Sustainable Engineering Management for International Development: lessons learned from a new and interdisciplinary MSc programme

Xiaojun Yin[1], Krijn Peters[2], Patricia Xavier[1] and James Holness[1]

[1]College of Engineering, Swansea University, UK

[2]College of Arts and Humanities, Swansea University, UK

x.yin@swansea.ac.uk

Abstract

Swansea University has developed a Sustainable Engineering Management in International Development Masters course which attempts to pave the way for a new brand of 'global' engineers equipped with core engineering skills, complemented by understanding of how engineering both affects and is affected by environmental and social factors/dimensions. Stepping outside of the traditional academic delivery box, the course enrols students with different backgrounds and experiences, with an equal balance of engineers and non-engineers taking theoretical modules, each delivered intensively over a two-week period and structured around real-life projects. The curriculum is centred around transdisciplinary learning using a project-based learning approach with year-long projects in development contexts, following key principles of global service learning. This paper explores the first three years of course delivery, through the lenses of four academics involved in course conception, curriculum design, delivery and development, each from the different perspectives of social science, internationalisation, engineering education and engineering practice.

Introduction

There has long been a recognition that the traditional curriculum is no longer effective in preparing students to overcome complex and intractable problems (Forster *et al.*, 2017). For contemporary development collaboration or interventions, a group of Swansea University academics who worked together on a multidisciplinary research project in international development felt strongly that there is a need for a new brand of 'global' engineers in sustainable practice and that engineering education needs to equip students with core engineering skills which are complemented by an understanding of how engineering both affects and is affected by environmental and social contexts. This need led to stepping outside of the traditional higher education box to give 'birth' to a Master of Science (MSc) course in Sustainable Engineering Management for International Development (SEM4ID).

The SEM4ID MSc curriculum is oriented around global service learning (GSL) projects, using a project-based-learning (PBL) pedagogical approach (Blumenfeld *et al*., 1991), with key skills developed and/or strengthened through project delivery and transdisciplinary learning, whilst working in a specific (overseas) community context. As well as undertaking inductive needs assessments, design and delivery management of an appropriate engineering intervention, students have responsibilities to manage their relationships with the community and the stakeholders, identify how best to apply their skill sets and work effectively in a multidisciplinary team. The field work supported by theoretical teaching delivered by the College of Engineering (CoE), the College of Arts and Humanities (CoAH), School of Management (SoM) and external practitioners, is designed to prepare students to function sensitively in foreign cultures, develop and act on the whole-problem definition. The students work to

transfer ideas into engineering solutions, critically evaluate the appropriateness of technological applications for a given social and economic context and monitor and evaluate the impact of projects.

Whilst the potential benefits for learning and skills development through GSL using PBL has been well documented, the delivery of a mastered course centred around GSL presents huge challenges, from course approval to logistic organisation to operating ethically in the field to effective partnering with the community. A number of barriers had to be overcome to start the SEM4ID MSc and the course continues to face different challenges with each cohort/project cycle.

This paper reflects on the first three years of programme delivery from the perspective of four academics who developed and currently run the SEM4ID MSc course, each from the different disciplinary viewpoint of social science, internationalisation, engineering education and engineering practice.

Dean of Internationalisation: stepping outside of the traditional academic box

The SEM4ID MSc programme is a result of a transdisciplinary research collaboration between social science academics within CoAH and several engineering academics within the CoE at Swansea University. This group was previously engaged in multidisciplinary research work related to various aspects of improved access through rural motorcycle taxi track development in Liberia. As a further development of this research, the academics supervised a group of Master of Engineering (MEng) students to work specifically on a project to design a motorcycle trailer, building and testing it in-situ. Even though the initial design produced in Swansea was functional, when the local motorcycle riders tested it Liberia, they decided it was not usable. The students revisited the design assumptions using feedback from the local riders and embarked upon a 'human centred' design process in the field, to develop prototypes which were more acceptable (Brown *et al*., 2015).

It was clear to the supporting academics that the experience had been of incredible value to the professional development of these young student engineers, having gained first-hand experience of fundamental engineering practise through the field-based project. More importantly still, this experience was gained in a very different environment and amongst a different culture to that which they were familiar. Critically, the students had realised the important role of the end user, through community engagement. During the final debrief, one student stated that he felt he had learnt more in the one-week field trip than in the last year of his degree.

