

Communication

Lessons Learnt from Educating University Students through a Trans-Disciplinary Project for Sustainable Sanitation Using a Systems Approach and Problem-Based Learning [†]

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[†] An earlier article “Sankaran, S.; Abeysuriya, K.; Gray, J.; Kachenko, A. Mellow yellow: Taking a systems thinking approach to designing research on transitioning to more sustainable sewage management. *Syst. Res. Behav. Sci.* **2013**, doi:10.1002/sres.2227” dealt with the research design aspect of the project described in this paper. This paper deals with the educational opportunities and outcomes associated with the research project.

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Abstract: This article discusses how a Systems Thinking (ST) approach to student learning, employing Problem-Based Learning (PBL) interventions, at several different universities in Sydney, Australia was incorporated into a broader trans-disciplinary research project, the aim of which was to examine how urine diversion in an urban, institutional setting might form the basis of phosphorus collection—phosphorus being a non-renewable resource used in agricultural fertilizers. The article explores how the ST

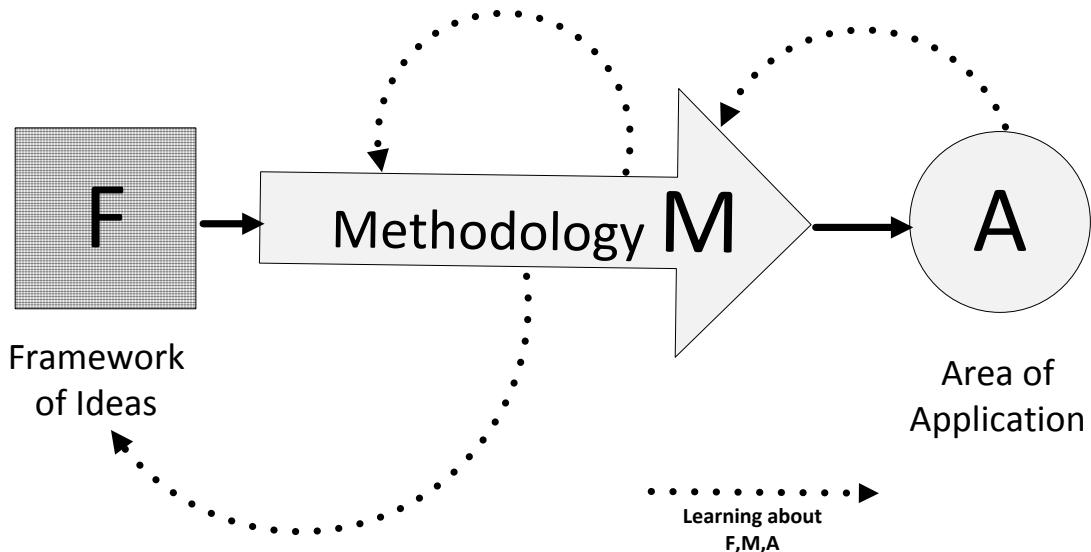
approach employed by the researchers themselves was adapted to embrace student engagement opportunities and how it permitted opportunities for Problem-Based Learning interventions. Five academics forming part of the research team consider the effectiveness of ST-styled student engagement via Problem-Based Learning in three action research cycles used in the research project. In sharing their experiences they provide an honest, “no-holds barred” review of what worked and what could be done more effectively with the benefits of hindsight.

Keywords: systems thinking; action research; systems education; legal studies; visual communication; civil and environmental engineering

1. Introduction

The student learning experiences described in this article may be envisaged as a set of actions that were planned as part of a sustainable sanitation research project. Philosophically the research was set in a Systems Thinking based intellectual framework (F) with Action Research as the Methodology (M) that guided the Problem-Based Learning interventions as the area of application (A) as shown in Figure 1 based on the FMA model proposed by Checkland [1] to set up any piece of research.

Figure 1. Elements of research (Based on [1]).



According to Savin-Baden and Howell [2], Problem Based Learning (or PBL) developed at a medical school at the University of McMaster in Canada as a new approach to medical education. The use of PBL spread to other medical schools across the world and from medical schools PBL spread to educating health workers. PBL spread further to professional preparation programs in engineering, architecture, economics, law and social work to name a few areas.

According to Barrows [3] the original model of PBL developed at McMaster had the following characteristics:

- (1) Learning is student-centered;
- (2) Learning occurs in small student groups;
- (3) Teachers are facilitators or guides;
- (4) Problems form the organizing focus and stimulus for learning;
- (5) Problems are a vehicle for the development of clinical problem solving skills;
- (6) New information is acquired through self-directed learning.

Boud and Feletti [4] clarified that “the emphasis of problem-based approaches is on learning processes of enquiry which proceeds by asking what needs to be known to address and improve a particular situation” and that “critical reflection is central to effective action”. Rangachari [5] describes it thus: “The term PBL means different things to different people”. “Shorn of all rhetoric, it is a format that encourages active participation by plunging students into a situation requiring them to define their own learning needs within broad goals set by the faculty. The students are presented with problem-situations that serve as springboards for learning. This is in sharp contrast to subject-based approaches that teach a body of knowledge prior to its application to specific problems”.

PBL gained favor as an innovative idea when it was observed that students who used PBL to study in medical schools adapted more easily to medical practice because PBL activated prior knowledge [6].

While PBL was being developed in Canada, a variation of PBL based on project pedagogy was developed in two universities in Denmark. One of them, Aalborg University, used the variation to meet industry expectations of competencies of engineers. The concept that developed in Denmark was explained by de Graaff and Kolmos [6] as “a form of teaching in which students—in collaboration with teachers and others—explore and work with a problem in close relation to the social reality in which it exists”.

The terms “problem-based learning” and “project-based learning” refer to models that have many similarities but the main difference between them is that while PBL is used to address open-ended and ill-structured problems (similar to the ones in which soft systems methodology plays a useful method of intervention) project-based learning refers to an assignment or task that students have to perform [6].

Savin-Baden [7] proposed five models of PBL:

- (1) PBL for epistemological competence—knowledge is propositional and used for narrow problem scenarios;
- (2) PBL for professional action—knowledge is practical and performance-oriented dealing with a real-life situation;
- (3) PBL for interdisciplinary understanding where knowledge is both propositional and practical and the problem scenario requires a combination of theory and practice;
- (4) PBL for critical contestability where knowledge is contingent, contextual and constructed by the learner for a given situation and the problem scenario is one that offers multidimensional possibilities.

De Graaff and Kolmos [8] reduce the main learning principles of PBL to three approaches:

- (1) Learning approach—learning is organized around problems. It places learning in context and bases learning on learners’ experiences;

- (2) Contents approach—concerns interdisciplinary learning and crosses boundaries as learning leads to exemplary practice and the learning outcome is exemplary to overall objectives;
- (3) Social approach in which team-based learning takes precedence and learning takes place through dialogue and communication.

As PBL developed it generated a number of debates that continue to raise questions of concern and/or interest. According to Savin-Baden [9] these include:

- (1) The extent to which a course or a program needs to be problem-based.
- (2) How it should be designed?
- (3) What counts as PBL, ways of implementation and types?
- (4) Should it be an instructional strategy or used only for curriculum design?

Savin-Baden [9] argues that PBL differs from other similar teaching methods such as project-based learning, problem solving, problem-solving learning, scenario-based learning, inquiry-based learning, problem-orientated learning, work-based learning and action learning. She is optimistic that PBL will continue to grow in higher education despite the various debates as its essential principles contribute to effective learning. It is, however, a difficult approach for students and teachers to grasp as it challenges them to accept that learning has to be managed in the midst of blurred boundaries and transitions. That was certainly the case in the sustainable sanitation project that forms the subject of this article.

For the purposes of contextualization, the following section details the particular sanitation project to which Systems Thinking (ST), Action Research (AR) and Problem Based Learning (PBL) were applied in an educational context.

2. Background

The sanitation project referred to above was the Transitioning to Sustainable Sanitation (TSS) Project or the Funny Dunnies Project, as it became affectionately known. It was a Sydney-based project that involved research by, and the participation of, academics and students at three universities as well as a range of industry partners. The project relied on AR within a ST framework and at different stages and in various circumstances, the academic members of the research team applied PBL to their students' learning.

The project was innovative at a number of levels including the scientific, environmental and technological endeavors it pursued, as well as the manner in which it sought to educate the students involved in it. The project's overall innovation was formally recognized when it won a New South Wales State government Green Globe Award for Innovation, in 2012.

What exactly did the TSS project aim to investigate?

The TSS project aimed to explore the possibility that urine diversion might become a viable concept in the urban environment.

Urine diversion and collection was considered important because urine contains high levels of phosphorus. Phosphorus is an element with a plethora of uses, and one key use is in modern agriculture where it is used in chemical fertilizers that support global food production.

As the world population increases, demands on phosphorus have increased. Yet, phosphorus is a non-renewable resource and mineral phosphate rock reserves are diminishing at such a rate that an

anticipated peak in global phosphorus production will occur by 2035 [10]. Accordingly, the pressure to find alternative sources of phosphorus has escalated.

