GP168/abs022

Curriculum design and higher order skills: challenging assumptions

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Abstract: *This paper is based on an Australian Learning & Teaching Council (ALTC) funded evaluation in 13 universities across Australia and New Zealand of the use of Engineers Without Borders (EWB) projects in first-year engineering courses. All of the partner institutions have implemented this innovation differently and comparison of these implementations affords us the opportunity to assemble "a body of carefully gathered data that provides evidence of which approaches work for which students in which learning environments". This study used a mixed-methods data collection approach and a realist analysis. Data was collected by program logic analysis with course co-ordinators, observation of classes, focus groups with students, exit survey of students and interviews with staff as well as scrutiny of relevant course and curriculum documents. Course designers and co-ordinators gave us a range of reasons for using the projects, most of which alluded to their presumed capacity to deliver experience in and learning of higher order thinking skills in areas such as sustainability, ethics, teamwork and communication. . For some students, however, the nature of the projects decreased their interest in issues such as ethical development, sustainability and how to work in teams. We also found that the projects provoked different responses from students depending on the nature of the courses in which they were embedded (general introduction, design, communication, or problem-solving courses) and their mode of delivery (lecture, workshop or online).*

Introduction – The logic of the innovation

Since 2008, Engineers Without Borders (EWB) have offered a first year engineering student design program known as the EWB Challenge, requiring students to develop solutions for a selection of real problems experienced in one of their development project sites. Sites vary annually and have included communities in India, Cambodia and remote Australia, focusing on issues such as fresh water supply, basic infrastructure and housing as examples. Students work in teams to arrive at their solutions and may nominate to enter a national competition, judged by a panel of industry and community experts.

Universities quickly embraced the opportunities presented by the EWB Challenge to move the first year curriculum away from abstract maths and physics to embracing activities aligned with practical engineering – solving real-world problems. Given the projects are team based, it also allowed universities to address graduate attributes around teamwork, communication and ethics. The content of the projects allowed for attention to be focused on sustainability, appropriate technology and related issues within an engineering context and application model. There has also been resistance to the EWB Challenge from those who question the value and outcomes of the projects, particularly in relation to engineering sub-disciplines (such as mining) who feel that the nature of the projects precludes their interests. Nevertheless, although the number of participating universities varies from year to year, at one time or another every university in Australia that teaches engineering has implemented the EWB Challenge. In this paper we report on an evaluation of 13 of those universities, all of whom implemented the EWB Challenge differently. Comparing the 'same' projects in different curricula allows us to assemble “a body of carefully gathered data that provides evidence of which approaches work for which students in which learning environments” (National Academy of Engineering 2005 p.26).

Variety of implementations

Although all of the universities used the projects in first-year courses, some were scheduled for first semester and some for second semester meaning there was a different level of university experience among students according to semester. However, a more striking contextual difference lies in the kind of course (subject) and its goals.

The names of the courses involved (a significant signal to students of what the course will be about) include allusions to design, sustainability, professional practice or problem-solving. However as we shall see the name of the course is not necessarily a clear indicator of what the real concerns may be and how the projects are implemented.

We argue that although projects such as those fostered through the EWB Challenge allow for pursuit of a whole range of learning objectives, they do not necessarily guarantee it and we need to be careful to identify the assumptions we make. What and how engineers learn is directly affected by a host of contextual factors, such as instructor attitudes and course design, including assessment requirements.

Realist evaluation

In the context of an increasing awareness that educational evaluation needs to treat educational interventions as social practices (Saunders *et al*. 2011), we chose the realist evaluative framework associated with Pawson and Tilley (1997) for its power to reveal “precise and substantive programme learning” (Blamey and Mackenzie 2007 p.451). It is also an approach whose realist epistemology, generative understanding of action, and focus on generalisable mechanisms for change could be expected to find a sympathetic audience in engineering’s similar discourses.