After reflection and significant liaison between the supporting members of staff who had accompanied the student team into the field, the idea of developing an MSc degree that centred around experiential learning evolved. The idea was to blend social science tools with fundamental engineering and project management principles through PBL in development contexts. The aim was to recruit students from any background to form well balanced (including gender balanced) project teams consisting of engineering, social science and other non-engineering graduates and/or practitioners, to further scaffold knowledge through interdisciplinary peer to peer learning. The aim of the curriculum was to equip graduates from any background with the ability to navigate around complex projects, to develop a holistic approach towards problem solving and be able to manage engineering interventions in different development contexts sustainably.

It was quickly realised that the diversity in the teaching and support team required would go beyond that of the existing academic cohort within Swansea University. To allow for teaching contribution from experienced practitioners and external consultants, essential for the delivery of this course, and to have the flexibility in timetabling to accommodate for the necessary field trips, the programme delivery is designed around short intensive two-week modules, rather than term-long ones. The curriculum is

structured to develop knowledge and skills in timely steps in preparation for project work and field trips.

The governance process meant that the programme had to be approved by key committees within Swansea University. All of these groups could see the value in the programme. However, there have been concerns over the risks associated with the field-based elements, the cost of running such a programme and the burden on support staff, given the "depth of engagement" essential in running a course like this. Course specific mitigation strategies had to be put in place before the course was finally approved. The course currently requires funding (albeit progressively reducing) in addition to what is available from student fees, which is a threat to its long-term survival.

Now in its third year, the SEM4ID MSc delivery format still faces institutional challenges in course organisation, timetabling and logistics, due to it being very different from the traditional courses, which the university is experienced in delivering. Accreditation by the Engineering Council with a licensed engineering institution also presents challenges, as the course assessments do not include any formal exams and is based 100% on coursework. Also, the core learning through the project work is carried out by multidisciplinary teams of engineers from various disciplines as well as non-engineers and it is more of an administrative challenge to directly verify individual learning outcomes aligning with requirements for the Accreditation of Higher Education Programmes (AHEP).

The social scientist: a sustainable international development perspective

These days development takes place via partnerships, something that is recognized by the Sustainable Development Goals and its predecessor, the Millennium Development Goals. The development jargon talks about: 'inclusiveness'; 'pro-poor'; 'gender-awareness/sensitive'; 'empowerment'; 'participation'; 'community-driven'; 'knowledge co-production', 'good governance' etc. While these terms often lack clear and agreed definitions – some terms are both a 'means to achieve a goal' and an 'end-goal' in itself – it provides a framework to critically assess a project cycle or technological intervention from its conceptualisation, to feasibility, design, production, use and monitoring and evaluation stages. Furthermore, contemporary development collaboration or interventions – even those that are engineering heavy - require a multidisciplinary approach, with engineers working together with social scientists (eg. gender specialists, anthropologists, economists, political scientists, etc.) and scientists (eg. biologists, geographers, health experts, etc). Old fashion 'box or discipline' thinking no longer suffices. A case in point is the rural road-construction in developing countries – once the exclusive domain of engineers. The project described below sowed the initial seed which led to the development of SEM4ID.

In Liberia, the Ministry of Public Works (MPW) requires feeder roads (typically low volume roads which connect to the country's primary road-network) to be constructed or rehabilitated according to international standards to be at least 5 metres wide and with water-crossings able to accommodate up to 40 tonnes, resulting in expensive and arguably over designed structures. For war and ebola affected Liberia, mobility and access is vital, in particular for semi-subsistence farmers who tend to be among the poorest of the poor. While MPW's strategy seems to be a sensible one, it does not acknowledge the rapid changes that have taken place in mobility in Liberia (and for that matter, across sub-Saharan Africa). Where before most if not all motorised transport in rural areas took place by conventional vehicles (shared taxis, pick-up trucks, mini-buses, etc.), nowadays the majority of passenger and goods transport takes place by motorcycle taxi. Our intervention (Jenkins & Peters, 2016) took this rapid – and market driven - change in the means of transport as the starting point, and proposed a new type of road infrastructure: upgrading rural footpaths (between farmstead and village and between village and roadside) to motorcycle taxi accessible tracks and assessing the socio-economic impact of this intervention. Through the creation of (gender-balanced) community-based organisations, the planning,

