SCALING SUPPORT FOR TEACHING SUSTAINABILITY: REFLECTIONS, BARRIERS, AND OPPORTUNITIES

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Abstract: While many schools have created local coursework or programs to integrate multiple disciplines and real-world experience, scaling these opportunities to reach a critical mass of students is often difficult due to technical and economic constraints. In contrast, efforts that connect multiple institutions to multidisciplinary resources may enable success by mitigating costs through replication and resource sharing. As an example, since 2012, Engineers for a Sustainable World (ESW) has been operating the Wicked Problems in Sustainability Initiative (WPSI), which connects project-based courses across multiple institutions and provides shared resources to enable faculty to expose students to real, complex topics such as providing sustainable housing or managing the roots of air pollution. After two years of successful operations at three schools, the authors are interested in scaling the asynchronous program to enable many more students to participate. However, numerous institutional and practical barriers are visible, such as the need for local champions, course time requirements, online tools, and long-term financial support. In preparation for the third annual cycle of WPSI, current faculty and staff reflected on the program's value, limitations, and potential to scale. This work presents reflections on successes from the first two cycles, and discusses the feasible reach of the program. In this paper, we consider how to address various systemic barriers, alongside changes proposed changes for the program going forward to maximize its impact, particularly on students who have not self-selected to enroll in courses on sustainability.

1 INTRODUCTION

Comprehensive education about sustainability requires exposure to real-world complexity. Sustainability issues are frequently "wicked," lacking definitive formulations or solutions due to the ambiguous contexts and competing interests produced by local contexts and multiple stakeholders with different values (Rittel and Webber 1973; Seager et al. 2012). Because of these aspects, students need exposure to wicked problems, and faculty champions are developing an increasing number of courses, modules, and initiatives on sustainability education. Numerous case studies of courses and curricular programs in real-world sustainability are published every year. These case study programs are almost entirely local and focused at a single institution, only occasionally including partners at other institutions (Brundiers and Wiek 2013). Commonly documented lessons include (a) the need for local champions as well as top-down support for wider local implementation (e.g. programs rather than individual courses), (b) the value

of staffed community liaison positions, and (c) the additional effort required to coordinate, plan, and assess effective education in real-world sustainability issues (Holden et al. 2008; Wiek et al. 2014).

At this point, some programs have grown modestly in scale as faculty have replicated peers' work and graduate students have brought to new institutions methods they experienced during their training. However, effectively incorporating these topics into a critical mass of institutions and curricula on a time scale coincident with global needs may require the community to find ways to incentivize and formally support the replication of successful approaches to those who do not self-select into the community. Effectively scaling course modules, whole classes, and overall programs can decrease the additional effort, pedagogical training, and local resources required for initial entry and may permit or even encourage additional faculty to participate.

The purpose of this paper is to (a) consider what benefits formal replication and support programs might provide, (b) briefly outline one specific program with objectives in this area that the authors have developed, and (c) reflect on the potential and limitations of such programs. The focus of this work is primarily on the faculty experience rather than on the development and assessment of specific student outcomes, which is covered in other work (Hess et al. 2014; Hess et al. 2015).

1.1 Project- and Problem-Based Learning

Two common approaches in developing educational approaches that account for the complexity of sustainability problems are problem- or project-based learning (Arnim Wiek et al. 2014). Problem-based learning (PBL) as an instructional approach has been used in a variety of domains throughout higher education programs for roughly 40 years (Savery 2006). The intent of PBL is to empower students to work collaboratively through complex, real-world problems. As such, the problems are generally ill-structured, with a goal not of designing towards a previously established solution, but rather of generating a creative and viable response (Jonassen et al. 2006; Strobel and van Barneveld 2009). PBL has been shown to promote better transfer of knowledge out of the engineering curriculum into the workplace (Strobel & van Barneveld 2009).

Project-based learning also focuses on collaborative learning, but is structured around the creation of a more specific deliverable for a client's well-defined problem. Students must manage a variety of design requirements (e.g. carbon footprint or toxicity as well as loading capacity) and consider tradeoffs in decisions. Myriad capstone course programs provide a resource-intensive example (Bright and Phillips 1999). Projects are completed using regular context and feedback from the client, often a community organization or an international partner, limiting the extent to which students can direct their own learning (Fruchter 2001). The iterative nature of the process provides repetition of key concepts and a deliverable that students can often see in operation, thereby improving confidence in their abilities (Hess et al. 2014).