Aware that urine diversion permits the separation of nutrients as well as the potential recovery of approximately 80% of nitrogen and 50% of phosphorus in domestic wastewater [11], the multi-disciplinary and multi-institutional TSS research team (including students) embarked on a pilot project in urine diversion and capture in an institutional setting. Put simply, the research team set about capturing urine at an early stage in the sanitation process before it became mixed with other sewage components including feces, chemicals, paper and water because it was anticipated that this method would increase the percentage of urine captured and reduce energy consumption [12].

In order to facilitate this, not only did specially designed urine-diverting toilets (Figure 2) need to be installed at an appropriate site and location, but also plumbing needed to be modified, sampling equipment installed and collection undertaken. Additionally, the project had to develop and implement methods to encourage users to actually try out the new toilets. It then had to build into the broader methodology mechanisms for monitoring users' reactions and their adaptability to the new technology.

Figure 2. Wostman urine diverting toilet used during the pre-pilot trial. Urine is diverted into the front section of the partitioned bowl (*Image: Jennifer Williams*).



In this context, a range of matters were flagged as being potentially important. They included: ensuring that the legal, regulatory and institutional requirements for the installation of such toilets and for the collection and storage of urine could be met; facilitating the uptake of the urine diverting toilets by stakeholders through appropriate and enabling design; monitoring the technical operation of the toilets and users' responses; and analyzing the urine collected. In particular, the research team sought to reveal the "range of independent factors that determine the successful uptake and potential scale-up of radical sustainable sanitation" [13].

Unlike many research projects that only involve academics or rely on the input of a handful of postgraduate students in one discipline, the TSS project incorporated both undergraduate and postgraduate students who were studying courses in a range of disciplines, and at three different universities. Students were a key part of the TSS project; they learnt a great deal and also contributed

to knowledge creation and research. Learning and engagement in the project were associated with the five research strands into which investigators, partners and students had grouped. Because the project was trans-disciplinary, by nature it encouraged intersection and overlap between the strands. The strands were: (1) Regulation and Institutions; (2) Technology; (3) Visual Communication; (4) Stakeholder Engagement; and (5) Integration (Table 1). Three cycles of AR were designed. They were: (a) investigation and design; (b) contract and commission; and (c) operate, monitor, evaluate and decommission. Students had engagement with the project at various phases in the cycles.

This article addresses the question: What lessons have been learnt from engaging university students in a trans-disciplinary ST project, applying PBL and addressing key sustainability issues of the era?

Part One provides a description of where PBL interventions were applied via learning platforms across the three relevant strands of: (1) regulation and institutions; (2) visual communication; and (3) technology. It discusses the intended educational opportunities and then offers an evaluation of what *actually* happened in the instances where PBL was planned/intended to apply. This part, therefore, constitutes a first order reflection. The discussion following in Part Two deals with what could have been done better, providing a second-order reflection. Finally, Part Three of the article offers a holistic reflection across the three strands of the project; a project providing a site for educational innovation within a ST framework and in which the key focus was environmental sustainability.

Table 1. Research strands, disciplines, programs and student numbers (*Table: Jennifer Williams*).

| Research strand | Academic Departments/University | Education Program | Number of students |
|------------------------------------|---|---|--------------------|
| Regulation and Institutions | | | |
| | UNSW Law, UNSW Australia (formerly known as University of New South Wales) Australia | Bachelor of Laws (from a university other than UNSW) | 1 |
| | | Masters in Environmental Law (from a university other than UNSW) | 1 |
| Technology | | | |
| | Faculty of Engineering & Information Technology University of Technology Sydney Australia | Bachelor of Engineering (Civil Engineering): Capstone Project | 1 |
| | | Bachelor of Engineering (Civil & Environmental Engineering): Capstone Project | 1 |
| Visual Communication Design | | | |
| | Faculty of Design, Architecture and Building University of Technology Sydney Australia | Bachelor of Design (Visual Communication): Information Design | 17 |
| | | Bachelor of Design (Visual Communication): Community Projects | 5 |
| | School of Humanities and Communication Arts University of Western Sydney Australia | Bachelor of Design (Visual Communication): Professional Design Studio | 10 |
| Stakeholder Engagement | NO STUDENT INVOLVEMENT | | |
| Integration | NO STUDENT INVOLVEMENT | | |

3. Part 1: PBL Applications to Student Learning in the TSS Project

In this part we outline the innovative approaches to student learning and teaching that were introduced across three of the research strands of the TSS project mentioned above. In particular, we focus on PBL interventions that, although taking different forms in different research strands, were

employed commonly across the project. They were employed to help foster co-operative learning [14], learning by doing [15] exploratory learning [16], social learning [17] and adaptive learning [18] among other things [19]. It was anticipated that such interventions would align well with the ST methodology used in the project; a methodology that we favoured because of its potential to serve students well in a rapidly changing society in which complexity characterizes many human endeavours. The following discussion is organized around the three research strands and outlines more specifically how the learning opportunities in a systems-focused space were designed.

3.1. Regulation and Institutions Strand

Van Buuren and others have noted that the literature on collaborative problem solving is deficient to the extent that it commonly underestimates the role, importance and characteristics of the governance system in which collaborative problem solving is employed [20,21]. The TSS project sought to address such neglect and deficiencies by devoting one strand to governance including regulation and institutional arrangements. The project, therefore, included a lawyer in the research team and it also sought to include the participation of law students in the Regulation and Institutions strand.

Regulation and Institutions Strand (UNSW Researcher—UNSW-R)

It was initially anticipated that in AR Cycle 1 (the investigation phase) later-year law students at UNSW Australia could, through involvement in the Regulation and Institutions strand, participate in the project by undertaking a comparative international review of institutional structures and legal frameworks that have been successfully adopted to facilitate resource recovery and re-use. It was also anticipated that student enrolment in a specific research thesis subject or in an elective—Environmental Law—which permitted students to design their own research task and sub-projects, would be the optimal way to proceed. It was envisaged that learning in this strand would build on PBL interventions employed in law teaching more generally where students are familiar with activities designed to simulate legal practice and legal problems so that, among other things, students learn to “think like a lawyer”. Learning to think like a lawyer commonly involves the ability to “mentally problem solve, ask legally relevant questions and identify legal issues, search for coherence in fact patterns, think linearly, perceive ambiguity, appropriately engage in deductive and inductive reasoning, see all sides of an argument, and simultaneously pay attention to detail while recognizing which issues are more important than others” [22].

It was intended that students in this strand would formulate questions and develop a research framework based on both their direct engagement with the TSS project and their understanding of institutional enablers and blockers evident in comparative, international jurisdictions as well as in the domestic jurisdiction in which the TSS project was to operate. Real-life scenarios would encourage exploration of the nexus between practicum, theory, doctrinal law and institutional frameworks, so fostering and developing positive experiential learning. Student engagement with and involvement in the Regulation and Institutions strand, as in the other strands, was designed to rely on authentic learning, or learning in real situations, rather than purely hypothetical ones.

Authentic learning, which is commonly dependent on PBL (and project-based learning) interventions, involves a range of elements considered relevant to educating the TSS project students about environmental sustainability through a ST approach. It was hoped that the project would:

- Provide authentic contexts that reflect knowledge's use and application in the real world;
- Provide opportunities to undertake real tasks;
- Provide access to expert performances;
- Expose the need to take on multiple roles and or viewpoints;
- Support the collaborative construction of knowledge;
- Promote reflection to enhance the formulation of abstractions;
- Promote platforms for the articulation of tacit knowledge and thereby allow that knowledge to be made explicit; provide scaffolding by the educator at the point of need; and
- Provide for real world assessments of the learning [23,24].

Students were, therefore, to engage with “chunks” of the project depending on the cycle and phase of the project itself. Consequently different students would be dipping into the project at different times but their learning experiences would allow them to appreciate the holistic and integrated nature of the project overall, an outcome it was thought would be largely achieved through open dialogue, group work and regular meetings between different strand participants, along with effective reporting-back practices and procedures.

One key aspect of the plan was to offer the law students the opportunity to conduct applied research that focused on mapping the legal and regulatory framework under which the pilot project and later, non-pilot applications of it, would operate. Hence the law relating to urine collection, storage, transportation, experimentation and re-use, was relevant. The law needed to be laid out and its point(s) of intersection with the project, identified. This was envisaged as exploratory PBL. It was a potentially challenging task because the law governing areas of new technologies (such as sustainable sewage options) is commonly law designed for other more conventional purposes. That law needs to be transposed from one setting and applied in another new (and often unconventional) setting. Hence part of the PBL intervention was to involve students through an exploration of existing law in a range of jurisdictions, determining if that law had application in the context of sustainable sewage. Students were thus confronted with a complex problem that needed a creative approach to understanding and resolution. They had to adjust to the idea that the law was not waiting in neatly packaged compartments simply to be “discovered”. In other words, the PBL interventions were designed to help students “construct” the relevant law.

It was also envisaged that as part of the TSS project and the PBL interventions, students would contribute to the law reform process. They would contribute by assessing and analyzing the legal and governance issues that they, the students, confronted through involvement in the project, coming to conclusions about which aspects of law and governance acted as blockers to and/or facilitators of, the introduction and implementation of sustainable sewage options. Developing law reform initiatives where necessary was therefore, another function of the project and in this aspect, as indeed in many others, the students, were to become problem-solvers.