The approach starts from the position that aspects of **context**, including all of the activities that make up an intervention, provide the participants in the intervention with a range of possible ways of responding to it. These responses are **mechanisms** that bring about the outcomes or changes (or learning). Mechanisms are not the activities that the intervention puts in place but the choices the participants make about how they will respond, along with the capacities they bring with them to the task. Thus, if the intervention is the use of the EWB projects, context will include institutional factors such as course design, instructor characteristics and so on, and the mechanisms will be the choices students make about what to do in response to the course. For instance, in a context where course design and instructor behaviours mean that student teams are left to fend for themselves, students might adopt any of a range of responses that we have previously labelled “in at the deep end”, “mutual dependence” or “rugged individualist” (Jolly *et al.* 2009). The mechanisms which bring about change in this case are respectively, a development of teamwork strategies, a division of labour approach, or an understanding that teams don’t work and one person always needs to intervene. Each of these mechanisms leads to different outcomes. This analytic separation of activities from mechanisms is particularly useful in educational situations where there is a tendency for us to forget that the students are the sites of change and our actions as educators merely enable (or disable) that learning.

Methodology

We began our research with Wisconsin model program logic analyses (Figure 1) which included mapping how course controllers believed the use of EWB projects ought to work to produce the desired outcomes. This approach made explicit the ‘theory’ behind the implementation; that is, how participants expected their implementation to work, from input considerations through activities, outputs, outcomes and impacts (University of Wisconsin). Exposing the logic behind the implementations (because we do X, students will do Y and the outcomes will be Z) allowed us to examine how likely it was that course controllers’ expectations would be met (Brouselle *et al.* 2009). Naturally, those understandings and what was identified as desired outcomes varied across the sample. For each site, the program logic was used to identify what the relevant indicators would be, how data would be collected for that site, and what particular evaluation questions were of local interest.

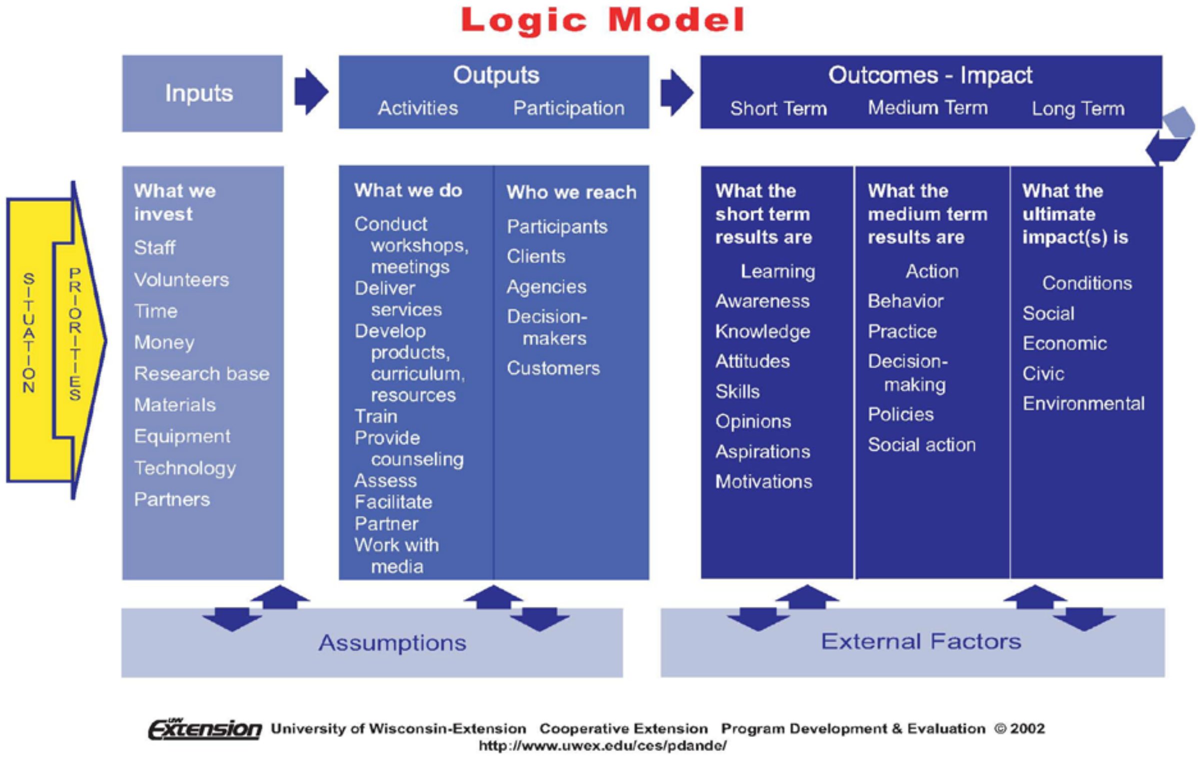

Figure 1: Wisconsin model of program logic

Data collection methods included observation, focus group, staff and student interviews, document analysis and exit survey although not all methods were used at every site. Transcripts were entered into NVivo9 for thematic analysis by constant comparative method. Preliminary analyses have been presented in papers and workshops to colleagues at the Australasian Association for Engineering Education annual conference in 2011 and workshops are planned at each of the participating universities to discuss and clarify results with them later in 2012.

