, Formative and Summative Evaluations Conducted?

All PPBL courses require students to submit a formal summative course evaluation and self-/peer-evaluation and engage students in formative evaluations along the project through face-to-face discussions or online surveys. The summative evaluations are being used to revise the design of the PPBL course for the next cohort while the formative reflections lead to improved project materials and changes in students' practices. Student teams and stakeholders are typically not involved in developing the evaluative criteria applied. Two PPBL courses (UPC, ASU) engage stakeholders in the evaluation: first, through a moderated class discussion to elicit perceptions on the course and projects from students, instructors, and stakeholders (UPC); and second, through facilitating conversation with stakeholders, which leads to knowledge-exchange and networking and helps instructors to manage expectations (UPC, ASU). To design formative evaluations as an integrated part of the PPBL course, instructors can adapt templates used in sustainability science [39] and experiential learning [53]. Beyond improving the specific group dynamics and outcomes, such evaluative activities can generate evidence of success: "It helped to show that an academic institute is definitively suitable of developing such projects. We showed that we–as a group–had the capacity and platform to develop transacademic projects. This is not obvious, I would say. Too many of the research institutes are too far away from reality to implement those kind of projects. They don't have the practice, skills, capacity, or contacts for that" (UPC).

#### 5.3.3. Are Students Provided Adequate Support in Developing Sustainability Competencies?

Most PPBL courses do not use sustainability competencies as a framework to derive learning objectives. From such a starting position, courses struggle with conveying the full range of sustainability competencies as suggested in the literature [7,54,55]. The learning outcomes refer mostly to specific substantive areas (e.g., energy, waste) and to interpersonal skills. "Students learned a great deal to talk in concrete terms about concepts that are theoretical and very vague. For instance, the ideas of "co-creation of knowledge" or "transacademic" are abstract, but the course made them very real" (UPC).

Although there is increased convergence on sustainability competencies, there is still a lack of specific tutorials and exercises to build and test these competencies. However, tested activities from experiential learning approaches could be adapted. For instance, ANU is using the learning portfolio-method [26]; yet, it is not fully adapted to the sustainability competencies. ASU uses reflective discussion-board contributions; yet, they could be improved by adopting the method of in-depth reflection asking students to: observe and document; analyze in accordance with relevant categories of learning; and

evaluate and articulate their learning success [56]. Thereby, the relevant categories are operationalized learning objectives derived from sustainability competencies and can be presented as a rubric, making self-evaluation accessible and transparent to students [57]. In addition, empirical research shows that instructor feedback is essential, so that students can link their experiences to course material, review and revise assumptions, and improve their learning strategies [56,58].

PPBL courses could further support students in developing sustainability competencies by involving stakeholders in this process, too. This is particularly relevant for interpersonal, normative, and strategic competencies. Embracing this opportunity would also spread wider sustainability literacy in society. Even if stakeholders have sustainability expertise, there might be opportunities for advanced mutual learning. This model requires to overcome the same challenges as discussed above related to collaborative interactions between students and stakeholders as well as extended peer-review.

### *5.4. Implementation Phase*

#### 5.4.1. Is the Implementation of the Research Results Moving Forward? Is Research on Implementation Lined Up?

While all PPBL courses have formulated explicit learning objectives, they also state that the implementation of research results is an essential goal, because the prospect of being able to make a positive difference in the world sparks motivation among students. Yet, half the PPBL courses fail to organize a working meeting with stakeholders to jointly discuss how research results lend themselves for implementation and how to wrap up the project to support stakeholders in preparing for the implementation phase. Rather, the project often concludes with a final presentation for students to learn about each others' research (and with stakeholders). Thereby, students, instructors, and stakeholders often miss the opportunity to discuss the strategic planning towards implementation as students' presentations focus mostly on what was done—instead of critically explore what should be done next and by whom based on their research. By this, all parties forgo a rich opportunity for learning, because the discussion on how research results could be implemented is where the rubber hits the road: "Some results were different than what the stakeholders had in mind. This is OK because our allegiance is to sustainability, otherwise it wouldn't be an honest approach if we just created what stakeholders wanted. Our goals are to think about a sustainability solution from a sustainability perspective and not to come in as consultants and provide a recommendation" (ASU). The implementation is the critical phase that actualizes transformations of practices in government, business, and civil society, based on the PPBL course processes and continuous commitment from all parties involved.