Project- and problem-based learning overlap in many ways, but are treated separately in this paper, as the resources required for successful programs can be quite different. Problem-based learning requires a wider swath of information and analysis methods. On the other hand, project-based learning generally requires a dedicated client: even where local partnerships are available, creating and maintaining them demands a large investment of time.

1.2 What can we scale?

Scaling can include several different approaches, as shown in Figure 1. The simplest might be enrolling more students in existing courses (either in existing sections or additional ones) or transferring modules from one course to another at the same institution, initiated by a personal connection and done with minimal localization (e.g. sharing slides). More complex replication might involve program management at an institutional level, where dedicated staff support faculty in implementing similar but disconnected courses different departments or curricular areas. A final approach would be expanding a single managed program to an increasing number of sites, potentially with new or stronger connections between sites. In all cases, instructional materials and methods are reused, and lessons learned can be transferred. More complex approaches to scaling benefit from dedicated staff to manage information and act as a public point of contact for newly interested individuals or sites.

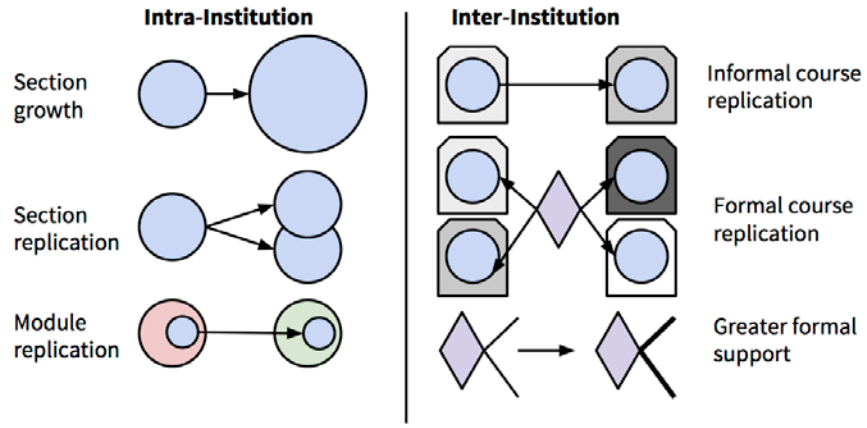

Figure 1: Alternative scaling methods

In the long term, scaling impacts from student-led projects (e.g. capstone courses) is not straightforward. Enabling these projects to be impactful generally requires potential clients, significant time commitments from local clients, and pre-term work by instructors to define projects at a manageable level. High-impact programs that do not rely on local partners are rare. Engineers Without Borders Australia's Challenge program successfully uses project-based learning with a single shared client for a large number of sites in four countries, but is made possible by an external organization's extensive management (Buys et al. 2013).

1.3 Barriers to scaling instructional programs

Replicating any instructional material faces challenges, particularly when sharing between institutions. Common challenges include (a) variations in course size, as design for a class of 15 is quite different than for one of 50, (b) term length variations (e.g. semesters versus quarters), and (c) availability of local connections for student projects, if required. To the best of the authors' knowledge, no formal programs for sharing sustainability modules or course designs have received widespread exposure, although many researchers are developing content intended for replication (Antaya et al. 2014).

At the program level, adding new institutions or support services requires additional program staff time, with the specific relationship varying from linear to logarithmic. Availability of long-term funding for everyday activities can require novel program design, and evidence has shown that innovative approaches fade after short-term funding expires (Graham 2012). Finally, the need to balance high-level themes such as air pollution or housing with locally-available details that enrich the course experience (e.g. the needs of a specific neighborhood or experiences of a specific non-profit) can make it difficult to expand a program while maintaining (or increasing) its educational quality.

2 THE WICKED PROBLEMS IN SUSTAINABILITY INITIATIVE

Starting in 2012, Engineers for a Sustainable World (ESW) has been supporting the Wicked Problems in Sustainability Initiative (WPSI). WPSI supports problem-based learning methods within locally taught project-centered classes. All participating courses focus on an overarching annual topic, which changes each year and is chosen by participants at the ESW Annual Conference in the spring. ESW provides the following materials to faculty:

- An annual sustainability topic with many aspects of wickedness that is broadly applicable but context-dependent, such as air pollution (2013) or sustainable housing (2014)
- A set of professional mentors with expertise in that topic, for both recorded guest lectures and design reviews
- Assessment materials for gauging changes in student confidence and understanding of sustainability and wicked problems
- Curriculum materials, including syllabi, to help faculty create new courses or adapt existing ones