PBL (and in some instances project-based learning) were to be relied on to encourage students to work out what legal issues were relevant to the technological, design and implementation aspects of

the project. It was anticipated, therefore, that the law students would need to address questions such as the following: (a) what do I know already about sanitation regulation and governance? (b) what do I need to know about sanitation regulation and governance to contribute effectively to this project? and; (c) how might I find out what I need to know? UNSW-R, the academic researcher leading this strand, also intended that students would reflect on the fact that there would be some knowledge that students did not yet know that they needed to know. Some questions might not yet even be imagined. With this in mind it was anticipated that students would embark on their information discoveries and knowledge creation activities.

Accordingly, the project was rich with opportunities for students, including the opportunities to:

- Observe, respond to and analyze the interactions between complementary and competing pieces of legislation;
- Determine, in practical terms, which types of approvals needed to be sought throughout the project;
- Decide how and when such requirements could be satisfied in order best to progress the project;
- Apply the law to practical, real life issues that needed to be managed; and
- Observe and analyze the effectiveness of the institutional arrangements supporting regulation and governance, with a view to suggesting appropriate legal, regulatory and institutional reform.

It was anticipated that students would very much be project “insiders”, working on practical aspects of the study such as contacting government agencies and institutions to ascertain what consent and approval forms were required under legislation as well as interpreting various statutes. It was envisaged that they would also need to work out the interaction between different legislative instruments and the common law. This way, it was hoped that students would receive the full range of benefits associated with legal experiential learning, PBL and authentic learning that took place in an adaptable ST based space. They would “learn by doing”, benefitting from the approach by: taking responsibility for their work; gaining an appreciation of the importance of access to justice while developing professional ethics; and developing an awareness of the limitations of the law and legal practice. Involvement in the project was also designed to teach students civic responsibility and to strengthen communities [19,25]. Further, it was anticipated that student participation would provide a form of *service learning*—a learning and teaching strategy that blends or integrates “meaningful community service with instruction and reflection—[so as] to enrich learning experiences.” Well implemented, it has the effect of teaching students the value of community service and civic responsibility, resulting in strengthened communities [26].

With these objectives in mind there would necessarily be a close relationship between the students in this strand and members of all the other strands but particularly with members of the technological strand. Why? Because students in this strand would, through their legal research, contribute ideas on whether the specific and technical approaches to be employed by the research team were in compliance with law and regulation. Hence, students in this strand would need to engage closely with the plumbers, engineers and designers, for example.

It was always imagined that students would, through PBL, work in groups and break down their engagement with the project into manageable sized interactions, in the same way as doctoral students

are encouraged to think of their theses as a series of manageable chapters rather than one, large, amorphous problem that needs solving [27].

3.2. Visual Communication Strand

It was envisaged that the project would also engage University of Technology and University of Western Sydney students who were enrolled in either third (UTS) or fourth year (UWS) of their Visual Communication Design degrees. The objective of the Visual Communication strand was to design communications that would activate the involvement of participants in the TSS project and engage the imagination of the broader public in the issue of sustainable sanitation. In the well-known words of Herbert Simon; every design project is about converting existing situations into preferred situations [28]. It is important to note, therefore, that design thinking and practice was in synergy with the forward-looking and change-oriented dimensions of the TSS project.

The students would engage with the project through the development of a series of briefs as part of an industry partnership program. The visual tools to be designed would inform users about the “how” and “why” of the systems and develop a means of on-going, mutual communications with users, such as web tools. In keeping with the systems-based approach, students in the visual communication strand would seek feedback on the design elements so as to create improved and revised signage and tools.

Two researchers led the Visual Communication Strand: one each from UTS (UTS R1) and from the University of Western Sydney (UWS-R).

3.2.1. Visual Communication Strand—UTS Researcher 1 (UTS-R1)

The TSS project ran across an academic year in two third year subjects of the 4-year degree program at UTS: Information Design, and Community Projects. In the former, 17 students were responsible for their individually formulated projects; in the latter, a 5-person group collectively produced a body of work, again steering the direction of their project.

In designing student participation in the TSS project for Information Design, the normative PBL approach of presenting the “ill-structured” problem [4,15] to students was tested. Not widely embedded in undergraduate design study—the more directive project-based learning being the model most commonly used [29]—PBL provided the impetus for students to construct their own visual enquiries by actively determining the most significant aspects of a given issue to investigate. The notion of utilizing a PBL approach was drawn from the structure of the TSS study itself, where visual communication was intentionally positioned at the strategic “fuzzy front end” rather than at the more usual production back-end of projects. This placement had the potential to disclose design’s fuller disciplinary capacities, demanding an exploratory, speculative and provocative stance. It also demanded ongoing reflective engagement by the students over the arc of the project, as befitting both PBL and action research models.

Initially informed by subject expert briefings by the TSS project researchers, students framed their own projects through a questioning activity to determine the kinds of interventions that could benefit from design. They needed to be “metacognitively aware” [30] in order to: assess their existing knowledge; the deficit in their knowledge; and then evolve visual strategies in response. In this instance, two entwined issues were identified for enquiry: the global depletion of phosphorus and the rethinking

of human waste as a resource. This more autonomous, self-directed approach was in contrast to traditional models of design education of “solving” pre-framed tasks dressed as “problems”. It mirrors a limiting 20th century view of design as one of service provision rather than as a discipline employing a more expansive, nimble mindset to set agenda in a multi-faceted, trans-disciplinary enquiry where boundaries are fluid.

The TSS project was also foregrounded by a preparatory assessment task introducing students to information design systems, its pioneers, paradigm shifts in the discipline, plus its contemporary expansions, for example, experience design and interaction design. As part of their overall enquiry, students were encouraged to think beyond the comfort of disciplinary knowledge to quickly embrace many aspects of the TSS project; the intention here was to seed the idea of students framing their own projects.

Community Projects, run in the second semester, took on not-for-profit projects selected by UTS Shopfront (a gateway for community access to UTS); the cohort was divided into groups of five who were then allocated a project that is usually tightly controlled by the client. The group taking on the TSS project was advantaged with access to students from the first semester and to their research and projects; they were able to build upon knowledge grown by the first cohort. A key project team member also briefed them on soft systems. Again, they were required to assess critically the TSS research questions, determining where proposed design interventions could have the most traction for their chosen audience, in this instance, the UTS community. Each student was allocated roles within the project, and typical of PBL operating structure [29] the group was deliberately populated with a mix of strong, average and weaker students in order to offer learning opportunities in managing group dynamics, accountability, the giving and receiving of feedback from peers, and growing communication abilities.

3.2.2. Visual Communication Strand—UWS Researcher (UWS-R)

The TSS project was offered as a “Live Brief” to final year students in the Professional Strand of the Bachelor of Design (Visual Communications) degree in the School of Humanities and Communication Arts at UWS.

A group of seven students worked on the brief in the first semester and five in the second semester. UWS-R developed a project brief for students to respond to, and a key project team member based at UTS gave a briefing presentation, explaining the significance of the project in more depth. Students in the Professional Strand work in a studio environment that unlike the traditional classroom involves longer and more intensive periods of experimentation and research through practice. The design studio itself can be described as a problem-based learning environment with its emphasis on collaborative process, the ready application of concepts to practice and the validation of students’ prior knowledge as they work to define the problems in the brief, in their own terms.

PBL is an approach where an “ill-structured” problem provides a stimulus for learning [4] The PBL intervention in the Professional Strand was in the nature of the problem embedded in the brief that students were commissioned to solve. This centered on the problem of “waste = food”. Students had some background understanding of this concept from Braungart and McDonough’s “cradle to cradle” thinking [31], which allowed them to grasp the central rhetorical challenge of the project: how can

design help to recode what had been considered a waste product as a potentially precious resource for use in agricultural applications with a range of direct environmental and ultimately socio-cultural benefits? However, this problem was significantly more complex than those typically structured into curricula in the Professional Strand. Normally, students in this strand demonstrate their “industry-ready” professionalism and technical skills by solving relatively simple briefs in a direct service relation to the client. This is more akin to a traditional project-based learning approach wherein problems are tailored to the students’ current knowledge base and written in a more prescriptive manner [29].

The TSS project provided students’ with a rich “real world” set of problems that activated their critical problem solving skills. The “waste = food” problem demanded a significant amount of theoretical “skilling up” and students had quickly to acquire, share and apply new knowledge as they collaborated with each other to move toward the preferred solutions. Rather than these being decided in advance by the client and presented as a *fait accompli*, the link between critical thinking and action in this scenario came from the students’ own self-directed learning.

3.3. Technology Strand

As part of the undergraduate engineering program, students are introduced to the concept of working on different types of projects in the real world. Some of these projects have defined specifications, or “a brief”, while others are more open-ended. Students learn to deal with different types of projects in subjects such as Design and Innovation Fundamentals and Engineering Project Management. They are also exposed to problem-based learning and finding solutions to ill-structured projects while undertaking discipline-related subjects such as Environmental and Sanitation Engineering, and Pollution Control and Waste Management. Students usually work in groups and are required to undertake needs analyses while considering constraints, uncertainties and risks in order to establish priorities and goals in trying to solve the problem. This prior PBL knowledge was useful in helping students to work on the TSS project.

Technology Strand—UTS Researcher 2 (UTS-R2)

As part of the Technology strand, undergraduate engineering students of Civil and Environmental Engineering majors were considered ideal to be involved in the TSS project. These students are exposed to the theoretical aspects of challenges to sanitation issues, especially with respect to water conservation and resource recovery. The TSS project raised these issues and aspects of the project also related to risks to health and safety; issues with which UTS R2 wanted students to engage.