Three of the PPBL courses (UPC, ANU, ETH) prepare for the implementation phase through early agreements with stakeholders and students that the project is expected to produce actionable knowledge; or by inviting stakeholders to co-lead final events and provide feedback on students' presentations with respect to potential implementation (UBC, ASU, DAL).

5.4.2. Are Students Involved in Implementation Efforts as Part of Their Overall PPBL Experience?

As mentioned in Section 4.4, students' involvement in the implementation phase refers to their role as researchers (to evaluate the implementation) or as an intern at the organization (to support the implementation from within). However, neither option has been planned for in the courses studied. The pattern of "order and pick-up the solution" prevails: none of the cases has had experience with students conducting research on how solution options get implemented. Yet, instructors and program officers consider this an important success criterion for the future (ANU, ASU, DAL UBC). In the case of on-campus projects, providing incentives such as scholarships, seed- or co-funding for implementation of students' projects through the students themselves seems a successful strategy to involve students into the implementation stage as the cases of ANU and UBC demonstrate. The importance of accompanying implementation research becomes evident in these models. "Well meaning interventions turned bad because [they] generated more problems. This is a good learning outcome: it illustrates the nature of the beast!" (ANU).

To respond to the need for implementation *research* as part of the overall PPBL experience, such evaluative research on implementation could be incorporated into the initial PPBL course proposal; or a process model could be introduced that alternates between cohorts that focus on developing solution options and cohorts that conduct research on implementing those solution options. Alternative models of implementation research would be internships or thesis projects. Other models could be adopted from implementation science and intervention research [46,52]. SEED, a collaboration between the Jack Basking School of Engineering and the Social Sciences Division at the University of California Santa Cruz provides their students with templates to outline how to continue with a project in the future.

## 6. Discussion

The result synopsis above shows that there are promising PPBL efforts in sustainability programs around the world. Yet, a variety of challenges prevail. In reviewing the literature and the cases, we found that three challenges for designing, implementing, and evaluating PPBL courses in sustainability remain salient:

(1). Define learning objectives for the PPBL course that are derived from and aim at the acquisition of sustainability competencies [7,19,26,54];
(2). Use design-criteria and practical experience for incorporating a strong transacademic approach into the PPBL course [37,40];
(3). Fully account for key principles of PPBL, including self-directed learning and advanced team working, as well as for a sustainability research methodology that is both problem- and solution-oriented [22,23,25,48].

In view of these challenges, we focus in the following on innovative approaches for how to bridge these gaps between the theory and practice of PPBL in sustainability, drawing from the reviewed cases. Faculty and staff involved in PPBL recognize the need for addition efforts in each of the three challenge domains. For instance, the majority of project officers are interested in deriving course learning outcomes from key competencies in sustainability: "[Our learning objectives] are not set out like this, in this complete fashion; but this would be a good thing to do" (ANU). As for transacademic

research collaboration with stakeholders, students discuss approaches of collaboration and co-production of knowledge in class, based on a series of readings. However, students mostly apply extractive methods such as interviews or presentations with feedback, integrating the provided knowledge themselves. Hence, they do not practice methods of *co*-production of knowledge (ANU, DAL, UBC, ASU). Shifting from an extractive to a co-constructive mode of knowledge production is difficult, but rewarding: "We learned a lot through these projects as organizers, but also students learned a great deal to talk in concrete terms about concepts that are theoretical and very vague" (UPC).

To support adoption of sustainability science concepts into PPBL courses three approaches gleaned from the reviewed cases seem promising. First, leveraging the experience of advanced graduate students: Two cases provide PPBL courses that combine advanced graduate and undergraduate students in the same course (ASU) or appoint doctoral students to a team of graduate students in a PPBL course (ETH). In both cases, the graduate students act as sustainability science and PPBL coaches to undergraduate and graduate students respectively. Reflecting on their own learning experience, they are responsible to convey tutorials to help practicing sustainability concepts over the course of the project. Reinforcing the experience of their peers, in turn, allows the graduate students to gain practical experience as principal investigator in research design, PPBL-teaching techniques, and transformational sustainability research. Second, instructors practiced team-teaching in three PPBL courses (DAL, ANU, UPC). While some instructors invited and briefed (!) subject-matter experts to come to the plenary sessions and offer training for students and faculty; others split the class-sessions up among co-instructors or even adopted a rotational approach over the course of semesters. Furthermore, instructors in one case constituted a formal advisory board that provides guidance to the institution and training and peer-learning sessions for faculty interested in PPBL courses (ASU).