Implementing the EWB Challenge

The program logic interviews revealed a variety of basic assumptions about the benefits of the EWB projects. No matter what the published objectives and course title was, course controllers were interested in developing higher order (sometimes called 'soft') skills and very often assumed the nature of the projects would deliver those skills without further attention. In one case where the course title included the word 'sustainability' there was in fact no explicit attention to it in the syllabus. The program logic approach was very useful for exposing such assumptions.

Course names and published objectives are important because they influence student and staff expectations and expectations are important contextual variables affecting how both staff and students make choices about how they respond to the experience of the course. In the space available we can only begin to discuss student responses and we will confine ourselves to discussion of the three main assumptions only. These are:

- Third world settings focus students on project contexts and social sustainability
- Projects provide for tangible outcomes in real world settings and this is motivating to students
- Teamwork approaches will deliver 'soft' skills

Project context and sustainability

At the most general level we can see at least three ways in which students understood the significance of the context of the projects. The first of these was where students recognised that they needed to engage with the engineering process and that the details of the actual setting were secondary to that:

> *Here*[in Australia], *you're going to jump to a conclusion that you think is alright but with this we didn't really know what would fit so we actually had to devise a process to go through to find out what would work (Student focus group).*

This illustrates one potential outcome of making the EWB projects the context for the design; the exotic nature of the location has prevented the students from going for the taken-for-granted solution and drawn their attention to generic engineering processes. Other students concentrated on the physical details of the site and their design, as the group who told us: "the location of our bridge has to be at certain points, so that it doesn't have those impacts like flooding in the monsoon season." In this case the exotic location with problems not often encountered at home made the students pay attention to the nature of the problem, rather than rushing to conventional solutions. These two sets of responses are evidence that using the EWB projects can indeed draw attention to defining the problem in context, an objective that many course controllers alluded to in their interviews with us. However, a third group of students couldn't see the project as anything more than a sterile and needlessly complicated university exercise: "the university changed the problem, like we looked on [the internet] and there was no problem with salt in the water or nitrate in the water". They found this deeply demotivating. The problem here seems to have been that the students perceived that the problem was not 'real', in that the context was not as described by their course materials. In this case, if the course required attention to particular problems which didn't actually arise in the EWB case, it may have been more productive not to use it.

Similarly, there was a range of understandings of what sustainability was and its relative importance. There seems to be a tendency to confuse sustainability, especially social sustainability, with usability or appropriateness, as in:

> *I know the triple bottom line thing and you have to be socially sustainable as well , and financially and environmentally, because you can't just make something environmentally sustainable and make it really, really expensive because then people aren't going to use it…it has to be feasible. It's providing for all needs not just tree hugging needs, which are important as well.*

Durability is also sometimes mistaken for sustainability as when a student tells us "sustainability is, is my solution going to last a certain number of years or is it going to last further on?" The classic Brundtland-type definition of sustainability is rarely expressed but it does sometimes surface:

> *we've realised that we need to be looking at this aspect, not just using the resources now but being able to use resources in a way that we'll be able to use resources in the future*.

For many institutions use of the projects was a first attempt to include explicit attention to sustainability in the engineering curriculum so this partial understanding of sustainability may be an advance. Only two of the universities in our sample had courses in later years which were dedicated to sustainability, although some universities did use EWB projects in their final year subjects for a variety of purposes. This is a trend that seems to be gaining ground and it seems likely that a complicated subject such as sustainability needs to be tackled incrementally over the whole curriculum. Certainy we have had some lecturers tell us that "you can't teach sustainability to undergraduates"and one would not expect these lecturers to make much of the sustainability topics potentially contained in the EWB projects. Unfortunately in some instances, using the EWB projects has been seen as a way for departments to claim to have dealt with sustainability, regardless of the actual learning outcome.

