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Building capacity to achieve sustainable outcomes for wicked problems

H.R. Maier [a] , **S. Culley** [a]

[a] *School of Architecture and Civil Engineering, The University of Adelaide, Adelaide, South Australia*
Email: holger.maier@adelaide.edu.au

Abstract: A hallmark of environmental engineering is the need to deal with complex systems, as well as interactions between society, the environment and infrastructure (Figure 1c). This often requires dealing with professionals and stakeholder groups with different backgrounds and perspectives, as well as understanding and managing trade-offs between competing objectives and how these change over time in order to achieve sustainable outcomes (Figure 1b).

In order to enable Environmental Engineering students at the University of Adelaide to develop these skills, the capstone course Decision Making for Sustainable Solutions was developed in 2022. The course provides an authentic, immersive learning experience in which students have to work together to "solve" a wicked problem. This enables them to utilise and combine a variety of the technical skills they have developed throughout their degree program, while developing a much broader range of "soft" skills (Figure 1).

The wicked problem considered in the course is the renewable energy transition. The course is delivered as a roleplay, in which groups of students represent organisations from different sectors that develop renewable energy transition pathways and technology roadmaps. This is done initially in isolation from the perspective of their organisation / sector. The plans produced by the different organisations are then shared to enable students to see different perspectives on and solutions for the same problem, before students from organisations from different sectors work together to arrive at a negotiated compromise solution. Finally, students step outside of their role and reflect on what they have learned from their experience.

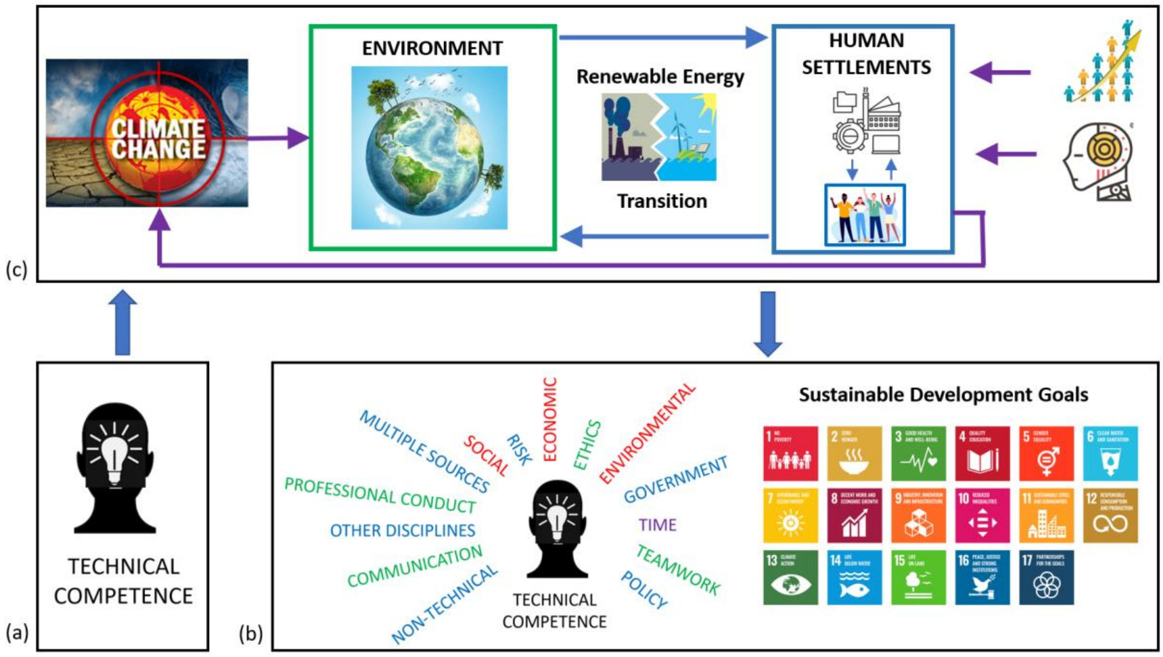

Figure 1. Overview of teaching approach, as part of which (a) students with a high degree of technical competence (c) participate in an immersive learning experience on the renewable energy transition to (b) develop a broader range of skills, as well as a deep understanding of sustainability and the complexity of decision-making

Keywords: *Wicked problems, complex systems, decision making, sustainability, roleplay, renewable energy*

1. INTRODUCTION

A hallmark of environmental engineering is the need to deal with complex systems, as well as interactions between society, the environment and infrastructure within these systems. This often requires dealing with professionals and stakeholder groups with different backgrounds and perspectives, as well as understanding and managing trade-offs between competing objectives and how these might change over time in response to various drivers (e.g. climate change, population growth, technological development) in order to achieve sustainable outcomes (Figure 1c).