These ideas are not new–they have been documented in conceptual and case-based studies. Yet, they are mostly related to disciplinary or interdisciplinary settings [59–61]. The innovation lies in adopting them for PPBL courses in sustainability with stakeholder collaboration. Van der Leeuw *et al.* [62] posit that such multilateral relationships might be critical for innovating the next generation of academics: "If students played an equal role in the development of curricula, selection of course content, and initiation of applied projects, how different might the impact of the academy become"? However, introducing such novel processes requires additional time in courses that already experience time constraints:

> "Superficially, we did activities that got students started on [transformational sustainability research]. But these are thought-concepts and theoretical ideas. Course wise students achieved to understand the problem from a sustainability perspective—but really thinking through how they apply requires more time. Students had these "ohhh!!" moments, but there was no time to work on it in more detail and foster it and turn it into more" (ASU).

Some approaches gleaned from the reviewed cases seem promising. For instance, one case introduces new concepts, methods, and skills in stages and "on the job" in order to progressively respond to students' needs such as team-working skills or intervention methods (ANU, ETH). To guide such staged learning, it is helpful to structure the semester along the modules of the transformational sustainability research framework outlined above and to engage students in self-assessing their sustainability competencies and learning objectives for each module. Alternatively, a variety of cases found ways to "expand" the semester, e.g., through connecting the PPBL course with prerequisite

courses or a series of (overnight) fieldtrips and training sessions for students to socialize and experiment with PPBL techniques (ANU, DAL). Other programs make the course a "semester-filling" endeavor in terms of course credits, discouraging students to take on other responsibilities (UPC, ETH). Other PPBL courses run over the course of two semesters to allow faculty and students enough time to learn and dedicate time to the project [12].

However, logistical challenges will remain as long as PPBL courses remain individual hotspots in the curriculum. This touches on longstanding discussions of transforming curricula towards PPBL [17,23,63] and towards sustainability [6]. While the examples present an argument for the feasibility of stand-alone hybrid approaches, others call for a systemic approach of inclusive education [26]. Expanding on Biggs' [26] systematic perspective means also to include the campus as a living laboratory for sustainability as well as the academic sustainability science community. Four of the six cases (UPC, UBC, DAL, ANU) have established formal partnerships with the University's office of sustainability [41,64]. This is beneficial in a variety of ways. Most universities have a mid- and long-term sustainability plan, which generates sustainability projects and allows to couple mid- and long-term PPBL course programming with campus sustainability planning [65]. This results in more planning security and less planning effort per PPBL course for instructors and campus managers respectively. Furthermore, using the campus as laboratory saves overall travel-time for all parties involved since fieldwork, service-learning, interviews and meetings can be conducted on site [32]. A formal contract and spatial proximity provide advantages for implementation, research on implementation, and project-continuation [46]. An However, students might want to take on the dual role of researcher / interface important requirement, however, would be to hire a transacademic interface manager to avoid burdening faculty or staff with the dual role of academic / professional coach and interface manager [11]. manager as it offers exploring a future job profile in a comparatively save environment.

Finally, educational science needs to become more active in tailoring PPBL opportunities for sustainability programs through valuable contributions that can advance the educational practice [66]. To inform the rigorous adaptation and application of PPBL principles in sustainability programs, a closer collaboration between educational and sustainability scientists would be helpful to expand the data produced by various case studies (mostly self-reported) into systematic and comparative research of approaches [16,67,68]. Considering that only two of the cases have published their work so far (ANU, ETH), the guidelines introduced above could serve as a scaffold for instructors, students, and stakeholders to write up their PPBL courses in sustainability to make projects comparable, which enables knowledge exchange and mutual learning.

## 7. Conclusions

This article presents a framework for designing problem-and project-based (PPBL) courses in sustainability education and applies the framework to six degree-granting programs in higher education worldwide to provide insights on current PPBL practices. The results show that a great deal of similarity among the six cases, as well as compliance with recommended PPBL principles exists.