- A framework for design reviews that includes rubrics, inter-institutional peer review, and external mentors
- A shared community across a range of disciplines and course types to provide many approaches to the same problem
- The opportunity for students to present final projects to a broader community and get feedback and assistance from that community to support implementation

ESW-National staff members coordinate WPSI and to-date participation in the program has been free. During the pilot year (Fall 2013), WPSI launched in a course on Social Entrepreneurship at the University of Pittsburgh (Pitt) and a course on Wicked Problems at Rochester Institute of Technology (RIT). During the second iteration (Fall 2014), Rose-Hulman Institute of Technology (Rose) joined as a third school, including WPSI in two sections of a required technical writing course, Technical and Professional Communication. Aspects of these three courses are shown in Table 1. All three were three-credit discussion-focused traditional courses with teams working on a long-term deliverable. Deliverables from the first two years are available on the Initiative website at www.eswusa.org/wpse.

Table 1: Properties of 2014 courses connected to WPSI

	Pitt	RIT	Rose-Hulman
# of Students	14	12	40
Discipline	Primarily engineering, mixed flavors	Mixed engineering, design, and humanities	Primarily engineering, mostly mechanical
Level	Honors – Mixed undergraduate & graduate	Upper-class undergraduate	Junior
Final deliverable	Social business plan around focal issue	Proposal for campus or community change	Proposal & presentation to address focal issue

WPSI is specifically focused on building contextual and problem-based learning, and is intended as part of a larger set of local course offerings involving sustainability. Two of the individual courses have thus far been focused on different primary topics – technical writing and social entrepreneurship – and WPSI adds content focused on sustainability and complexity, particularly in the definition of problems that students will encounter as they practice course skills. While courses have included central projects, they have not been connected to a specific client in a way that would constitute formal project-based learning.

In preparing this paper, we asked all staff and faculty that have participated to date (and who are authors on this work) to reflect on their experiences as instructors and as learners. We were particularly interested in faculty expectations compared to experience and in whether participants felt that WPSI could be scaled to ten or more schools without significant losses in quality. As the sample size was quite low (n = 4), our method was to come to a group consensus on the derived outcomes presented in the following sections.

3 RESULTS & DISCUSSION

3.1 How might WPSI be scaled in the future?

In considering WPSI's goals and what a larger successful program would look like, we arrived at five major metrics. First, the primary focus of WPSI must be on educational **attainment**, meaning students' progress toward specific learning outcomes. Second, from a faculty perspective, a focus on **instructional efficiency** (defined as faculty course development time and resources required per credit hour) is essential. Third, if WPSI were to shift to a project-based learning model (e.g. having students work with an external partner), **external impact** (e.g. at the campus or community level) becomes a critical focus. However, this impact is difficult to measure, requiring metrics specific to each project (e.g. community

savings on utility bills, additional maintenance requirements imposed on facilities management). Lastly, successful programs should include both a high **quantity** and wide **diversity** of students, meaning many students of variable majors across diverse institutions. Teaching 500 civil engineers is likely less valuable to long-term shifts in the engineering profession than 100 each of civil, chemical, electrical, industrial, and mechanical engineering. Likewise, wider geographic distribution involves students in diverse regions who bring diverse regional perspectives in problem framing. In proposing these metrics we recognize that individuals' opinions on their relative importance will vary, as engineering education itself has many wicked aspects!

3.2 What have been WPSI's successes and failures thus far?

WPSI, to date, has included three institutions, five sections of three courses, and approximately 75 total students. Attainment, as measured by changes in pre-post surveys (Hess et al. 2015), design reviews (Hess et al. 2014), and course evaluations has proven strong in all cases. Four of five sections were small (10-15 students), thereby limiting the number of overall participants. However, the diversity of participants has been high with courses spread across three institutions and more than 10 majors (inside and outside of engineering) represented. The benefits or challenges of multi-disciplinary classes, both within engineering and with non-engineers, are explored in greater depth in a companion paper for the ASEE 2015 Annual Meeting, which focuses on the assessment methods, including student reactions to and engagement with the course (Hess et al. 2015).