In order to enable Environmental Engineering students at the University of Adelaide to develop these skills, the capstone course Decision Making for Sustainable Solutions was developed as part of the Environmental Engineering degree program in 2022 (https://www.adelaide.edu.au/course-outlines/109874/1/sem-2/2023/). The course provides an authentic, immersive learning experience as part of which students work together to attempt to "solve" a wicked problem – the renewable energy transition. This enables them to utilise and combine a variety of the technical skills they have developed throughout their degree program, while developing a much broader range of "soft" skills (Figure 1). The course draws on the authors' experience of leading a number of research projects for the Future Fuels CRC that are focused on assisting the gas industry decarbonise by replacing natural gas with bio-methane. A number of the end users from these projects assisted with the development of this course, along with Environmental Engineering graduates from the University of Adelaide who work in renewable energy.

2. TEACHING APPROACH

The teaching approach adopted is a roleplay, as this represents an authentic and engaging setting for dealing with wicked problems. It also enables different perspectives on an issue, the meaning of sustainability and a range of generic skills to be developed in an immersive and experiential manner (Maier et al., 2007; Maier, 2007). The key to developing successful roleplays is the interplay between the issue / problem being addressed and the roles that engage with this issue / problem. The issue / problem has to be both wicked and controversial and the roles need to have different perspectives on, and a strong vested interest in, the issue / problem.

The generic structure of the roleplay developed for the Decision Making for Sustainable Solutions course is shown in Figure 2. As can be seen, the first step is "role adoption", as part of which groups of students adopt the roles of different pre-defined stakeholders in the renewable energy transition. As part of this step, students familiarise themselves with the policies and responsibilities of the organisation they are going to represent as part of the roleplay. The next step is "knowledge development", as part of which the various organisations work in isolation to address the issue / problem from the perspective of their organisation

As part of the "knowledge sharing" step, students have the opportunity to gain insight into the views of the other organisations on the issue / problem and the degree to which they align with or differ from their own. If the roleplay is designed well, this is an "aha" moment for students, where they realise that there are multiple perspectives on the same issue and that the "solution" to the problem they have developed from the point of

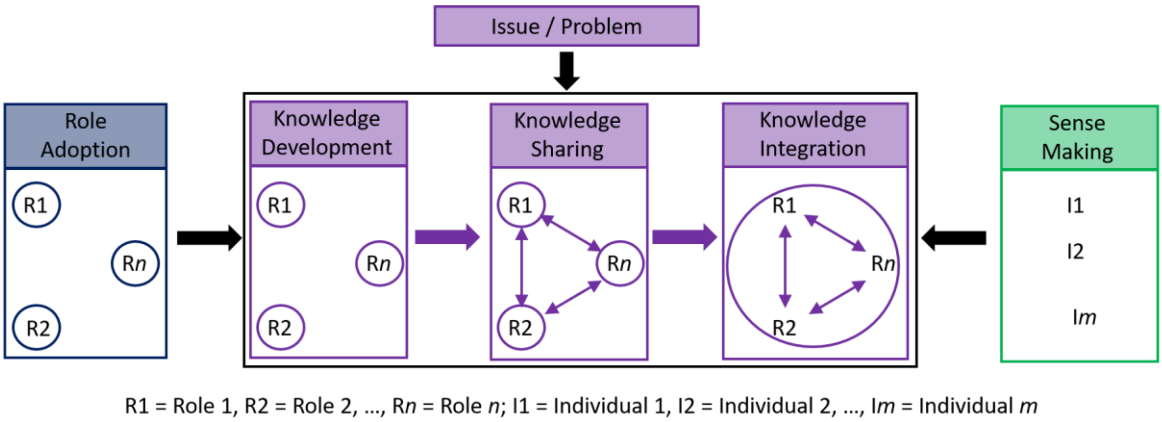

Figure 2. Overview of roleplay-based approach for building capacity to achieve sustainable outcomes for wicked problems

view of their organisation is unlikely to work for other organisations with different backgrounds and perspectives.

The “knowledge integration” step requires students from different roles to work together to arrive at a negotiated compromise solution. At the conclusion of this step, students step outside of their role and reflect on the activities of the roleplay in the final “sense making” step, which is done on an individual basis. This is where the majority of deep learning occurs, as students draw on their experiences and reflect on what happened during the interactive phase of the roleplay and relate this to the core learning outcomes.

3. THE RENEWABLE ENERGY TRANSITION ROLEPLAY

3.1. Roles and issue

As mentioned previously, selection of appropriate roles and issues / problems is key to the success of any roleplay. For the renewable energy transition roleplay, care was taken to select roles that represent a range of sectors that are affected by and have a vested interest in the renewable energy transition, as shown in Table 1.