organisation, construction and maintenance of these local labour and local materials intensive interventions were firmly put into the hands of the beneficiaries. Our study found that the economic impact - mainly by making it possible for farmers to bring agricultural produce to markets using motorcycle taxis rather than having to head-load, allowing for a larger volume to be monetised - and benefits following improved access to education and health facilities were significant and value for money (Peters *et al.*, 2018).

Motorcycles are generally characterised as intermediate forms of transport and associated developments such the trailer to increase payload, designed by Swansea University MEng students are considered as intermediate technology. However, to label something as 'intermediate' may reflect Rostow's 'linear-stage' thinking (Todaro, 2000). A more appropriate and contemporary term is 'appropriate' technology or innovation, acknowledging the context specific availability of resources/commodities and the need to use human ingenuity rather than blue-print thinking. Appropriate innovation and technology, sometimes described as 'frugal innovation' (Leliveld & Knorringa, 2018), aims to do more with less and is generally compatible with the three pillars of sustainability: social, economic and environmental, or at least considerably more than conventional resource-intensive innovations.

The focus for the SEM4ID MSc course is for students to deliver projects with technology or engineering elements which are 'appropriate' for the setting, paying due attention to the limited resources of the community where it is based. A solution may require the engineering technology involved to be basic/frugal, but the key value is in the process of verifying appropriateness through genuine interdisciplinary teamwork and co-production. For instance, while the structure for a chicken manure fertilizer compost drum, designed by one of the SEM4ID project teams was basically no more than a welded frame with rollers and a crank-arm, some of the challenges the student group were confronted with (and collectively had to find solutions to) when constructing it included: 1) The non-availability of the main organic input (chicken manure) due to the unforeseen closing down of a chicken farm, exemplifying the high uncertainty in availability of inputs due to rapid economic changes. 2) Challenges in working with local students due to culturally induced miscommunications/misunderstandings and different expectations associated with hierarchical structures. 3) Logistical challenges resulting from budgetary uncertainties, reflecting uncertain and volatile environments for operation and; 4) Mitigating varying perceptions of attitudes to safety and risks, in a context where bricklayers may wear flip-flops and welders use sunglasses. Rather than just delivering the appropriate innovation's hardware (eg. the compost tumbler), finding solutions to these hybrid (engineering, social, economic, cultural, etc.) problems and challenges – together with local students and local project participants – is the real contribution our GSL projects made.

The engineering education perspective: developing an integrative pedagogy to rehabilitate engineering students into engaging with social context

The course structure was developed to mix and match engineering and social science taught content and methodologies in order to combine action-orientated engineering problem solving with more inductive approaches to facilitate more equitable working in partnership. Students and staff from engineering have found this transdisciplinary shift more challenging than the social scientists involved, and the pedagogy adopted in the course has had to shift over time to accommodate this. Rather than a simple merging of skillsets between the two disciplines, engineering students have often struggled with being confronted with the inadequacy of their academic engineering training in preparing them to work with real people on a project that could have positive and/or negative consequences for vulnerable communities. Instead of 'topping-up' their knowledge with extra skills, it seems to involve a re-creation of their own conception of engineering and engineers. There are complex social and financial

relationships underpinned by persistent racial, colonial and gendered structures of power, for which most engineering students do not have either the awareness to recognise, or the language to explore. As recognised by Downey (2015), there is "*continued dominance across many countries of an image of engineering formation that places highest value on mathematical problem solving*". This prioritisation of mathematical processes leaves engagement with 'fuzzier' social, moral and ethical issues to the periphery of the curriculum. Yet the ability of students to unpick and explore the social context of the situation is a pre-requisite for an appropriate level of socially just 'problem definition'.