The similarities indicate consolidation on the proposition that PPBL courses can fulfill an important function in sustainability education. Promising is the compliance of all cases with key principles such

as addressing complex, wicked sustainability problems, adopting a focus on developing sustainability solution options, and recognizing the need for teamwork and stakeholder collaboration.

Cases differ from each other through their respective strengths and innovative approaches to address challenges. Cases that anchor their PPBL courses institutionally, for instance through a formal partnership with the University sustainability office, are in a better position to implement solution options with their stakeholders. This allows them to take the next step and have students conduct research on the implementation (ANU, UPC, UPC). Research on implementation is a weakness across all case studies. Courses that work in the same project and with the same stakeholders over one to two years have seized opportunities for capacity building of students, faculty, and stakeholders by testing models for co-leadership, team-building, and incipient peer-review processes (ETH). The innovation of PPBL courses offered in sustainability programs lies in the translation and application of concepts and methods of sustainability into educational practice; in particular, with respect to sustainability competencies and transformational sustainability research methodology (DAL, ASU).

Collaborative learning among PPBL courses worldwide would be useful to share experiences and synthesize best practices of designing PPBL courses in sustainability. This article contributes to this effort through a general framework and an initial comparative study. The template is not meant to force courses into a rigid regime, but to provide guidelines that allow instructors anticipating opportunities and challenges, and adapting them to different institutional settings. Existing international organizations, such as the Association for the Advancement of Sustainability in Higher Education, or the International Society for Sustainability Science, could be engaged to facilitate this international dialogue and joint advancement of the educational practice. On this basis, the next research endeavor could be undertaken, which explores in how far PPBL courses in sustainability support the acquisition of key competencies in sustainability and lead to real-world impacts, as originally envisioned.

## Acknowledgments

We would like to thank two anonymous reviewers for helpful comments on an earlier version of this article. The authors have also received useful feedback from participants of the Td-net Conference 2011 on “Implementation in Inter- and Transdisciplinary Research, Practice and Teaching” (Bern, 14–16 September 2011).

## Conflict of Interest

The authors declare no conflict of interest.

## References

1. Spangenberg, J.H. Sustainability science: A review, an analysis and some empirical lessons. *Environ. Conserv.* **2011**, *38*, 275–287.
2. Wiek, A.; Ness, B.; Brand, F.S.; Schweizer-Ries, P.; Farioli, F. From complex systems analysis to transformational change: A comparative appraisal of sustainability science projects. *Sustain. Sci.* **2012**, *7 (Suppl 1)*, 5–24.

3. Yarime, M.; Trencher, G.; Mino, T.; Scholz, R.W.; Olsson, L.; Ness, B.; Frantzeskaki, N.; Rotmans, J. Establishing sustainability science in higher education institutions: towards an integration of academic development, institutionalization, and stakeholder collaborations. *Sustain. Sci.* **2012**, *7* (*Suppl 1*), 101–113.
4. Rowe, D. Education for a sustainable future. *Science* **2007**, *317*, 323.
5. Segalàs, J.; Esbrí, M.E.; Benson, M.P. European project semester: 30 ECTS of PBL in sustainability with multicultural and multidisciplinary bachelor students groups. In Proceedings of International Conference in Engineering Education Engineering Sustainability for a Global Economy, Belfast, UK, 21–26 August 2011; pp. 1–9.
6. Sterling, S.; Thomas, I. Education for sustainability: The role of capabilities in guiding university curricula. *Int. J. Sustain. High. Educ.* **2006**, *1*, 349–370.
7. Wiek, A.; Withycombe, L.; Redman, C.L.; Banas Mills, S. Moving forward on competence in sustainability research and problem-solving. *Environment. Sci. Policy Sustain. Dev.* **2011**, *53*, 3–13.
8. Scholz, R.W.; Lang, D.J.; Wiek, A.; Walter, A.I.; Stauffacher, M. Transdisciplinary case studies as a means of sustainability learning: Historical framework and theory. *Int. J. Sustain. High. Educ.* **2006**, *7*, 226–251.
9. Onuki, M.; Mino, T. Sustainability education and a new master's degree, the master of sustainability science: the Graduate Program in Sustainability Science (GPSS) at the University of Tokyo. *Sustain. Sci.* **2009**, *4*, 55–59.
10. Brundiers, K.; Wiek, A.; Redman, C.L. Real-world learning opportunities in sustainability: from classroom into the real world. *Int. J. Sustain. High. Educ.* **2010**, *11*, 308–324.
11. Brundiers, K.; Wiek, A. Educating Students in Real-world Sustainability Research: Vision and Implementation. *Innov. High. Educ.* **2011**, *36*, 107–124.
12. Lang, D.J.; Wiek, A. The role of universities in fostering urban and regional sustainability. In *Institutional and Social Innovation for Sustainable Urban Development;* Mieg, H.A., Töpfer, K., Eds.; Earthscan: London, UK, 2012; pp. 393–411.
13. Steiner, G.; Posch, A. Higher education for sustainability by means of transdisciplinary case studies: an innovative approach for solving complex, real-world problems. *J. Clean Prod.* **2006**, *14*, 877–890.
14. Moust, J.H.; Berkel, H.J.V.; Schmidt, H.G. Signs of erosion: reflections on three decades of problem-based learning at Maastricht University. *High. Educ.* **2005**, *50*, 665–683.
15. Stauffacher, M.; Walter, A.I.; Lang, D.J.; Wiek, A.; Scholz, R.W. Learning to research environmental problems from a functional socio-cultural constructivism perspective: the transdisciplinary case study approach. *Int. J. Sustain. High. Educ.* **2006**, *7*, 252–275.
16. Bacon, C.M.; Mulvaney, D.; Ball, T.B.; DuPuis, E.M.; Gliessman, S.R.; Lipschutz, R.D.; Shakouri, A. The creation of an integrated sustainability curriculum and student praxis projects. *Int. J. Sustain. High. Educ.* **2011**, *12*, 193–208.
17. Wiek, A.; Xiong, A.; Brundiers, K.; van der Leeuw, S. Integrating problem- and project-based learning into sustainability programs–A case study on the School of Sustainability at Arizona State University. *Int. J. Sustain. High. Educ.* **2013**, submitted for publication.