Reality and motivation

A significant majority of students appear to be attracted to engineering because they want to solve problems and to do good in the world. These students find the EWB Challenge motivating, not only because "you know you're going to make a difference in the community" but also because they feel reassured that the content of their courses is really relevant and is giving them significant engineering experience:

> *And that's, I find, to be a really bad link between studying and the real world is that yes they can use real world examples [in other courses] but you haven't actually used it. You've only done research on it. Whereas with EWB, you've used the content that you're learning to put in a good solid solution.*

Given that the projects are undertaken in first year when students have little technical knowledge, the reality of the EWB projects, coupled with their low technical demands, is also appreciated:

> *That's why it's good that it's set in Devikulum because then we don't need all the technical knowledge. It's just using the engineering process without needing anything else although we can use other stuff.*

On the other hand in previous years when students discovered that the solutions they were designing for an Australian Aboriginal community were already in place they expressed disappointment that they could not in fact make a difference that wasn't there already. Similarly some students doubt that any solution put forward by first year students will ever be adopted. In fact EWB does work with winning teams and client communities to bring solutions to implementation, but student awareness of this fact is low.

As we saw in the last section, reality is motivating but students must feel that there is at least a chance that their solution could be implemented. In the cases where students have the opportunity to build prototypes or working models of their design, this can be the tangible evidence that their solution can work that they appear to need to engage with the problem.

There is however, a subset of students (and in some instances staff) for whom the EWB projects do not live up to what they expect an engineering project to be. These students are described by their peers as "those who came into it because they liked maths and physics" and are not excited to find out that there's more to engineering than that. A typical response from such a student is:

> *So I don't find much of a need for much technical knowledge in there and I find that your hand's pretty much held the whole way through…so much background information is given to you.*

While these students are interested in solving problems, only mathematically difficult and highly technical solutions satisfy them. This presents a challenge to educators who need to prepare working engineers in a country with a significant skills shortage and a small R&D sector. The potential exists to use the EWB projects to begin to modify attitudes such as these but we have seen few examples of this happening.

Developing teamwork skills

In all the cases we have seen the EWB Challenge projects are undertaken as team-based work. There are, however a range of approaches to organising and managing teams and of student responses to being told to work in teams. In some instances, lecturers spend considerable time and effort using devices such as the Belbin questionnaire to sort students into teams and to suggest roles for them. Some courses offer detailed instruction in teamwork processes and communication skills while in other cases students are left to find out about teamwork for themselves.

Of course one impulse behind the use of teamwork is ever-increasing class sizes and the burden of marking. But teams are also the curricular device used to develop graduate attributes such as "the ability to function effectively as an individual and in multi-disciplinary and multi-cultural teams, with the capacity to be a team leader or manager as well as an effective team member" (IEAust 1999). Managing teams so as to get the kind of shared input that would facilitate development of such attributes presents a problem to course controllers, particularly in large classes. A common device is the use of some kind of peer assessment calculation to modify final results by the contribution to the teamwork. However, what students judge to be equal or adequate contribution may not match the institutional learning goals. Student responses to the team environment are variable as the following quotations show:

> *we'd decide on our concept, we figured out what we would need to research to develop this concept, we'd divvied up the research tasks and then told everyone you've got two weeks, now go and do the research.*

> *The person with the higher mark, who want the higher mark, normally is willing to go further and work harder for it and then they feel like they're doing all the work but that's just because they want a higher standard than the others.*

> *he'd write one paragraph while I was writing the next one and we'd tie them together and just keep jumping around and editing each other's work*

The first of these may be called the ‘go away and do’ response, a division of labour that shows co-operation but little collaboration. While this kind of approach is common in workplaces and arguably acceptable there, it is not the kind of team environment that will help all students to develop knowledge and skills in all areas.

The second quotation illustrates the team dominated by the rugged individualist who is willing to work extra hard (and sometimes deny other team members learning opportunities) to get the highest mark. It recognises only one way of leading and very little accommodation to disciplinary or cultural difference such as is envisaged in the graduate attribute.

The final example shows what we might be tempted to call true collaboration where each student has the opportunity to be familiar with and learn from the others’ input. It involves both leading and being led and good communication skills but is the rarest kind of teamwork found in our sample. While all of these may be legitimate practices at various stages of the course it is an open question whether they all deliver the teamwork skills assumed to be outcomes of the projects.

Discussion – Implications for curriculum design

With such a range of student responses to all aspects of the projects, the Realist evaluation framework provides a way of factoring out which aspects of context and mechanisms have most impact on outcomes. We have space to deal with only a few aspects of this analysis here for the purposes of illustrating how the previously described variations may be understood and dealt with systematically.