In the process of finding an appropriate pedagogy for the course, the teaching, learning and assessment strategy is moving towards the integrative approach suggested by Jamison (2014). This proposes a dramatic shift from the traditionally value-neutral, context-light paradigm of engineering education towards a recognition that engineering both informs and is informed by social, environmental and economic factors. It necessitates changing how engineering is viewed and practised, and places weight on understanding how both personal agency and professional agency interplay with wider context.

Three principle interventions have aided the transition for engineering students:

Needs assessment adopting techniques drawn from grounded theory

Grounded theory (Glaser & Strauss, 1967) is a qualitative research method that uses observation data and inductive reasoning to build context-specific theoretical foundations from which to plan appropriate interventions. Since engineering students are traditionally educated in deductive research methods following the scientific method, inductive approaches are an unknown methodology. By broadening their toolkit of methodological techniques, the aim is to assist the students to be able to switch consciously between inductive and deductive modes appropriate to the situation. This is to combat the tendency of the engineering students to solve problems before they have spent enough time understanding the underlying need and root causes of a situation.

Empathetic design thinking

Design Thinking (Brown & Wyatt, 2010) is a human-centred approach to design that prioritises empathy, root cause analysis and allows space for creative ideation. It has been the experience of the course educators that many enrolled engineering students often lack creative skills, and do not use a wide field of inspiration to stimulate design. Teaching design thinking and ideation methods (designing extreme solutions, proliferation of design ideas etc.) has helped the students to come up with a wider range of more creative solutions during design development.

Critical Reflection

The use of critical reflection, in particular the use of Reynolds (1998) framework requires bringing issues around social power to the fore for analysis and evaluation. Individual privilege, race, gender and colonialism are issues that are discussed both in the classroom and in one to one advice sessions. This is a visibly uncomfortable process for some students, particularly those who are unaware of how their privilege manifests. After their initial immersion trip to visit their partner, students are encouraged to identify one or more 'critical incidents' which caused them discomfort, and reflect on that situation from their own perspective and the perspectives of others, drawing on knowledge from established and informal (e.g. blogs) literature to triangulate their experience against wider theory. This helps to draw out how the students' own positionality is a factor that affects daily interactions, affecting every stage of the project, from how well they can understand the underlying need to how effectively and equitably they can conduct work with their project partner. The aim is to have students conscious that they may be unwittingly reproducing unhelpful power dynamics in their relationship with their partner. Many students come to the course with a 'server-served' attitude, and the aim of critically reflective practice

to move them towards an interdependent relationship striving for equity, recognising that all project partners have agency (Bruce, 2018). The consequence of this is that many students start to question whether it is right that their learning experience is occurring potentially at the expense of the time and effort of their partners. It is positive that they are asking the teaching staff these questions, as it evidences a critical mindset in action. However, this is a conversation that most engineering educators are not equipped to deal with, and where the partnership with social scientist colleagues on this program is invaluable.

The engineering practitioner's perspective: a balancing act between academia, project delivery and community impact

Whilst the benefits of experiential learning through GSL projects has been observed by the SEM4ID course instructors, the measure of success for the course is not as straight forward as just meeting the desired learning outcomes. There is also a huge social and ethical responsibility to ensure that the projects serve the communities where they are based (Larsen, 2016). A key challenge for the course is in striking a balance between meeting the community's needs, students meeting the desired learning outcomes, and also on some level, to fulfil the intended research output. The academic institution and students stand to gain from the typical GSL process, irrespective of the project outcome, but where does this leave the community and the other stakeholders? Of course, the goal and desired outcome is to create positive impact for the community, however, the responsibility of simply 'doing no harm' is just as challenging (Hartman and Kiely, 2014).

For GSL, there is an increased demand for accountability and demonstration of community impact and global learning outcomes, followed by academic research to outline priorities, key issues, questions, and dilemmas for GSL in practice (Lough & Toms, 2018). Academia aside, from a practitioner's perspective, it is a challenge to deliver an engineering project which is deemed successful by all stakeholders, whether it is in a developed or developing setting. In a 2015 KPMG Global Construction Survey, it was found that 53% of the owners of projects suffered from underperforming projects in the previous year (KPMG, 2015). Community capacity building is also no easy feat, even for well-established development practitioners with resources. While the World Bank has invested billions of dollars on hundreds of projects in Africa over decades, the failure rate of projects was over 50% (Dugger, 2007). Many other agencies and donor countries have not performed with much more success (Associated Press, 2007). If it is difficult for experienced professionals to get it 'right', then what chance do MSc students have in delivering successful projects, when they are constrained by the academic schedule, limited by uncertain financial resources and the lack of experience?