18. Ferrer-Balas, D.; Adachi, J.; Banas, S.; Davidson, C.I.; Hoshikoshi, A.; Mishra, A.; Motodoa, Y.; Onga, M.; Ostwald, M. An international comparative analysis of sustainability transformation across seven universities. *Int. J. Sustain. High. Educ.* **2008**, *9*, 295–316.
19. Segalàs, J.; Ferrer-Balas, D.; Svanström, M.; Lundqvist, U.; Mulder, K.F. What has to be learnt for sustainability? A comparison of bachelor engineering education competences at three European universities. *Sustain. Sci.* **2009**, *4*, 17–27.
20. Kolb, A.Y.; Kolb, D.A. Learning Styles and Learning Spaces: Enhancing Experiential Learning in Higher Education. *Acad. Manag. Learn. Educ.* **2005**, *4*, 193–212.
21. Barrows, H.S. Problem-based learning in medicine and beyond: A brief overview. In *Bringing Problem-Based Learning to Higher Education: Theory and Practice; New Directions For Teaching and Learning Series*; Wilkerson, L., Gijselaers, W., Eds.; Jossey-Bass: San Francisco, CA, USA, 1996; 68, pp. 3–11.
22. Hmelo-Silver, C.E. Problem-based learning: What and how do students learn? *Educ. Psychol. Rev.* **2004**, *16*, 235–266.
23. Savery, J.R. Overview of Problem-Based Learning: Definitions and Distinctions. *Interdiscipl. J. Problem-based Learn.* **2006**, *1*, 9–20.
24. Kilpatrick, W.H. Dangers and difficulties of the project method and how to overcome them: Introductory statement: Definition of terms. *Teach. Coll. Rec.* **1921**, *22*, 283–287.
25. Blumenfeld, P.C.; Soloway, E.; Marx, R.W.; Krajcik, J.S.; Guzdial, M.; Palincsar, A. Motivating project-based learning: Sustaining the doing, supporting the learning. *Educ. Psychol.* **1991**, *26*, 369–398.
26. Biggs, J. What the student does: teaching for enhanced learning. *High. Educ. Res. Dev.* **2012**, *31*, 39–55.
27. Donnelly, R.; Fitzmaurice, M. Collaborative project-based learning and problem-based learning in higher education: Consideration of tutor and student roles in learner-focused strategies. In *Emerging Issues in the Practice of University Learning and Teaching*; O'Neill, G., Moor, S., McMulling, B., Eds.; All Ireland Society for Higher Education (AISHE): Dublin, Ireland, 2005; pp. 87–98.
28. Bereiter, C.; Scardamalia, M. Learning to work creatively. In *Powerful Learning Environments: Unravelling Basic Components and Dimensions*; De Corte, E., Verschaffel, L., Entwistle, N., van Merrienboer, J., Eds.; Pergamon: Amsterdam, The Netherlands, 2003; pp. 55–68.
29. Yasin, R.M.; Rahman, S. Problem oriented project based learning (POPBL) in promoting education for sustainable development. *Procedia. Soc. Behav. Sci.* **2011**, *15*, 289–293.
30. Sarewitz, D.; Clapp, R.; Crumbley, C.; Kriebel, D.; Tickner, J. The Sustainability Solutions Agenda. *New Solutions* **2012**, *22*, 139–151.
31. Jerneck, A.; Olsson, L.; Ness, B.; Anderberg, S.; Baier, M.; Clark, E.; Hickler, T.; Hornborg, A., Kronsell, A.; Lövbrand, E.; *et al.* Structuring sustainability science. *Sustain. Sci.* **2011**, *6*, 69–82.
32. Adomssent, M.; Godemann, J.; Michelsen, G. Transferability of approaches to sustainable development at universities as a challenge. *Int. J. Sustain. High. Educ.* **2007**, *8*, 385–402.
33. Walsh, A. An exploration of Biggs' constructive alignment in the context of work-based learning. *Assess. Eval. High. Educ.* **2007**, *32*, 79–87.