The specific issue each of these roles has to address is to make a submission to the Federal Government on the best way to achieve the renewable energy transition for their sector, including development of a transition pathway to renewable energy sources (Figure 3b) and development of the technology roadmaps that enable these pathways to be implemented (Figure 3c). When doing this, each organisation has to try to achieve the objectives of their sector, while also ensuring the goals of the Federal Government (Figure 3d) are met. Development of the transition pathways and technology roadmaps requires students to draw on the research, modelling and analysis skills they have developed in previous years in order to obtain estimates of future energy demands, how these could be met by different energy sources, what associated impacts and costs are, what technologies are likely to available when and under what conditions and so on.

Table 1. Summary of organisations (roles), the sector they represent within the renewable energy transition and the primary perspective they bring to the table

Organisation	Sector within energy transition	Perspective
BHP	Mining/Manufacturing	Exporting green minerals/products
WSP	Mining/Other	Environmentally sustainable solutions to mining for renewables
Toll	Transport	Decarbonising land and maritime transport
Smart energy council	Energy supply/Residential	Electrification of residential/commercial usage
APA	Energy Supply	Renewable gases (hydrogen, biomethane)
Coles	Transport/Agriculture	Net zero emissions among supply chains
Acciona	Construction	Renewable energy for heavy industry
Central Land Council	Other	Land use requirements for energy transition
ANZ	Other	Financing renewable energy technologies

3.2. Activities and assessment tasks

A summary of the timeline of student activities and associated assessment tasks and weightings is given in Figure 4. As can be seen, during the role adoption stage, students select their role and the group of students assigned to a particular role (organisation) produce a role statement report, which summarises their organisation’s views, responsibilities and policies related to the renewable energy transition.

During the knowledge development stage (Figure 4), students produce their initial solution report, which outlines and discusses their proposed renewable energy transition pathway and the corresponding technology roadmap. This report highlights how the proposed solutions meets both the goals of their sector and those of the Federal Government (Figure 3d). Given the diversity of organisations, the diversity of sectors they represent and their diversity of perspectives (Table 1), there is significant variation in the transition pathways and technology roadmaps proposed by the different organisations. Development of the transition pathway and technology roadmap requires students to develop all relevant underlying models used to justify the proposed solution.

As part of the knowledge sharing stage (Figure 4), each organisation gains access to all other initial solution reports, making them aware of the differing objectives and needs of other sectors and how they conflict or align with their own. Each organisation critically evaluates the reports from the other organisations in preparation for a public forum, during which each organisation is able to question the other organisations about their

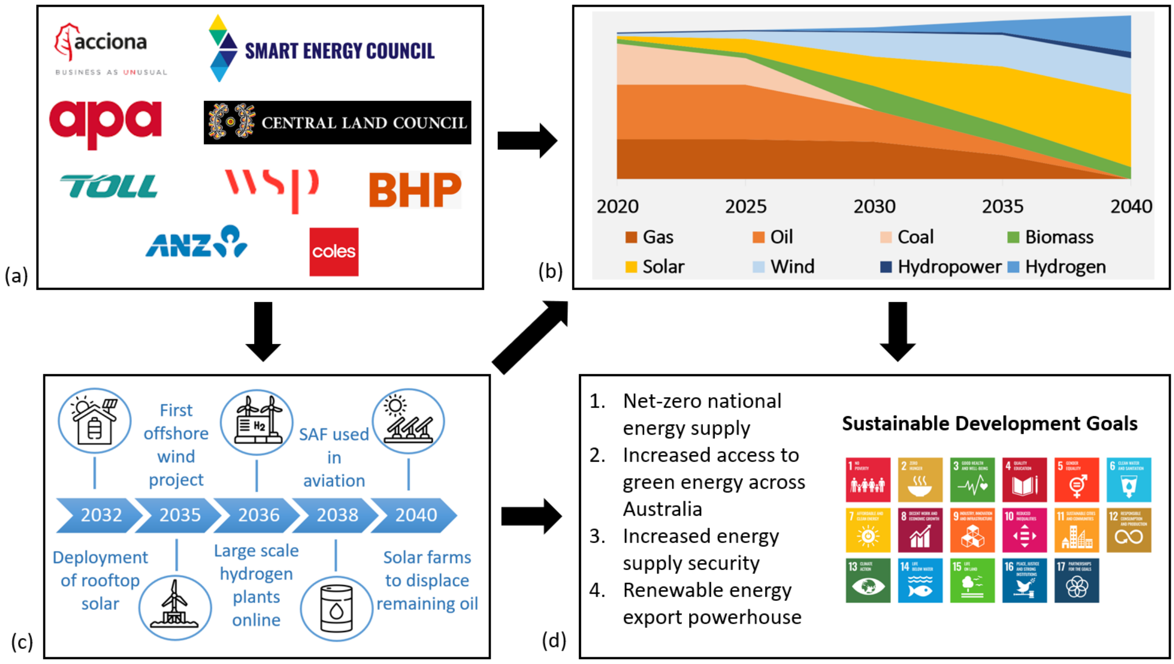

Figure 3. Summary of (a) different roles (organisations) with diverse perspectives and interests in the renewable energy transition (see also Table 1) used in 2022, the issues / problems these organisations had to address, including (b) the development of a transition pathway to renewable energy sources and (c) the development of technology roadmaps to enable these pathways to be implemented, and (d) the overall goals to be achieved by the transition