Students from undergraduate engineering programs and in their last stage of study were selected for this project. One of the key aspects of the project was to select an appropriate site for setting up the urine diversion toilet. As UTS is divided into ten different buildings, one student undertook a detailed survey of each. The data collected included information about space available, traffic movement, proximity to people, layout and water/wastewater pipeline accessibility and other related information. This student also designed a system enabling collection of urine from the UD toilet for sampling and analysis as well as undertaking a detailed literature review of urine diversion technology used elsewhere in Australia and overseas. The second student’s work was related to identifying risks associated with

using urine as a fertilizer, and techniques that can be used to reduce or avoid any risks to people and the environment.

In all cases students were encouraged to become part of the “would-be problem solvers” who intended to take purposeful action to address a “problematic” situation [32]. Academics also saw student involvement in the above-mentioned ways as assisting the mutual reinforcement of “institutional and socio-cultural transformations including new infrastructure planning processes, enabling regulatory and legal frameworks; and altered user practices” (Sankaran *et al.* [32]) [33].

In keeping with a systems-based focus that was embedded in the AR methodology, flexibility and re-orientation were to form key elements of the teaching/learning pedagogy informing student involvement—involve ment that relied heavily on PBL. It was considered important to be able to adjust learning and research objectives, initiatives, directions and models throughout the project so that they better responded to developments that emerged. Such flexibility proved to be a very useful element of the methodology and as the discussion below indicates, ultimately permitted enhanced learning and research outcomes.

The following outlines more specifically how the learning opportunities in a systems-focused space were set up, particularly opportunities for PBL interventions.

4. Part 2: Evaluation of What Happened in Relation to the PBL Interventions in the TSS Project

As with many initiatives much happened “betwixt cup and mouth” and the student education component of the TSS project was no exception. This part of the article, therefore, takes the educational initiatives discussed above in Part One and evaluates them by discussing what happened according to plan and whether there were any surprises.

4.1. Regulation and Institutions Strand—UNSW-R

Very little happened according to plan in relation to student engagement in this strand of the project.

The opportunities for PBL (and project-based) interventions in this strand evaporated dramatically when no students at the relevant investigator’s university took up the opportunity to be involved in the TSS project by enrolling in a course which would have accommodated the TSS project’s learning experience. This outcome was largely the result of timetabling issues, which meant that no relevant environmental law courses (either undergraduate or postgraduate) were on offer at the right time to align with the AR cycles.

As a result, evaluation of the planned PBL interventions became difficult, but not quite impossible, to undertake. Why, not quite impossible? Because there was a surprise—an unintended happening which the AR model allowed the project to accommodate. The surprise element was the unexpected involvement of two students from a non-participating university. As a result of their involvement some evaluation of the PBL interventions in this strand became possible.

It is perhaps useful to appreciate how those two students came to be involved in the project and in what capacity, in order to understand some of the constraints that were imposed on their participation and engagement with the project. Their status arguably had some bearing on the evaluation of their engagement.

UNSW-R was contacted by: (1) an undergraduate law student, at a different university, who was keen to become a legal academic intern for a session; and UNSW-R was also contacted by (2) a postgraduate student, who was keen to use the TSS project as an example of applied research, for a Masters in Environmental Law, at an unrelated institution.

With the permission of the relevant academic administrators, UNSW-R supervised both interns as part of their university placements. With the interns' agreement, they were assigned to work on the TSS project. However, neither intern's progress was to be assessed and evaluated by the quality of her research alone nor by the skill with which she managed the PBL interventions but rather by other factors considered relevant to the effective completion of an internship, including the sufficient manifestation of attributes such as co-operation, diligence, commitment, punctuality, team-work capacity, ability to accept supervision and ability to assume responsibility, for example—all commendable assets but not necessarily the same attributes as the PBL intervention sought to foster. Hence there was a dissonance between evaluating the effectiveness of the intern's performance *qua* the internship and evaluating the effectiveness of the PBL interventions *qua* the teaching and learning methods by employed the ST based project. With these caveats in mind the following evaluation of the PBL applications' effectiveness is explored below.

UNSW-R initially encouraged the undergraduate intern to reflect on what she already knew about governance of the relevant field, recognizing that we "come into the world already theorizing" and that we bring some existing knowledge, no matter how little, to just about all that we do [34]. Basing PBL involvement on this supposition was designed to encourage the intern to see that she was not starting her research from a palimpsest—she could take comfort in the fact that she knew something from the outset. However, the approach was not entirely successful. The intern found it difficult to conceptualize what she knew already as being, in any way, relevant to the TSS project and consequently the (recognition of pre-existing knowledge) approach served to intimidate her, causing her to feel overwhelmed by the research task that lay ahead. Instead of taking "ownership of the project", the intern responded by seeking to transfer responsibility to UNSW-R with the intern asking questions such as, "What do *you* want me to do?" "Can *you* explain the law to me?" "What do I do today?" Review sessions regularly saw the intern responding that she simply did not know the answer and seeking teacher direction rather than teacher facilitation. When suggestions were made as to how she might frame relevant questions to assist progress, the intern resisted—not because she was difficult or cantankerous—but more because the internship was proving not to be of the nature that she had expected. There was an insufficient alignment between: (a) the intern's expectations about what embarking on an internship with a legal academic would mean, and; (b) the reality of participation in a ST project that relied on high levels of student involvement and the employment of problem solving, decision making and investigative activities. These participatory elements together with the relatively autonomous student learning environment that existed—all of which are hallmarks of PBL and project-based learning [35,36]—were not what the intern thought she had bargained for.

In evaluating what actually happened in terms of PBL implementation in this strand, it is relevant to turn to the issue of skills development. Communication skills that would assist in the creation of new environmental sustainability knowledge were skills that the project sought to develop in its student participants. In this regard, intern 1 (the undergraduate intern) was encouraged to reflect on the benefits of liaising with the project's industry partners with whom she could engage, in order to assist

the development of a review of alternative sanitation options already in operation in Australia (e.g., waterless urinals). Industry partners' technical expertise could inform and enhance the development of legal knowledge in the sustainability realm and a reciprocal connection between problem solving and the surroundings to which the problem solving is connected could be established [20]. However, as de Jong and Boelens have pointed out (by reliance on the Alders table) mere recognition of the connection would not necessarily solve the political deadlocks that may ensue in relation to collaborative problem solving [21]. Greater attention would also need to be paid to "the decisive agency of new and evolving technologies within the entangled networks of sociality and materiality resulting in unprecedented, non-linear and fuzzy political problems" [21]. Given that the TSS project is a clear example of a new and evolving technology embedded in sociality and materiality, de Jong and Boelen's words arguably carry considerable force.

Aside from these theoretical concerns, there were also discipline-based concerns that arose in relation to intern 1's potential dialogue with industry partners. Oral feedback revealed that, part of the intern's reticence in pursuing dialogue with industry partners arose from a presumption that any such dialogue would be closed and limited by discipline-based thinking with which she was not familiar and where "involved actors" with "their own meanings and values that are fixed and securely anchored in their own contexts and interest, as in the histories of their surroundings" would prevail [21]. She thought it would be not unlike Hommels' description of "situations in which planners, architects, engineers, technology users, or other groups are constrained by fixed ways of thinking and interacting" [37] that may, in turn, lead not to "support and resilience solutions" but rather to "political deadlocks" [21].

Further, another limiting factor was the student's innate (or perhaps socially constructed) personal timidity and lack of confidence to make the necessary telephone calls to industry partners. She feared that her ignorance could be revealed and that embarrassment would ensue. Suggestions as to the benefits of scripting telephone conversations prior to making calls were not a success. The intern resisted and instead reverted to requests for teacher direction and teacher explanation. The attempt to introduce discovery learning through PBL was seemingly affected by the same difficulties as those described by Blumenfeld *et al.* [38]. They referred to the poor uptake of hands-on learning opportunities resulting from the relevant program not being sufficiently based "on the complex nature of student motivation and [the] knowledge required to engage in cognitively difficult work". They concluded that the lack of widespread acceptance of early discovery learning curricula was associated with insufficient attention being devoted to the students' viewpoint [38].

Additional opportunities for face-to-face and/or remote teacher-student engagement were not taken up and despite the provision of some initial references [17] designed to kick-start the research, the intern found it difficult to "own" the project in meaningful ways and to engage with the relevant field of law. In particular, she was uncomfortable with the notion of speculative responses. She instead, far preferred concrete outcomes. The flexibility, doubt, speculation and tentativeness that came to be associated with learning in the TSS project proved particularly challenging and UNSW-R greatly underestimated the implications of this.

Further, if evaluation of the PBL intervention were, in part, at least, also to be based on authentic assessment outcomes [39,40] then it would have to be said that the intervention was not highly successful. It did not deliver the desired outcomes. By the end of the internship, no framework for the governance of the relevant elements of the TSS project had been formulated by the undergraduate

intern under UNSW R's guidance. Some aspects of the framework had been uncovered but the overarching picture was still missing and no roadmap had been worked out which covered the existing plumbing codes of practice, guidelines, policies, legislation and regulations that operated to help manage the implementation of the TSS project.