34. Gibson, R.B. Sustainability assessment : basic components of a practical approach. *Impact Assess. Project Appraisal* **2006**, *24*, 170–182.
35. Gruenewald, D.A. The best of both worlds: A critical pedagogy of place. *Educ. Res.* **2003**, *32*, 3–12.
36. Segal, E.A. Social Empathy: A New Paradigm to Address Poverty. *J. Poverty* **2007**, *11*, 65–81.
37. Wiek, A. Challenges of transdisciplinary research as interactive knowledge generation experiences from transdisciplinary case study research. *GAIA* **2007**, *16*, 52–57.
38. Cash, D.W.; Clark, W.C.; Alcock, F.; Dickson, N.M.; Eckley, N.; Guston, D.H.; Jäger, J.; Mitchell, R.B. Knowledge systems for sustainable development. *Proc. Natl. Acad. Sci. USA* **2003**, *100*, 8086–8091.
39. Blackstock, K.L.; Kelly, G.J.; Horsey, B.L. Developing and applying a framework to evaluate participatory research for sustainability. *Ecol. Econ.* **2007**, *60*, 726–742.
40. Lang, D.J.; Wiek, A.; Bergmann, M.; Stauffacher, M.; Martens, P.; Moll, P.; Swilling, M.; Thomas, C.J. Transdisciplinary research in sustainability science-Practice, principles and challenges. *Sustain. Sci.* **2012**, *7* (*Suppl 1*), 25–43.
41. Brunetti, A.J.; Petrell, R.J.; Sawada, B. SEEDing sustainability: Team project-based learning enhances awareness of sustainability at the University of British Columbia, Canada. *Int. J. Sustain. High. Educ.* **2003**, *4*, 210–217.
42. Talwar, S.; Wiek, A.; Robinson, J. User engagement in sustainability research. *Sci Public Policy* **2011**, *38*, 379–390.
43. Wiek, A.; Lang, D.J. *Transformational sustainability research*; Working Paper, School of Sustainability, Arizona State University: Tempe, AZ, USA, 2013.
44. McNall, M.; Sturdevant Reed, S.; Brown, R.; Allen, A. Brokering Community-University engagement. *Innov. High. Educ.* **2009**, *33*, 317–331.
45. Van Kerkhoff, L.; Lebel, L. Linking knowledge and action for sustainable development. *Annu. Rev. Environ. Resour.* **2006**, *31*, 445–477.
46. Fraser, M.W.; Galinsky, M.J. Steps in intervention research: Designing and developing social programs. *Res. Soc. Work Pract.* **2010**, *20*, 459–466.
47. Hmelo, C.E.; Lin, X. Becoming self-directed learners: Strategy development in problem-based learning. In *Problem-Based Learning: A Research Perspective on Learning Interactions*; Evensen, D.H., Hmelo, C.E., Eds.; Lawrence Erlbaum Associates Publishers: Mahwah, NJ, USA, 2000; pp. 227–250.
48. Roessingh, H.; Chambers, W. Project-Based Learning and Pedagogy in Teacher Preparation: Staking Out the Theoretical Mid-Ground. *Int. J. Teach. Learn. High. Educ.* **2011**, *23*, 60–71.
49. Stull, J.C.; Varnum, S.J.; Ducette, J.; Schiller, J.; Bernacki, M. The many faces of formative assessment. *Int. J. Teach. Learn. High. Educ.* **2011**, *23*, 30–39.
50. Dolmans, D.H.; de Grave, W.; Wolfhagen, I.H.; van der Vleuten, C.P. Problem-based learning: Future challenges for educational practice and research. *Med. Educ.* **2005**, *39*, 732–741.
51. Knight, A.T.; Cowling, R.M.; Rouget, M.; Blamford, A.; Lombard, A.T.; Campbell, B.M. Knowing but not doing: selecting priority conservation areas and the research–implementation gap. *Conserv. Biol.* **2008**, *22*, 610–617.
52. Bammer, G. Integration and implementation sciences: building a new specialization. *Ecol. Soc.* **2005**, *10*, 6.

