Assessment of socio-technical and co-design expertise in humanitarian engineering

1 Focus and relevance

Humanitarian Engineering (HE) is emerging in universities and professional workplaces worldwide. HE projects exist at the intersection of engineering and sustainable community development, and therefore socio-technical and co-design expertise are fundamental. However, such skills and mindsets are difficult to teach, learn, and assess. There is a need to develop effective teaching and assessment strategies, dependent upon clearly operationalised definitions of both socio-technical and co-design expertise. Although there is an evolving consensus around co-design, the literature lacks a clear understanding of the key features of socio-technical expertise. We addressed these gaps through the following research questions:

1. How does experienced humanitarian engineers' socio-technical and co-design expertise differ from those of novices?
2. How do students develop socio-technical and co-design expertise?

We explored these questions by developing a theoretical framework and instrument that can be used for program and unit evaluation, and to evaluate the development of socio-technical and co-design expertise in engineering students and practitioners.

2 Context

2.1 Humanitarian engineering practice and education

Humanitarian engineering (HE) focuses on the design of products and systems to support the sustainable development of resource-constrained communities [1]. Engineering programs have long offered service-learning courses with a focus on HE, as they help attract diverse engineering cohorts and prepare students for the workforce [2]. Recently, some universities have begun offering HE minors and majors [3]. As such programs become more popular, more students will engage with communities and the number of engineers engaging in community development will increase. Consequently, understanding what attributes humanitarian engineers need to possess, and how to assess such attributes, becomes critical.

Research focused on best practice in HE provides insights into which attributes are required. For example, involving and empathising with community members is a key success factor in HE projects [4], whereas ignoring the socio-economic, political, cultural, historical and environmental dimensions of the project context leads to failures and negative impacts on the communities engineers had intended to serve [5]. These studies suggest that co-design expertise, or the ability to involve the local community across all stages of the design process, and socio-technical expertise, the ability to integrate social and technical dimensions in solving a design problem, are particularly important in HE.

2.2 Scenario-based Assessment

Assessments of abstract skills, such as socio-technical or co-design expertise, can range from self-reports to observational studies. Self-report instruments have been used to assess a large number of constructs, but have been criticised for being unable to accurately predict behaviour [6]. Conversely, simulation-based assessments [7] can be more reliable in directly assessing participants' behaviours in realistic situations. However, they are time-consuming and only used with small sample sizes.

Scenario-based assessments offer a compromise between self-reporting and simulation-based assessments. While being more time-consuming to score than self-report scales [8], they can evaluate the potential behaviours of participants in realistic situations while being administered to more respondents than simulation-based assessments. Scenario-based tools share three main components: a description of an open-ended, realistic situation presenting a problem to be solved, questions related to this scenario, and a rubric.

In engineering education research, scenario-based instruments have been used to assess a wide array of constructs, including adaptive expertise [8], design skills [9], interdisciplinary problem-solving [10], knowledge of global, societal, economic, and environmental contexts [11], and empathy [12]. Until we commenced this study, however, there were no instruments to reliably assess socio-technical and co-design expertise.

3 Research Design

Our research design has had two main stages. The first stage has focused on developing a theoretical framework describing socio-technical and co-design expertise, and a valid and reliable scenario-based instrument. The second stage has comprised evaluating how different learning experiences impact students' development of socio-technical and co-design expertise.

3.1 Stage 1: Theory and Instrument Development

When studying expertise there are generally two approaches: the absolute approach and the relative approach [13]. The former entails the study of exceptional people alone, while the latter investigates differences between novices (i.e., individuals with no or minimal exposure to the domain being studied) and experienced practitioners (i.e., individuals with extensive experience). Because at the beginning of this study, we did not have an objective means to determine the expertise of individuals *a priori*, we took a relative approach by collecting data from students about to start their engineering degree and from engineering practitioners with experience in HE education and practice.