The second surprise in the project (referred to above) was the involvement of a second student (Intern 2), not associated with a participating university. Intern 2 was enrolled in a postgraduate law degree (but not a professional law degree) and did not hold an undergraduate law degree. Although the trend to introduce non-professional postgraduate law degrees has many advantages, the intern's inexperience with black-letter law research, proved challenging for the student and disappointing for some of the project participants. While this particular intern clearly had some expertise in policy-oriented research, she was fairly unfamiliar with the range of, and the extent to which she would have to engage with, legal databases and employ fundamental skills such as those of statutory interpretation for example, if she were to participate effectively in her experiential learning opportunity.

Engaging with Intern 2 involved detailed reviewing of her hard copy work, suggesting outlines and planning frameworks, as well as guiding her towards specific legislation *etc.* An AR approach to such learning and teaching permitted an ongoing evaluation and re-evaluation of what was possible and not possible in the circumstances. Accordingly, the goals initially imagined needed to be re-set and re-determined. This proved to be one of the very positive aspects of employing PBL within a ST framework. While there were practical problems associated with generating the anticipated type and levels of research in this case, the SF framework, in which the PBL took place, proved to be a real asset in helping to educate for a sustainable planet.

4.2. Visual Communication Strand—UTS-R 1

The normal internal structures of both subjects needed some juggling to accommodate the flexible framework in which the TSS project would ideally operate. This was principally due to prescribed learning outcomes and time constraints imposed on subjects. Project design to this extent was unknown in the students' prior learning, and in their 4-year course, is only introduced in the final year of the program, though still highly scaffolded. Less travelled ground was PBL: encouraging students' autonomy and self-direction, providing a good degree of "intellectual space" to draw out and shape key communication issues, determining the most appropriate vehicle (media) and visual language best suited to carry content (also created by students). In practical terms this meant that students were far more responsible for a greater array of design decisions than the lecturer/client-driven brief might provide. They were asked to think and work more speculatively. For some, it was liberating, allowing them to move across disciplinary boundaries; for example, one student drew heavily on "experience design" and "fun theory" leading him to seek out advice in interaction design from specialists in the Architecture faculty. He had designed a heat- and motion-sensitive installation to explain "closing the loop" nutrient recovery cycle (Figure 3). Another student consulted with IT post-graduate students to make sense of speculative concepts for measuring usage of UD-installed toilets. Still another used burgeoning skills in motion graphics to develop a substantial animation piece explaining peak phosphorous and asking the UTS community to use the UD toilets; the work ultimately netted him a Gold AGDA Award—AGDA being the peak professional body of the Australian Graphic Design

Association—and representation at the annual Society of Responsible Design's "Change" exhibition. Others created environmental graphics in toilet cubicles to explain the user's role and import in donating their urine.

Figure 3. "Thank you for your pee" heat sensitive sticker, a still of "closing the loop" cycle, and *in situ* as motion sensor lightboxes in front of urinals (*Designer: Jethro Lawrence, UTS*). Reproduced with permission from [41], published by Elsevier, 2012.



These types of students—highly intelligent, engaged, independent learners with excellent visual and aural communication skills—embraced the self-directed nature of PBL, though they still needed substantial guidance in constructing the parameters of their projects. However, this level of work required far more time from both students and UTS R-1 than the subject was designed to accommodate. As a result, and due to the commitment of all parties, work moved well beyond arbitrary timeframes imposed by the university timetable. Other students, though, were bewildered by blurred boundaries, finding comfort in designing familiar artifacts of limited value, such as posters and paper sculptures; this response was also to be expected. Some of the work was thoughtful and effective. Overall, the more successful work—"successful" in this instance was defined by identifying a need for communication between potential users using appropriate research methods, through to designing understanding and utilizing a visual language that would meet that need—from both cohorts was borne from expansive engagement with issues presented by the TSS project; the least effective work, unsurprisingly, defaulted to aesthetics and conventional typologies, such as branding, rather than communicating more pressing and relevant issues of concern.

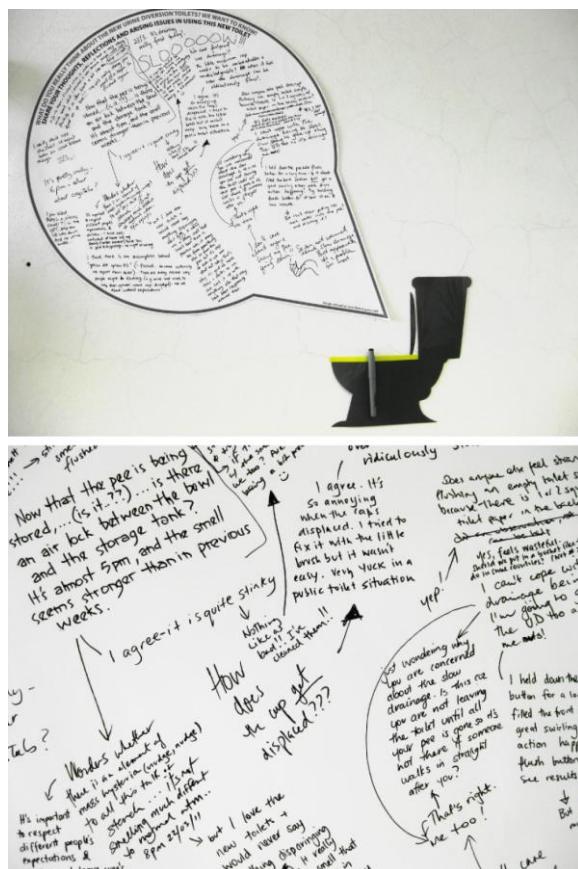
The mentoring of the second cohort by several members of the first group was completely led by the students. The latter had become "subject experts" in extracting and navigating significant issues to address. So while the new cohort had access to TSS personnel, of equal import were the experiences

and work previously produced by their peers, an informal kind of knowledge transfer and certainly true to PBL goals. Instead of thinking in subject silos and designing afresh, the new group built upon the first semester work, incorporating a bank of graphic symbols as well as furthering initial concepts. From there, they designed a system for whole-of-campus engagement with the testing of UD toilets that ranged from a re-thinking of “waste as resource” through to measuring usage of UD toilets and speculating on what the collected urine could actually yield in terms of produce.

4.3. Visual Communication Strand—UWS-R

The brief offered students a range of possibilities to pursue, including: the creation of a visual language for the story of “P” that could be used to “prime” audiences ahead of the trial; the creation of a modular visual identity for the project that could be used across a range of platforms; the creation of *in situ* signage to facilitate user adaption to the new technology (Figure 4); and the development of social engagement tools to elicit feedback and responses from end-users of the system. Students spent the first couple of weeks developing their contextual knowledge, working their way through the provided “starter” resources and exploring various visual approaches in relation to these possibilities. While it took longer than usual for students to claim ownership over the problems, the PBL approach saw students successfully directing their own learning on a “need to know” basis in the process of developing concepts, which Duggan and Dermody [29] refer to as “just-in-time learning”, with instructors taking a facilitating rather than directive role.

Figure 4. Graffiti board *in situ* and detail (*Designer: Yana Mokmargana, UWS*). Reproduced with permission from [41], published by Elsevier, 2012.



At the half-semester point, two key researchers based at UTS visited UWS for a client briefing session. Students presented their working concepts to the researchers that included a visual identity incorporating the closed loop of nutrient recovery and reuse and signage to encourage correct use of the urine diverting toilets. The researchers were invited to provide comment and feedback, and after some reflection, select preferred concepts. The plan was for students to “work up” these selected concepts for the remainder of the semester, for use in the trial.

In the second semester students developed on-demand communication tools such as the graffiti board that gathered social data across 26 weeks of the trial. It was empowering for students within the Professional Strand to see the impact their work could have beyond delivering on the stated requirements of a client brief. In a project as multidimensional and forward thinking as the TSS project, design became a critical tool for promoting ecological literacy and social learning. A value of PBL in a studio context was that it facilitated a constructive relationship between design and research, rather than research being “contextually severed” from the practice environment [29].

4.4. Technology Strand Evaluation—UTS-R2

Civil and environmental engineering undergraduate students were also selected to be part of the TSS project. Following PBL interventions it was envisaged that these students would employ “learning by doing” [15], by “exploratory learning” [16] and “adaptive learning” [18]. In order to foster those approaches, it was important to select students with the appropriate skills to work on the TSS project—a more open-ended enquiry, especially with respect to the Technology strand. For this purpose, the project was discussed within the Faculty of Engineering and Information Technology (FEIT) after which information sessions with students were established; these garnered keen interest from some students. While each undergraduate engineering student is required to undertake a six or twelve credit point capstone project—to be completed either in one or two semesters respectively—discussions with students revealed that not all had the requisite skills to undertake the extensive research aspects required by the project. One particular student, however, stood out and went on to be involved in the initial phase of the project where different sites were being sought to locate the urine diversion toilets. This student was also involved in identifying different designs used to set up systems so that urine samples could be collected for analysis. Other students were “interviewed” by a wider project team and were considered as not having the capacity to undertake the project. One of these students however, went ahead to complete a desk-based project highlighting the risks of resource recovery.