From an instructional efficiency perspective, the authors feel that WPSI has been successful. The instructor at RIT indicated, "Support in bringing in subject matter experts and course and project evaluation materials saved development time each semester." Participation in WPSI was the Pitt instructor's first collegiate teaching experience, and the support from a community of instructors made instructional efficiency possible, particularly with working through open-ended and complex material throughout the course. While assessment and curriculum materials were frequently updated during the first two years, faculty feel that as documents stabilize, these materials will become readily available to community participants. Faculty generally felt that the resources and support provided by WPSI were helpful, although additional curricular material would be valuable for new WPSI-connected classes, particularly around background readings and the sequencing of various topics to be covered.

External impact has been low because none of the three courses have provided students with specific clients for whom they might develop a solution, and so far no proposed project has been implemented. The focus of WPSI overall has not involved a central client and as a result impacts have been limited to professional mentors (both shared and locally) who have taken some ideas from students' projects back to their own practice. All instructors are interested in implementing local projects, and feel that having students work with local clients would be beneficial. However, client relationships would need to be developed by local faculty as it is difficult to develop these relations off-site. WPSI has not, to date, provided material to help with the establishment and maintenance of such relationships.

3.3 What lessons have we learned from the first two WPSI iterations?

Hybrid physical/digital programs have unique advantages. First, WPSI provides access to complex material that is traditionally unavailable for an instructor developing a course from scratch, thereby improving instructional efficiency. Second, as an asynchronous and distributed program, WPSI instructors retain local control and the students retain the advantages of in-person project teams. At the same time, WPSI's digital communities allow participants from a much more diverse set of backgrounds to connect and share insights. Although purely online programs (a common approach to scaling material) do not require physical resources, WPSI allows for course-by-course instructional variety along with cross-institutional interactive learning.

Central programs have an advantage in supporting accreditation criteria. Instructors often need to demonstrate that new approaches meet accreditation criteria. Formal programs may provide assessment instruments and a system for documenting progress, thereby allowing faculty the freedom to use existing assessment measures and focus on content and pedagogy. WPSI's strength in this area is most visible

with the pre- and post- course assessment instrument and the staged design review materials, but all of WPSI's program objectives map to one or more of the ABET criterion 3 outcomes.

Distributed programs provide limited support for improving local impacts. Improving external impacts requires more specific connections for community implementation. Clients may be needed to provide project direction, design specifications, and feedback. The time and resources to maintain relationships with these clients is a cumbersome task for faculty champions. Yet, a repeated lesson from WPSI and ESW overall is the difficulty of supporting local partnerships from afar. While examples exist that use a shared client for project implementation (Buys et al. 2013), local impacts will demand local partners and local people to develop and maintain the relationships. Community partnerships can scale within single institutions, as relationships developed for one local course can be used for multiple sections, instructors, years, and potentially between nearby institutions.

Faculty community-building should not be overlooked. An unexpected benefit was that the community between faculty members was much stronger than the community between students. The original program was intended to require minimal contact so that adding new instructors and courses did not require complex scheduling, but regular meetings were one of the strong points in the first two years of operation. The benefits of coordinating efforts for peer review and discussing weak points in individual courses was seen to be beneficial for all faculty, regardless of their level of experience with WPSI specifically or with teaching in general. While related to instructional efficiency, this lesson is less about program outcomes and more about program sustainability and continued investment by key participants.

3.4 How could we scale WPSI?

The experience with WPSI provides encouragement that such a hybrid distributed/local program can improve attainment and provide access to a set of resources for faculty that would be otherwise unavailable or difficult and time-consuming to prepare. With this in mind, and the ultimate goal of engaging larger numbers of students in critical thinking around wicked problems and sustainability, we explore ways to scale WPSI and handle the potential barriers therein. WPSI has the potential to improve in all five outcomes described in 3.1: (a) attainment, (b) instructional efficiency, (c) external impact, (d) student quantity, and (e) student diversity. As a support system for local courses, scaling the program may involve adding more courses, increasing their size, increasing diversity, or improving faculty support to decrease development time or increase impacts of projects.

The simplest approach to scaling WPSI is to add more courses. In the near future, additional faculty will likely be passionate local champions at different institutions who are familiar with ESW, eventually expanding to faculty at participating institutions connected by their participating peers. Additional faculty participants encourage refinement of provided materials or development of new materials to support alternative use cases, improving efficiency. New courses also expand both the faculty and student communities, allowing for greater diversity and greater peer support during and outside the courses. Especially impactful expansion might bring WPSI into core curriculum courses such as capstone or senior design, or earlier courses centered on problem- or project-based learning. While such courses entail higher barriers because of accreditation requirements, core curriculum participation is essential to establishing the program and its content firmly within each institution, as well as for providing all students in a degree program (as opposed to the self-selected few) with meaningful exposure to sustainability.