Mechanisms

The mechanisms are the factors influencing the choices people make in their response to the EWB projects. At the highest level, these choices were found to include concern for context and concern for sustainability (Table 1).

Table 1: Cluster-level Mechanisms

Cluster	**Description**
Concern for project context	This cluster of mechanisms relate both to the perceived ‘reality’ of the projects either as real engineering or as real-world problems, as well as to the ways in which decision-making is affected by taking context into account.
Concern for sustainability	This cluster contains mechanisms that reflect a variety of understandings of what sustainability is and how important or unimportant it is perceived to be.

Table 2 illustrates the themes that make up the ‘concern for context’ cluster and provides brief illustrations of the data that gave rise to the themes. The whole data sets are substantially larger than these illustrative tables, with many more examples of each theme and subsidiary themes which are not pursued here.

Mechanisms are labelled as ‘supporting’ where they contributed to positive outcomes, and ‘inhibiting’ where they created problems for the effective use of the EWB projects.

The developing world context of the EWB projects is assumed by most academics to automatically confer advantages in engaging students, giving them an understanding of the real-world effects of their discipline and drawing their attention to sustainability issues. While these effects are evident in some cases, in others they are countered by contrary mechanisms such as the drive to get good marks. Some of the variety of responses comes from the assumptions and habits that students bring to the EWB projects but these can be influenced if we are aware of what they are likely to be. For instance the “nothing you can take away” mechanism can be addressed by looking for applications of the knowledge being acquired in the student’s chosen sub-discipline. However, most lecturers immediately think of setting contexts in order to provoke the desired mechanisms.

Table 2: Concern for project context

Concern for project context - supporting		
Category description	**Category name**	**Illustrative examples from data**
Giving reality to the project by building a model/prototype	The "**making something**" mechanism	Example – open ended survey question response: What was the most positive thing about the EWB project? *seeing a physical outcome from our efforts being put into action*
Students perceive that what they are doing relates to professional practice	The "**real engineering**" mechanism	Example – focus group with students (Go8b) *a lot of people came in because they liked maths or physics or something in school and then you do this and you realise that yeah there's maths and physics in it but there's so much more in it than just maths and physics.*
The reality of the situation prompts concern for downstream effects	The "**responsibility**" mechanism	Example – focus group with students (Go8c) *I think the responsibility is bigger than just putting in a plan and not worrying about what happens after that and it's about a long time commitment to something and making sure that there's no ill effects somewhere down the line*
The patent needs of the community prompt engagement and application	The "**doing good**" mechanism	Example – focus group with students ATNa) *I think if you focused more on the fact that you were doing it to help the community it would be easier because you'd be a lot more interested in it.*
Concern for project context - inhibiting		
Details of design pursued in terms of marks awarded	The "**mark chasing**" mechanism	Example – observation of teams in tutorial (Go8a) *ignore salt entirely, we'll get better marks*
Students don't believe their designs will ever be used.	The "**it won't happen**" mechanism	Example – student focus group (Go8NZ) *It didn't really make it like – we didn't get to do anything. We just made up a little story about how… what we would do if that happened. You know, it wasn't going to happen, so…*
Students see context as too remote from their engineering futures	The "**nothing you can take away**" mechanism	Example – focus group with students (ATNb) *if you were doing aerospace engineering, that sort of stuff, it's really hard to sort of…you can relate the problem-solving aspect of it to it, but besides that, there's really nothing you can take away from it.*

Contexts

The contexts that were found to have most influence on the successful use of the EWB projects include the alignment of project context and design constraint, the alignment of assessment criteria with project goals and activities and the behaviour of tutors (Table 3).

Table 3: Cluster-level Contexts

Cluster	**Description**
Alignment of project context and design constraints in design and delivery of course	This cluster is concerned with how well the project as presented in EWB briefs is reflected in actual learning activities.
Alignment of assessment criteria	Students (and tutors) respond very strongly to assessment criteria so the descriptions of what is needed and the weightings given to various aspects of assessment are important conditions in triggering mechanisms.
Tutor behaviour	The climate the tutor develops in the class, the way they model the work of engineers and the mechanisms they exhibit, all create significant social and cultural conditions for the implementation of the EWB projects.