It was observed that all students involved in the Technology strand of the TSS project benefitted from PBL by “learning by doing” [15], “exploratory learning” [16] and “adaptive learning” [18]. The project aims were quite open-ended where students had to use design and technical skills acquired in other subjects together with their own experience to find appropriate pathways leading to a solution. Students also had to work in an environment where they had to consult, communicate and work with trans-disciplinary team members. This challenged them to work out of their comfort zone and helped them to gain important life-long learning skills. Overall, it can be said as part of the Technology strand the PBL interventions were successful. The reasons that the students were able to be engaged in the project were due to the initial dissemination of the objectives of the projects; proactive discussions by the project team; engagement of the project team in student discussions; and evaluation of student

work. It was not possible to involve more students throughout the different stages of the project due to the following reasons: (a) student engagement required involvement, time, and education; (b) not all students were found capable of undertaking research at the level that the project team expected; and (c) the objectives of the topics that the students wanted to undertake did not completely align with the objectives of the project.

5. Part 3: Discussion of What could have been Done Better

5.1. Regulation and Institutions Strand

Regulation and Institutions Strand—UNSW-R

Participation Entry Requirements

In retrospect, more rigorous and project-specific screening processes for student participation in the TSS project would have been prudent. Evidence of a willingness to engage with a ST-based approach and an interest in sustainability issues should have been seen as obvious pre-requisites for participation in this strand, but because of the difficulties involved in attracting students referred to above, they were not so seen. Tough decisions about the suitability of students to the project needed to have been made but instead the driver of necessity prevailed. When it was feared that there would be no student participation at all in this strand, checks and balances for participation were largely waived and a very flexible attitude to involvement was embraced.

The planned system whereby students were funneled into the Regulation and Institutions strand via their enrolment in feeder elective subjects failed to yield students because, as noted, the timing of relevant, elective subjects did not align satisfactorily with the timing of the AR cycles. Whether this problem could be resolved in the future remains uncertain.

Copyright Issues

Another issue, which the benefits of hindsight suggest is worth ironing out before student involvement begins, is, in fact, a legal issue. It is the question of who owns the copyright in the research produced by an intern who is not associated with any of the participating universities? This is a similar, or at least related, question to that which arises in regard to academics' own research where that research is undertaken under grants involving industry partners. If the TSS project or a similar project were to run again, it would seem wise to seek an assignment of copyright at the point any parties joined the project. This may take some negotiating between institutions but is contractually possible and could, in some circumstances, greatly enhance the benefits and outcomes of the project.

A Different Attendance Model for the Undergraduate Intern Participation

Implementation of the PBL approach within the ST framework may have been more effective if the undergraduate internship had been designed to operate over several shorter periods during the week rather than over one whole day a week. Smaller/shorter interactions with the project and UNSW-R arguably may have created better opportunities for positive reinforcement and provided a more

effective space for the absorption, calibration and recalibration of ideas; the latter being a fundamental aspect of ST. Greater opportunities for confidence building may have been another outcome of a revised attendance model because the project would possibly not have seemed so daunting if engagement with it was more often and in shorter bursts. When the project was isolated to a particular day per week the intern was less inclined to discuss issues with UNSW-R, set short-term goals, test propositions, evaluate them, and re-set goals and methods *etc.* Instead the intern set “big goals” because she had “big” workdays. When she could not achieve the outcomes set, she became dispirited and was inclined to relinquish responsibility, shifting it to UNSW-R. In retrospect, it may, therefore, have been more fruitful to employ a different attendance model. More emphasis would have been placed on the need for regular (perhaps daily) interactions with the teacher/supervisor, bearing in mind that such interactions needed only to be brief.

Alignment Issues—Methodology, Framework, Intervention and Skills Development

Some aspects of the AR methodology, the ST framework and the PBL interventions on which the project relied to educate students in the environmental sustainability sphere, appeared (superficially at least) to run counter to the actual skills that the project sought to develop and embed. For example, the project, in part, sought to teach law students to think linearly but it simultaneously employed PBL interventions in a ST framework that caused students to think non-linearly about sustainability issues. Under the ST framework students became experienced at finding only half the answer to a question or problem before moving to another question, only to return to the original question at a later date. They were forced to weave their way in and out of a labyrinth of regulatory and governance material, learning to bind half threads of thoughts and roughly hewn knowledge together in their quest for a coherence of fact patterns and to determine the ways in which the law applied to these facts. The employment of this non-linear approach to learning and teaching seemed to the interns to be at odds with the deductive and linear reasoning that the project, in part at least, sought to develop. There was a purported disconnect between the tools of teaching and the desired project outcomes. To the students (but not the educators) that was potentially confusing.

In retrospect, it may have been better to highlight the seeming contradiction between the PBL interventions within the ST framework (that is methodology and applications) on one hand, and the desired learning outcomes on the other and then to explain how these purported differences may be reconciled. Were this project to be undertaken again, better explanations would be given at the outset. As it was, however, student involvement of the nature that finally occurred was not planned and, therefore, was not as well integrated as it might have been.

The Law, the Limits of Student Participation and Unrealistic Expectations

Finally, in order to provide improved learning spaces for students, particularly interns whose learning involves legal research, it may also be useful to explain more effectively the nature of legal research and legal knowledge not just to the interns themselves but also to other investigators involved in the project. This suggestion is made because academics, like many others, sometimes tend to work in silos and do not necessarily understand the opportunities and constraints that exist in specialisms outside their own experience. As a result, a lack of understanding may give rise to unrealistic

expectations of an intern from other researchers who do not share or adequately appreciate the intern's specialism. For example, in the legal domain, non-lawyers commonly think that the answer to a legal question already exists and that it is simply a matter of looking up legislation or a case and the answer is evident. Sometimes that is so but more commonly and particularly in relation to the law governing new technologies, the law has to be cobbled together from pre-existing law that has been designed to cover very different purposes and circumstances. Finding out whether there is already law governing a situation and what that law is, may involve detailed and complex research into cases in a number of different jurisdictions on varied topics, as well as the identification and interpretation of a range of interlinking statutes, regulations and other environmental assessment instruments, for example. Making all project participants aware of such issues may mean that interns/students do not bear the burden of unrealistic expectations. That is not to infer that any such difficulties, actually, arose in this project. It is, however, relevant to the question of what would be done differently next time—how things could be improved. In that regard pre-empting the likelihood of siloed knowledge and the unrealistic expectations which may go with that, would be likely to assist this or similar, future projects. Such awareness would potentially further enhance the breaking down of barriers across disciplinary boundaries, a key tenet of the TSS project.

5.2. Visual Communications Strand

5.2.1. Visual Communication Strand—UTS-R1

Not all students are capable of working in this field. Careful consideration needs to be given to recruiting student participation in trans-disciplinary work, how it could integrate with more traditional structures of university education as well as offering preparatory pathways to fully engage in such an opportunity. For projects such as the TSS project, there is a need to move beyond the arbitrary confines of both discipline silos and subject timeframes and towards a space that is year-round, physical as well as virtual, and multi-institutional.

The Achilles heel of visual communication design—privileging the aesthetic—was also in play throughout the TSS project. Some artifacts were self-indulgent, of questionable import to the overall goals of the project, and served primarily to display the technical prowess of the designers at the expense of communication. The idea of the “beautiful object” had, in essence, seduced them. It was safe and familiar territory. This comment arguably speaks to the current state of the discipline itself, still finding its way to greater capabilities. In the case of some students from the first semester cohort, the aesthetic response using traditional typologies was a refuge from the complexities of research demanded of a trans-disciplinary project beyond their capabilities at that stage of their development.

Giving students more guidance in asking the right questions is also key. The nature of action research and trans-disciplinary design is an unknown proposition to most design education activities, particularly at undergraduate level, as is privileging the “speculative prototype” as a legitimate outcome in itself. It is typical in visual communication design that only the commercially fabricated artifact is of value. However, working in a strategic space also yields an outcome, sometimes made tangible through an artifact or visualizing a system, and at other times through the interrogation of existing norms that mold a project differently.

5.2.2. Visual Communications Strand—UWS-R

As is common in PBL contexts, the learning outcomes become far more apparent at the end of the process rather than during it [29]. Students often felt out of their depth in the process, even though several student works from the TSS project were selected for exhibition in the Society for Responsible Design's graduate sustainable design exhibition and competition, "Change"—a clear measure of success.

Probably the key lesson from the application of PBL in this project is that students need more opportunities of this kind throughout their degree. The metaphor of the springboard is often used to describe the capacity of PBL to promote self-directed learning by immersing students in a complex situation that requires that they "define their own learning needs" [5]. This approach makes an important contribution to professional design education as critical problem solving skills and self-directed learning are increasingly valued graduate capabilities. The more traditional approach of project-based learning inducts students into design as a predominantly client-serving profession. However the professional landscape is changing. The multidimensional problems of the contemporary context, such as those embedded in the TSS project, push designers decisively out of their traditional client-serving role at the back-end of a design process into positions of leadership and concept generation at the front. A PBL approach helps to equip students with the knowledge and skills appropriate to respond to, and positively influence that context.

6. Technology Strand

Technology Strand—UTS R-2

Participation Entry Requirements

It was envisaged that more than three students, at different levels, would be involved in the project. However, as the TSS project "evolved", it was difficult to ascertain the entry requirement or what attributes students should have before they undertook the project. Nevertheless, students were interviewed prior to being engaged, and it was found that some students did not have sufficient "research skills" to participate in the project. This issue could be dealt with in a better way by identifying and specifying what attributes students should have, and disseminating this during presentation to students.