Attainment should remain the same or improve as the number of participants grows, due to the independent nature of each course. The marginal cost of additional sections using the same assessment instruments and recorded guest lectures is negligible. If the same university hosts multiple project-based courses, the ability to reuse local partners for project clients could improve impacts without changing instructional efficiency. Although the authors envision WPSI participation as a starting point, additional project-based courses could exist outside of the initiative and benefit from the same relationships.

Improving the support structures and incentives provided represents a separate opportunity for scaling WPSI. Options may include providing support for local partnership development, more robust course development materials, or facilitating additional conversations between faculty members or between

groups of students. These changes would add to the value proposition of the initiative and potentially allow new activities in existing courses and lower barriers to participation for interested faculty.

Resource requirements limit scaling in some aspects. During the first two years, participating faculty coordinated inter-institutional peer review. While all instructors saw this activity as valuable, organizing the exchange of student assignments might not be feasible with many additional courses. Coordinating faculty on different calendars, even with asynchronous courses, requires increasing amounts of staff time. Identifying enough mentors for additional courses, while not overloading individual mentors, is a linear scaling problem, although coordinating connections between institutions and mentors or between institutions is more logarithmic as each additional institution requires less additional staff time.

In improving the initiative, we are interested in focusing immediate efforts on improving instructional efficiency and on reaching a larger and more diverse group of students. Increasing the magnitude of the program's external impacts must be a more distant goal due to the need for local resources. We will focus on problem-based materials as the core of WPSI and add resources for supporting project-based courses – such as help in building local connections – only as time and expertise permit.

The authors considered growth to ten schools following WPSI's first two iterations, a three-fold jump from 2014 participation. The consensus was that this target was quite feasible in terms of the management of changes with respect to avoiding detrimental effects. The range where a different program model would be required is difficult to hypothesize. A higher target might be a course at 40 institutions, roughly the size of the ESW student chapter network. At this range, a regular cohort of mentors, a dedicated technology platform, and at least one dedicated staff member would be required, along with financial support from – in order of decreasing sustainability – participating institutions, corporate sponsors, or grants. The asynchronous nature of WPSI avoids the need to coordinate course schedules, but coordinating the exchange of student work, currently done by hand, would require the use of different technological systems that may have financial costs or new learning curves for faculty and students alike. Regardless of scale, continuous monitoring can help identify where local approaches might be more effective.

4 CONCLUSIONS

No single program will maximize all of the metrics discussed, and no single program will be appropriate for all institutional and educational models. We do feel that program design around sustainability education can and should be intentionally discipline-agnostic. WPSI, as an asynchronous and digital approach managed by an independent organization, has been able to support student growth around complex learning objectives. In WPSI's first two years, we have included a wide set of disciplinary and geographic viewpoints. Faculty experience thus far has been very positive. However, WPSI cannot unilaterally create lasting local impacts, as ease of adaptation into the core curriculum remains to be demonstrated, and a scaled-up version will require additional paid staff.

Institutions with a strong commitment to sustainability education would likely be well-served in adopting models like Arizona State University's PPBL initiative, which shapes many courses across the School of Sustainability (Wiek et al. 2014). With institutional support for staff, effective project-based learning with long-term partners becomes plausible with efficient use of faculty time. The primary value of joining a larger program such as WPSI for well-developed local programs is likely to be the transfer of instructional techniques and additional geographic perspectives, as inter-course community within the institution may be sufficient to provide different disciplinary viewpoints.

The goal of this work is not to identify better ways to teach specific sustainability topics. Instead, we hope to encourage additional conversations about externally managed and hybrid digital/physical programs and their potential for exposing more engineering students to complex and multi-disciplinary problems such as those within sustainability. A program such as WPSI that can lower the barrier to an initial class and build faculty confidence in new teaching methods can drive initial curriculum change at many institutions while building a generation of engineers attuned to complex problems in a variety of topics at greater efficiency to faculty members.

The hybrid approach allows many of the benefits of both digital scaling and in-person teamwork. While few hybrid models have been tried, the preliminary results encourage further exploration and study. Support on initial courses can also help train graduate students and faculty for creating more complex and curriculum-spanning programs. We are hopeful that programs like WPSI can support easier replication and refinement of empirically grounded assessment and pedagogical techniques while simultaneously creating critical communities of practice to realize systemic change throughout higher engineering education and, in turn, practice.

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