Table 4 briefly illustrates some of the themes that make up the first cluster and provides brief illustrations of the data that gave rise to the themes. Contexts labelled ‘enabling’ are those social and cultural conditions that facilitate the operation of supporting mechanisms. ‘Disabling’ contexts are those that make it difficult for supportive mechanisms to be triggered.

Table 4: Alignment of project context and design constraints

Alignment of project context and design constraints - Enabling		
Category description	**Category name**	**Illustrative examples from data**
Actual conditions in subject community define what students need to do in class	The “**community needs**” context	Example – observation of tutor in class (Go8a) *you won’t get perfect solutions. Refer to constraints in brief*
Project context is used to foster diversity of approaches	The “**allowing for difference**” context	Example – focus group (NGUa) *no two designs are the same because everyone had to think their own different way, and what they, how they were going to overcome the problem that was presented to them. Cos everyone had different ideas and stuff, everyone’s different*
Alignment of project context and design constraints - Disabling		
Presentation of project/build emphasises technological problem	The “**ping pong balls**” context	Example – notes from discussion with tutors (Go8a) *Some groups have used colour detection as the principle for identifying debris as ping pong balls used in the model are orange. I said “but in the real world…” and the tutors said “yeah it won’t work but it was really cool the way they worked it out”*
Presentation of project does not treat it as real.	The “**this is just background**” context	Example – interview with student (Rb) I think it was in the design brief but it may have been elsewhere online - it said that the idea of using human waste as fertiliser clashes with local beliefs and values. So you…and that it would require significant support for the community to actually get on board with doing this. ... And the response…which is fine, that’s not my issue, this is just a background.

While one might expect that creating enabling contexts automatically leads to the triggering of supportive mechanisms the actual situation turns out to be more complicated than that. In one case (Go8a) although considerable effort had been put into aligning projects across a number of engineering disciplines to community need and the course included the requirement to produce a working model of the design there were still a number of problems. The models had to be demonstrated publically on a set day and they had to work within given parameters, including time. While the ‘making something’ mechanism was effectively triggered, the ‘mark chasing’ one was also strongly in evidence. Because there were differences in some cases between what would work best in a time-limited demonstration and what would work best in the community setting, and because students naturally wanted the best marks they could get, the final designs were sometimes not optimum for the real world context. This has been effectively addressed this year by making sure the demonstration conditions match what is required in the real world, but the case illustrates that we need to pay close attention to the detail of the factors leading to learning, and their interactions.

Conclusion - the best use of EWB projects

There can be no single recipe for how best to make use of EWB projects in any particular instance but there are some tools and aspects of our ongoing analysis which shed light on how principled curriculum design might proceed. Firstly, the use of a the program logic to make explicit what the assumptions are about how the projects will work to bring about desired outcomes can be helpful in making obvious to members of the teaching team where different understandings exist and where there are gaps in the implementation logic.

The C/M/O analyses can be used to reflect what might be changed to improve outcomes or shift the emphasis. For instance, where the projects are presented to students as “just background information” it should be no surprise to find that the potential for the projects to motivate and engage students (that is to trigger the supporting mechanisms in Table 2) is reduced. If any of those mechanisms are responses that curriculum designers are interested in seeing, they therefore need to pay attention to how the projects are situated and explained within the overall course design.

The final stage of the research project, currently underway, involves changes to courses using the EWB projects based on the analysis presented here and elsewhere. One of these changes was rather small scale and has already been discussed. It was the course that adjusted assessment criteria and conditions to better balance the needs of demonstrating a working model and the real-world context. A second case (Ra) has been addressing the context of tutor behaviour in an online version of a course built around the EWB projects. Having realised the power of alignment in course activities and assessment details this case provided its tutors with a structured plan for weekly interaction with online groups which should have gradually scaffolded learning suitable for the assessment set. Unfortunately tutor compliance with the plan was hard to attain and this illustrates some major difficulties and an extra dimension of the online context.

Our third development from the project so far has been the importation of the EWB projects into a final-year multidisciplinary course at a major university (Go8c) outside of, although including engineering. This course offered an opportunity to examine in detail the claims made for the projects in terms of fostering skills in multidisciplinarity, teamwork, communication and attention to sustainability. It has been very successful in developing these attributes and the implications of all three of these developments from our original evaluation will be reported in an upcoming paper whose tentative title *Three Narratives of Collaboration*, indicates the issue that we see as central both to curriculum change and to successful use of the EWB projects.

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Acknowledgements

This research was made possible by an ALTC Priority Programs grant number PP10-1647.

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