Specifically, we asked both groups to complete the Energy Conversion Playground (ECP) design task [14]. This task is comprised of a scenario, describing a problem in the context of HE, and two open-ended questions. The scenario was based on real case-studies of HE practice and the two questions were developed to elicit socio-technical considerations and co-design strategies to solve the problem described in the scenario.

Table 1. Examples of application of Q^3 framework

Criteria	**Examples**
Theoretical validation	Scenario based on real case-studies of humanitarian practice Analysis cross-checked against literature
Procedural validation	Interactive and inductive analysis process grounded in the data, not on personal perceptions
Communicative validity	Workshop with other scholars to sense-check rubric
Pragmatic validity	Purposive sampling to collect data from diverse populations
Ethical validation	Ethical clearance, de-identification of data
Process reliability	Independent scoring and consensus building Inter-rater reliability

To create a theoretical framework, we inductively and iteratively analysed a subset of the students' and practitioners' responses and identified key theoretical features characterising different levels of expertise, and cross-checked these against the relevant literature. Next, we used this characterisation to create a rubric which we then used to score all the responses in our dataset. We scored each response independently and met multiple times to discuss our ratings, reach consensus, and update the rubric accordingly. Finally, we sense-checked our rubric by running a series of workshops with other scholars. The result was a reliable and valid instrument, grounded in both data and literature. Table 1 (above) provides examples of how we applied the Qualifying Qualitative Research Quality (Q^3) framework [15] throughout the entire process.

3.2 Stage 2: Evaluation of Learning Experiences

Since we conducted the study with the practitioners and students (stage 1), we have initiated pre-post and longitudinal studies to understand to what extent engineering students develop socio-technical and co-design expertise and how effective different learning experiences are at cultivating this development.

The pre-post studies involve courses using innovative pedagogies, focused on society, technology, and the environment. This includes summer and winter units at ANU and RMIT that incorporate the EWB Design Summit and Unbound programs, and units at Swinburne and ANU that incorporate industry and community projects. At Swinburne, we are also tracking cohorts of students longitudinally, collecting data once a year.

The data collection and analysis procedures are very similar for both pre-post and longitudinal studies. We ask students to complete the ECP design task, score their responses using the rubric developed during stage 1, and then use non-parametric statistical tests to evaluate changes in socio-technical and co-design expertise.