53. Eyler, J. Creating your reflection map. *New Direct. High. Educ.***2002**, *114*, 35–43.
54. De Haan, G. The BLK '21'programme in Germany: a 'Gestaltungskompetenz'-based model for education for sustainable development. *Environmen. Educ. Res.* **2006**, *12*, 19–32.
55. Barth, M.; Godemann, J.; Rieckmann, M.; Stoltenberg, U. Developing key competencies for sustainable development in higher education. *Int. J. Sustain. High. Educ.* **2007**, *8*, 416–430.
56. Ash, S.L.; Clayton, P.H. The articulated learning: An approach to guided reflection and assessment. *Innov. High. Educ.* **2004**, *29*, 137–154.
57. Knight, L.A. Using rubrics to assess information literacy. *Ref. Serv. Rev.* **2006**, *34*, 43–55.
58. Heritage, M.; Kim, J.; Vendlinski, T.; Herman, J. From evidence to action: A seamless process in formative assessment? *Educ. Meas.* **2009**, *28*, 24–31.
59. Caviglia-Harris, J.L.; Hatley, J. Interdisciplinary teaching: Analyzing consensus and conflict in environmental studies. *Int. J. Sustain. High. Educ.* **2004**, *5*, 395–403.
60. Little, A.; Hoel, A. Interdisciplinary Team Teaching: An Effective Method to Transform Student Attitudes. *J. Eff. Teach.* **2011**, *11*, 36–44.
61. Topping, K.J. Trends in peer learning. *Educ. Psychol.-UK* **2005**, *25*, 631–645.
62. Van der Leeuw, S.; Wiek, A.; Harlow, J.; Buizer, J. How much time do we have? Urgency and rhetoric in sustainability science. *Sustain. Sci.* **2012**, *7 (Suppl 1)*, 115–120.
63. Van Der Vleuten, C.P.M.; Verwijnen, G.M.; Wijnen, H.F.W. Fifteen years of experience with progress testing in a problem-based learning curriculum. *Med. Teach.* **1996**, *18*, 103–109.
64. Mcmillin, J.; Dyball, R.; Developing a Whole-of-University Approach to Educating for Sustainability: Linking Curriculum, Research and Sustainable Campus Operations. *J. Educ. Sustain. Dev.* **2009**, *3*, 55– 64.
65. Barlett, P.F., Chase, G.W., Eds.; *Sustainability on Campus: Stories and Strategies for Change*; MIT Press: Boston, MA, USA, 2004.
66. Barth, M.; Michelsen, G. Learning for change: an educational contribution to sustainability science. *Sustain. Sci.* **2013**, *8*, 103–119.
67. De Graaff, E., Kolmos, A., Eds.; *Management of Change: Implementation of Problem-Based and Project-based Learning in Engineering*; Sense Publishers: Rotterdam, The Netherlands, 2007.
68. Lehmann, M.; Christensen, P.; Thrane, M.; Jørgensen, T.H. University engagement and regional sustainability initiatives: some Danish experiences. *J. Clean Prod.* **2009**, *17*, 1067–1074.