Conflict of "Time" Requirements

As student engagement required a considerable time commitment by the project team, continuing to engage students in the trial on the terms employed in this strand, proved not to be feasible on an on-going basis. One major drawback of the way students engaged in the project was that the same students did not continue throughout the project. As part of the undergraduate engineering program, students are allowed to undertake either a 6 months or a one-year project, while the main TSS project had a life span of 3 years.

The plan was to involve as many undergraduate engineering students as possible during every stage of the project. However, ultimately it was only possible to involve one student in the initial phases of the project and another student during the second stage of the project. If this "time" conflict could have

been addressed at the proposal stage of the project, and attended to during the initial phases, we believe more students could have actively participated.

7. Towards Defining “Best Practice” in Trans-Disciplinary Projects

It is evident from the discussion above, that trans-disciplinary projects applying PBL, particularly in the sustainability context, still represent virgin territory, with “best practice” yet to be established. While there were several examples of progress, much exploratory work remains from at least two major perspectives. They are:

- (1) Loosening arbitrary business-model university structures—such as time, money, competitiveness—in order to accommodate genuine collaboration in the search for new knowledge;
- (2) Excavating the trans-disciplinary project itself in terms of how to plan engagement, as well as select and prepare students.

These thoughts are expanded upon, below.

7.1. Time Commitments for Academics

In several strands, the issue of the labor and the time-intensive nature of student engagement with the TSS project came to the fore. The *quid pro quo* was questioned. In the Regulation and Institutions strand, for example, one of the internships unfortunately came to an end before very much had been achieved. This was disappointing for UNSW-R, the intern and any other team members dependent on anticipated, specific, research outcomes. On reflection, it would have been better if all parties had been able to ascertain, in more realistic terms, how much of a time commitment the TSS project would require. The situation was similar in the Technology strand. While the yield of work was strong in the Visual Communication strand, the time commitments for both academics and students also increased due to the demands of trans-disciplinary inquiry.

Whilst the academics supervising students in this project remained strongly committed to student engagement, acknowledging opportunities for independent learning and greater levels of inquiry, they, over time recognized that experiential, authentic, problem-based learning, as detailed above, places considerable demands on their resources. Those time constraints coupled with the fact that Australian universities presently operate on funding models which have seen reduced contributions from government and a consequent pressure to self-fund, also suggest that the likelihood of academics embedding experiential approaches to teaching and learning may diminish.

To explain, budgetary austerity, high student numbers and the resultant workload pressures arguably encourage the retreat to teaching and learning approaches which are less demanding on academics, less experimental and less focused on learning by doing. The tendency may be to opt for more time- and cost-efficient interventions, irrespective of their pedagogical strengths and weaknesses. One result may well be that large cohorts of students move through their university experience having been exposed to few interactions with PBL, self-directed learning and ST. If students are ultimately confronted with such exposure, it may come as a shock, being perceived as foreign, unfamiliar and frightening. They will not have been previously well acculturated to the style of learning and may find the exposure challenging in the same way as did intern 1 in the Regulations and Institutions strand of

the project. However, the benefits of learning by doing, particularly when coupled with an AR approach are potentially great. AR permits for example, recalibrations and adaptations to accommodate better new or changed circumstances. It is reactive to events, permitting contextualized responses crafted to accommodate changed/changing circumstances and it would be disappointing to see such opportunities diminish.

7.2. Competitive/Uncollegial Practices

Unfortunately, in at least one instance, some uncollegial practices impacted on the project at a university level and served to hamper the effectiveness of student engagement. Competition between universities, a lack of understanding about the nature of the TSS project and a lack of collegiality may have been responsible for the necessary range of resources not being available to the relevant students. Where universities choose to emphasize market-based business objectives (relying on competition) in favor of educational drivers, such outcomes are arguably more likely to result.

7.3. Formal Student Evaluations

Although a final, reflective face-to-face interview was undertaken with intern 1 in the Regulation and Institutions strand, it proved impossible to undertake the same with intern 2. And in the Visual Communication strand, while formal university-led student evaluations were undertaken at the end of each semester and with excellent results (for example, 4.25/5.00 for Information Design (UTS)), their generic nature did not generate enough detail to inform future iterations of trans-disciplinary work. Were this project undertaken again, with the benefit of hindsight, the inclusion of more formal, written evaluative reflections from all students would be incorporated across all strands and at various intervals. By necessity these would need to be tightly drawn to reflect the trans-disciplinary demands of engagement.

7.4. Energy, Momentum and Positivity

One very positive outcome of the TSS project was that it forged on itself, irrespective of the less than optimal results in some strands. For example, in the Regulations and Institutions strand it forged on by reliance on the *ad hoc* assistance of some of the plumbers and other technicians involved in the project who had some ideas on how approvals should be sought and to whom parties should speak inside institutions. Indeed the way the broader project team worked its way through the regulatory, governance and compliance web seemed to replicate what individuals or small businesses (without legal teams) might have to do in the real world. Key members of the project team rang friends, contacts in government departments, councils and other agencies as well as contacting skilled tradespeople. They sought advice and pooled information. Some information was supplied officially and other information, unofficially. The end result was that there was sufficient compliance to satisfy regulators and approving agencies although planning for future obstacles was made difficult when “unknown unknowns” emerged. Although unintended, the project team had unwittingly put itself in the shoes of ordinary people and businesses that seek to engage with the legal and regulatory framework. Consequently, the project team experienced first-hand some of the barriers and facilitators

relevant to the uptake of the urine diverting toilet technology. The energy and passion associated with the project, drove it. The ability of researchers and industry partners to work within the interstices demonstrated a powerful resilience that arguably was encouraged by the flexibility of the ST framework.

7.5. *Contextualizing and Planning Student Involvement*

The project was exciting due to the participation of the large number of stakeholders. It provided a good opportunity to test an AR-based approach because of the diversity of the group. However, as not all researchers were involved in the leadership of the project, it was hard to gauge at what stage the project was or where it was going. Student engagement was discussed neither at length nor formally in the planning stage with some of the researchers. As such it became difficult to contextualize student participation from the beginning to the end of the project. In any such future endeavour, it would be more effective to identify at least the type and number of student projects as well as time and resource commitment anticipated by the research project team. There would also need to be discussions about the level of student capability and the project members' expectations of students as well as the extent of student outcomes to be utilized in the project.

One other aspect to consider is the development of strategies to enable students from different strands to interact and learn from each other. Under the model used in the TSS project there was no opportunity for this. More rigorous initial planning in this regard would have been quite valuable. It would also enhance any future collaborative projects. Finally, the facility to include student reflection as part of the project outcomes would have been a helpful evaluative tool. The addition of an Education strand could alleviate such concerns, and set in motion a deeper, more demanding form of learning for participating students that could be transferred into further study and to industry.

8. Conclusions

In conclusion, this article has sought to reflect on the lessons learnt from the application of Problem Based Learning (PBL) within a Systems Thinking (ST) framework employing Action Research (AR) as the methodology. Its focus was on a trans-disciplinary research project involving a subset of university students and conducted across several universities and partner institutions in Sydney, Australia. It was designed to overcome the narrow and arbitrary delineations imposed by discipline boundaries, and hence deliberately brought together a trans-disciplinary research team, including academics engineers, lawyers and designers as well as technical staff. Importantly, it also incorporated a number of students from a range of disciplines who were either enrolled in courses taught by the relevant academics or associated with those academics in some other way, such as through internship programs. Student engagement has formed the key focus of the discussion in this article.

The academic investigators forming part of the wider research team were particularly conscious that didactic, autonomous, discipline-based courses rarely seek to foster an advanced social networking culture among students; a culture which is commonly credited with promoting deep learning. This project, therefore, sought to extend the trans-disciplinarity of the academics and industry partners involved, to student involvement in the project. Hence, a number of students from a variety of disciplines contributed to the advancement of the project by undertaking learning tasks that it was anticipated would inter-link, reinforce and engage with the work of a range of academics, industry partners and

other students. The tasks in which students were involved both cultivated and relied on an organic and adaptive approach to learning. The ST based approach employed by the research investigators was applied to the teaching and learning experiences offered to students.

The Transitioning to Sustainable Sanitation (TSS) project was premised on the pedagogical view that effective learning commonly involves *doing*, which many disciplines within the traditional curriculum development rarely incorporate, preferring instead to keep students as outside observers who learn passively rather than actively. As a result the article outlined and analyzed the effectiveness of various PBL interventions across a number of organizational strands within the ST framework. It also reflected on how effectively implementation of the project incorporated opportunities to revise, refine recalibrate and re-set direction—all of which are hallmarks of ST based approaches.

Implementation of the project revealed various problems, including the rigidity that tight, forward, course planning dictated, at times leaving little room for adjustment, change and experimentation in response to unanticipated situations and consequently foreclosing opportunities for creative, positive pedagogical initiatives. However, the overall conclusion is that despite problems associated with timetabling, the number of students involved and participation entry requirements for example, the project still created some very successful spaces for creative student engagement which promoted deep learning and sophisticated intellectual interactions in the sustainability sphere.