What the SEM4ID MSc projects aim to achieve is very challenging, the academics supporting the projects are learning just as much from the students and the community partners in order to make continuous improvements to how the projects are managed and run. To this extent, it is aimed that the projects at least 'do no harm' for the communities they support in the in the first instance, and with time, experiential learning and effective partnering, some of the projects may be able to deliver positive impacts for the communities. Along the way of project delivery there are opportunities for all those involved, including the students, academics, the local community, NGOs and the local civil and government organisations to learn from the experience. It is hoped that the SEM4ID MSc projects can provide case studies and examples of bottom-up community capacity building, which could be used as learning resources and serve communities in similar settings.

A key limitation in project delivery is posed by the nature of it being MSc research and the confining logistic constraints, this was highlighted by a project from the 18/19 cohort. The project team worked

closely with a school in Zambia to identify that one of the issues the school faced was their water supply. The school was putting all their resources into paying for water from a water company. Consequently, the school was not able to run their food programme for poorer pupils and they had to levy pupils for fees, which is discouraged by the Zambian government (MGE Zambia, 1996). Working together with the school, the project team focused on the solution of providing the school with a borehole. With a more accessible water source, as well as everyday use, the water from the borehole could facilitate an aquaponics system, which has the potential to further enhance the school's income generating capabilities. Following the initial needs assessment supported by a structured co-design process with the school, the students diligently applied for a grant to fund the borehole and obtained further resources through crowd funding and built an aquaponics system. The aquaponics system was built in the three-week period designated for project delivery, just before the cohort completed their studies.

Whilst the aquaponics system was built, the project is far from being complete. Much more work is required to ensure that the system is well maintained and when the system is not working, investigative work is done to identify the cause to enable further improvement. The school does not have the technical capacity and resource to be able to make the necessary technical improvements to the system. In order to support the school, a new project team from the 19/20 cohort will continue the aquaponics research work and the SEM4ID course will continue to support the aquaponics project until a stage when the system is sufficiently developed and the school has built capacity to run it independently. This may take a number of years, which was not accounted for at the project conception. In recognition that in order to complete projects meaningfully, it may take more than one student in take, some elements of the course will be redesigned to give space for long-term project planning which includes clear monitoring and evaluation processes to be managed by multiple cohorts.

Despite strategically designing a number of modules to develop students' skills in communication and managing complex relationships, and creating tools to help them function sensitively in a foreign cultural setting, communication, both internally within the multidiscipline and multinational teams and between the teams and the stakeholders remains challenging. Feedback and reflections from the students indicate that they learn the most from application of the theory learnt in the field. However, the learning process takes time, it has been observed that for most projects, effective communication only starts to happen towards the end of the project (Xavier & Holness, 2018). From a project delivery perspective, whilst the students could make a genuine contribution through their work, the project outcome is again limited by the available time in the field. To further support the communication process, we will explore providing the students and community partners with a broader course level terms of engagement, outlining the typical roles and responsibilities of partners on a SEM4ID MSc project and provide more support for project teams to develop their project specific amendments.

Conclusion

The SEM4ID MSc is still in its early years and in this paper, we focus on course development rather than detailing the observed benefits to date. This paper is deliberately written from the different voices and perspectives of some of the academics involved in the SEM4ID MSc conception, delivery and development. Whilst the collective vision and goals for the course are the same, when these are put under different lenses with varying focal points, what we individually observe and perceive as lessons learned, the challenges of stepping outside the box and the necessary future development of the course, take different shapes. Collectively, the process of working together to reflect on where the course has come from, where it is now and where it needs to go in the future and how to get there, aligning our slightly different priorities and points of views and translating these into changes, is essential to the course survival and future success. This process is also the essence of multidisciplinary work and

transdisciplinary learning. The voices of the host communities and other partners we work with is missing from this narrative. This is something we hope to explore this in more depth in the future.

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