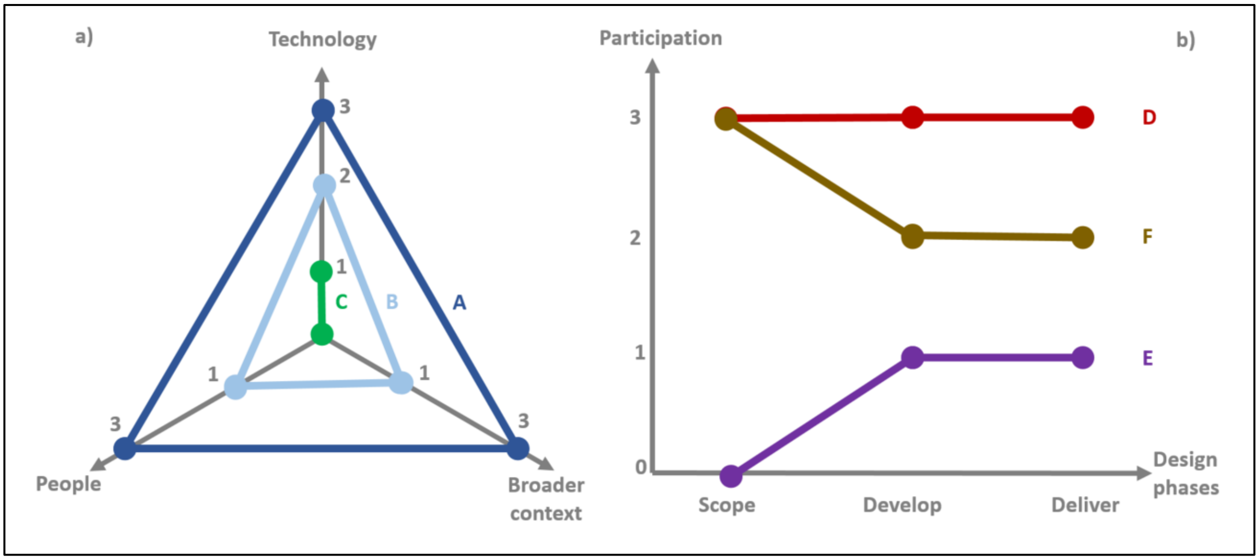
4 Results

Stage 1 of our research study has produced two main outcomes: a theoretical framework characterising socio-technical and co-design expertise, and an instrument to assess this expertise. In terms of socio-technical expertise, our analysis indicates that socio-technical experts demonstrate complex understanding of three domains: *technology*, *people*, and the *broader context*. Specifically, socio-technical experts consider both immediate and long-term technical aspects of design [*technology*], collaborate meaningfully with stakeholders [*people*], and recognize the complexities of broader socio-material and ethical dimensions of humanitarian engineering work [*broader context*]. In terms of co-design expertise, our analysis indicates that co-design experts are those who tend to use collaborative strategies when *scoping* a project, *developing* design ideas, and *delivering* the final product or service.

The ECP design task enables us to understand the expertise of respondents. Our rubric assesses the breadth and depth to which respondents have articulated considerations within the *technology*, *people*, and *broader context* domain on a quality scale from 0 to 3. For instance, figure 1a shows the profile of 3 respondents. Respondent A shows the behaviour of an expert, scoring high on all three domains. Conversely, respondent C is a typical novice, scoring only in the technical domain, but failing to consider people and broader context. Respondent B instead is between A and C in the expertise spectrum.

The co-design rubric enables us to score participants' responses on how well they are involving stakeholders throughout the three main design phases: *scope*, *develop*, and *deliver*. For instance, in figure 1b, respondent D demonstrates high-level expertise by mentioning collaborative approaches throughout the design process (and so scores 3 across the board). Respondent E shows typical novice behaviour by not mentioning anything for scoping (score 0) and going straight into developing and delivery without considering stakeholders (score 1). Respondent F shows a behaviour between novice and expert, describing a collaborative approach to scoping the project and a consultative approach to developing and delivering the project (score 2).

Figure 1. Socio-technical and co-design expertise profile of respondents.



Results from stage 2 are limited as this phase of the study is still ongoing. Our preliminary results suggest that it takes a long time to develop socio-technical and co-design expertise, and therefore that single-semester units focused on society, technology, and the environment, are insufficient in supporting students to develop this expertise.

5 Contribution

This work has made contributions in education, research, and to the broader community.

At our home institution, Swinburne, and with colleagues at ANU and RMIT, we are evaluating teaching interventions and tracking the development of expertise. As well as using a pre/post methodology to evaluate learning and teaching, we have used the ECP design task as a teaching tool in itself, in two ways: primarily as a prompt for reflection, by having students compare their pre- and post-responses and discuss together what this says about their own learning, and also, by unpacking the rubric with students, as a device for highlighting how we have operationalised socio-technical and co-design expertise. We are also beginning to use our work to inform curriculum development discussions. For example, one finding has been that long-term technical considerations are consistently identified by experts, but generally not identified by novices. This is a prompt to make sure such topics are properly addressed in the undergraduate curriculum, to ensure we are giving our students the best possible preparation.

We have contributed to the research community by sharing our validated assessment instrument for socio-technical and co-design expertise, and providing an exemplar of the development of scenario-based tools in novel contexts. In addition to our upcoming AAEE workshop, we have shared our research at REES 2019 [16], and have publications in press with JEE [17] and under review with EJEE [18].

More broadly, we were invited to share our work with the humanitarian engineering community at the 2018 EWB *Making an Impact Summit*, and to give a workshop on how co-design can be applied to education projects with policy-makers and project leaders from the Department of Education and Training Victoria. Thus, our research is not only impacting academic educators and researchers, but also practitioners beyond academia.

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