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Author Contributions

Janice Gray is the lead author of this article. She managed the authorial team and was responsible for the sections on Regulation and Institutions. She was also responsible for the Background section, the introductory material in the PBL Applications to Student Learning section and the Conclusion. She was the primary author of the Towards Defining Best Practice Section (with some assistance from Jennifer Williams). Janice was also the primary authorial editor and Jennifer the assistant authorial editor. Jennifer was responsible for the Visual Communications sections that pertain to UTS, the graphic treatment of Table 1, as well as Figures 2 and 3. Prasanthi Hagare was responsible for the Technology sections and contributed to the text of Table 1. Abby Mellick Lopes was responsible for the Visual Communications sections pertaining to UWS and Figure 4, while Shankar Sankaran was responsible for the Introduction section, Figure 1 and overall guidance on Systems Thinking.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Checkland, P. Soft Systems Methodology and Its Relevance to the Development of Information Systems. In *Information Systems Provision: The Contribution of Soft Systems Methodology*; Stowell, F.A., Ed.; McGraw Hill: London, UK, 1995; pp. 1–15.
2. Savin-Baden, M.; Howell, M.C. *Foundations of Problem-Based Learning*; The Society for Research into Higher Education & Open University Press: Birkshire, UK, 2004.
3. Barrows, H.S. Problem-Based Learning in Medicine and Beyond: A Brief Overview. In *Bringing Problem-Based Learning to Higher Education: Theory and Practice*; Wilkerson, L., Gilselaers, H., Eds.; Jossey-Bass: San Francisco, CA, USA, 1996.
4. Boud, D.; Feletti, G. *The Challenge of PBL*, 2nd ed.; Kogan: London, UK, 1997.
5. Rangachari, P.K. Twenty-up: Problem-Based Learning with a Large Group. In *Problem-Based Learning to Higher Education: Theory and Practice*; Wilkerson, L., Gijselaers, W.M., Eds.; Jossey-Bass: San Francisco, CA, USA, 1996.
6. De Graaff, E.; Kolmos, A. Management of Change: Implementation of Problem-Based and Project-Based Learning in Engineering; Sense Publishers Rotterdam: Rotterdam, The Netherlands, 2007.
7. Savin-Baden, M. *Problem-Based Learning in Higher Education: Untold Stories*; SRHE and Open University Press: Buckingham, UK, 2000.
8. De Graaff, E.; Kolmos, A. Characteristics of problem-based learning. *Int. J. Eng. Educ.* **2003**, *19*, 657–662.
9. Savin-Baden, M. *A Practical Guide to Problem-Based Learning Online*; Routledge: London, UK, 2007.
10. Cordell, D.; Drangert, J.-O.; White, S. The story of phosphorus: Global food security and food for thought. *Global Environ. Change.* **2009**, *19*, 292–305.
11. Larsen, T.A.; Peters, I.; Alder, A.; Eggen, R.; Maurer, M.; Muncke, J. Re-engineering the toilet for sustainable wastewater management. *Environ. Sci. Technol.* **2001**, *35*, 192A–197A.
12. Wilsenach, J.; van Loosdrecht, M. Impact of separate urine collection on wastewater treatment systems. *Water Sci. Technol.* **2003**, *48*, 103–110.
13. Institute of Sustainable Futures. Transitioning to Sustainable Sanitation—A Transdisciplinary Pilot Project of Urine Diversion; University of Technology: Sydney, Australia, 2013.
14. Slavin, R.E. *Cooperative Learning: Theory, Research and Practice*, 2nd ed.; Allyn & Bacon: Boston, MA, USA, 1995.
15. DuFour, R.; DuFour, R. Learning by Doing: A Handbook for Professional Learning Communities at Work; Solution Tree Press: Bloomington, IN, USA, 2010.
16. De Freitas, S.; Neumann, T. The use of ‘exploratory learning’ for supporting immersive learning in virtual environments. *Comput. Educ.* **2009**, *52*, 343–352.

17. Reed, M.S.; Evely, A.C.; Cundhill, G.; Fazey, I.; Glass, J.; Laing, A.; Newig, J.; Parrish, B.; Prell, C.; Raymond, C.; Stringer, L.C. What is social learning? *Ecol. Soc.* **2010**, *15*, 1–10. Available online: <http://www.ecologyandsociety.org/vol15/iss4/resp1/> (accessed on 24 December 2013).
18. Midgley, C. Goals, Goal Structures, and Patterns of Adaptive Learning; Lawrence Erlbaum: Mahwah, NJ, USA, 2002.
19. Laurillard, D. Rethinking University Teaching: A Conversational Framework for the Effective Use of Learning Technologies; Routledge Falmer: London, UK, 2002.
20. Van Buuren, A.; van Boons, F.; Teisman, G. Collaborative problem solving in a complex governance system: Amsterdam airport Schiphol and the challenge to break path dependency. *Syst. Res. Behav. Sci.* **2012**, *29*, 116–130.
21. De Jong, B.; Boelens, L. Understanding Amsterdam airport Schiphol through controversies. *Syst. Res. Behav. Sci.* **2014**, *31*, 3–13.
22. Steel, A.; Fitzsimmons, D. Answering Legal Problem Questions in a Grid Format. In *Marking Time: Leading and Managing the Development of Assessment in Higher Education*; Coleman, K., Flood, A., Eds.; Common Ground Publishing Pty. Limited: Champaign, IL, USA, 2013; pp. 77–90. Available online: http://works.bepress.com/alex_steele/25 (accessed on 24 December 2013).
23. Herrington, J.; Reeves, T.C.; Oliver, R. *A Guide to Authentic E-Learning*; Routledge: London, UK, 2010.
24. Herrington, J. Authentic Learning: Resources and Ideas about Authentic Learning and Authentic Learning; Available online: <http://authenticlearning.info/AuthenticLearning/Home.html> (accessed on 7 March 2014).
25. Giddings, J. *Promoting Justice through Clinical Legal Education*; Justice Press: Melbourne, Australia, 2013.
26. Evans, A.; Cody, A.; Copeland, A.; Giddings, J.; Noone, M.A.; Rice, S.; Booth, E. Strengthening Legal Education by Integrating Clinical Legal Experiences: Identifying and Supporting Effective Practices. Available online: <http://www.olt.gov.au/resource-best-practices-Australian-clinical-legal-education> (accessed on 24 December 2013).
27. David, E.; Paul, G.; Justin, Z. *How to Write a Better Thesis*, 3rd ed.; Melbourne University Press: Melbourne, Australia, 2011.
28. Schön, D.A. The Reflective Practitioner: How Professionals Think in Action; Basic Books: New York, NY, USA, 1983.
29. Duggan, B.; Dermody, B. Design Education for the World of Work: A Case-Study of a PBL Approach to Design Education at Dublin Institute of Technology (DIT). In *Handbook of Enquiry and Problem-Based Learning*; Barrett, T., Labhrainn, I.M., Fallon, H., Eds.; CELT: Galway, Ireland, 2005. Available online: <http://www.nuigalway.ie/celt/pblbook/> (accessed on 21 March 2014).
30. Stanford University Newsletter on Teaching. Problem-Based Learning. In *Speaking of Teaching*; Winter: Stanford, CA, USA, 2001; Volume 11, p. 1.
31. Braungart, M.; McDonough, W. *Cradle to Cradle: Remaking the Way We Make Things*; North Point Press: New York, NY, USA, 2002.

32. Sankaran, S.; Abeysuriya, K.; Gray, J.; Kachenko, A. Mellow yellow: Taking a systems thinking approach to designing research on transitioning to more sustainable sewage management. *Syst. Res. Behav. Sci.* **2013**, doi:10.1002/sres.2227.
33. Geels, F. Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Res. Policy* **2002**, *31*, 1257–1274.
34. Garth, B. *Negotiating the Curriculum*; Boomer, G., Lester, N., Onore, C., Cook, J., Eds.; Falmer: London, UK, 1992.
35. Thomas, J.W. A Review of Research on Project-Based Learning. Available online: http://www.bobpearlman.org/BestPractices/PBL_Research.pdf (accessed on 19 March 2014).
36. Jones, B.F.; Rasmussen, C.M.; Moffitt, M.C. *Real-Life Problem Solving: A Collaborative Approach to Interdisciplinary Learning*; American Psychological Association: Washington, DC, USA, 1997.
37. Hommels, A. Changing Obdurate Urban Objects: The Attempts to Reconstruct the Highway through Maastricht. In *Urban Assemblages: How Actor-Network Theory Changes Urban Studies*; Far ás, I., Bender, T., Eds.; Routledge: London, UK, 2011; pp. 139–161.
38. Blumenfeld, P.; Soloway, E.; Marx, R.; Krajcik, J.; Guzdial, M.; Palinecsar, A. Motivating project-based learning: Sustaining the doing, supporting the learning. *Educ. Psychol.* **1991**, *26*, 369–398.
39. Moursund, D. *Project-Based Learning Using Information Technology*; International Society for Technology in Education: Eugene, OR, USA, 1999.
40. Lombardi, M.M. *Authentic Learning for the 21st Century: An Overview*; Oblinger, D.G., Ed.; Educause Learning Initiative, ELI Paper 1, May 2007. Available online: <http://net.educause.edu/ir/library/pdf/eli3009.pdf> (accessed on 17 May 2014).
41. Mellick Lopes, A.; Fam, D.; Williams, J. Designing sustainable sanitation: Involving design in innovative, transdisciplinary research. *Des. Stud.* **2012**, *33*, 298–317.

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