submission in order to support those elements of the reports that align with their goals and discredit those that do not. This process highlights the importance of backing up solutions and assumptions with credible evidence and adopting state-of-the-art and transparent modelling and analysis approaches. At the conclusion of the knowledge sharing stage, the Federal Government issues a brief outlining which issues need to be considered in the development of the final transition pathway and technology roadmap, based on the initial solution reports and presentations from the various organisations.

During the knowledge integration stage (Figure 4), the Federal Government invites a member from each organisation to be part of the task force that develops the final transition plan and technology roadmap in accordance with the brief the Government issued at the conclusion of the knowledge sharing stage. The task force includes at least one member from each of the sectors (Table 1), requiring a negotiated compromise solution to be reached, balancing the needs of the different sectors. In practical terms, this means that a number of task forces are established, so that each student can be part of a task force. The fact that students are part of a group of students with whom they have not worked with previously, and who play the role of organisations

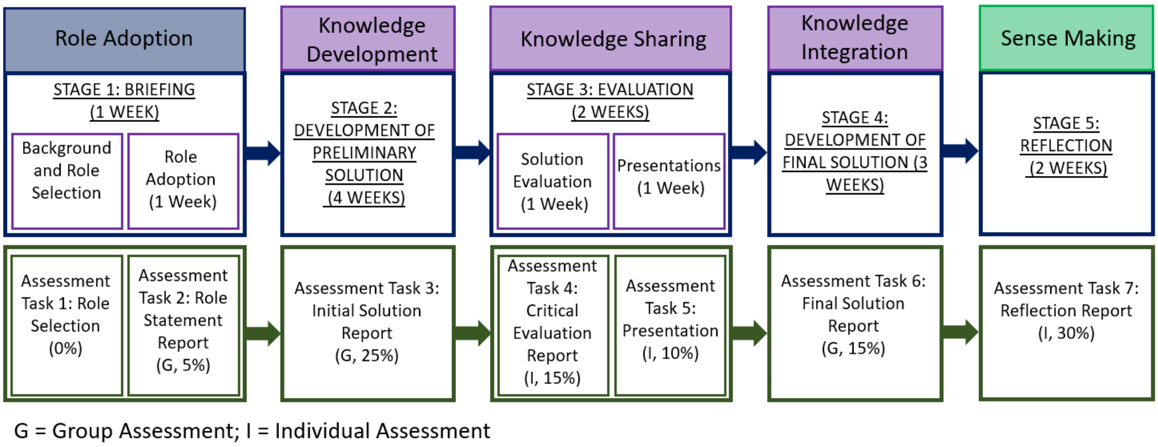

Figure 4. Timeline of student activities and associated assessment tasks and weightings

with different goals and perspectives, provides opportunities to develop a range of "soft" skills. Development of the final renewable energy transition pathway and corresponding technology roadmap by each task force marks the end of the "roleplay" component of the course.

As part of the sense making stage, students step outside of their organisational role and reflect on the degree to which their participation in the roleplay has assisted them with achieving the course learning objectives related to gaining a better understanding of the complexity of engineering decision-making, sustainability, the importance of modelling and data to support credible decision-making and the development of a range of generic skills (see Section 3.3).

3.3. Assessment rubrics

Given the self-directed nature of the course, the assessment tasks play a vital role in the development of the desired learning outcomes. Consequently, the learning outcomes are articulated clearly and explicit assessment rubrics are provided. In addition, great care is taken to ensure that students are able to interpret the rubrics, which is achieved by recorded videos explaining the rubrics and providing detailed exemplars for all major reports. The exemplars represent submissions from an organisation that is different from those students adopt (e.g. the transition pathway in Figure 3b and the technology roadmaps in Figures 3c and 5 are taken from one of the exemplars). The exemplars are also annotated to highlight what part of the submission aligns with different grades. This enables students to gain a clear understanding of what is needed to achieve different grades, but still requires them to apply this to the context of their organisation.

An example rubric for the technology roadmap component of the initial solution report is given in Figure 5. As can be seen, the different categories against which submissions are assessed are clearly articulated, along with descriptors of what each grade corresponds to for each of these (partially obscured by the blue arrows in Figure 5).

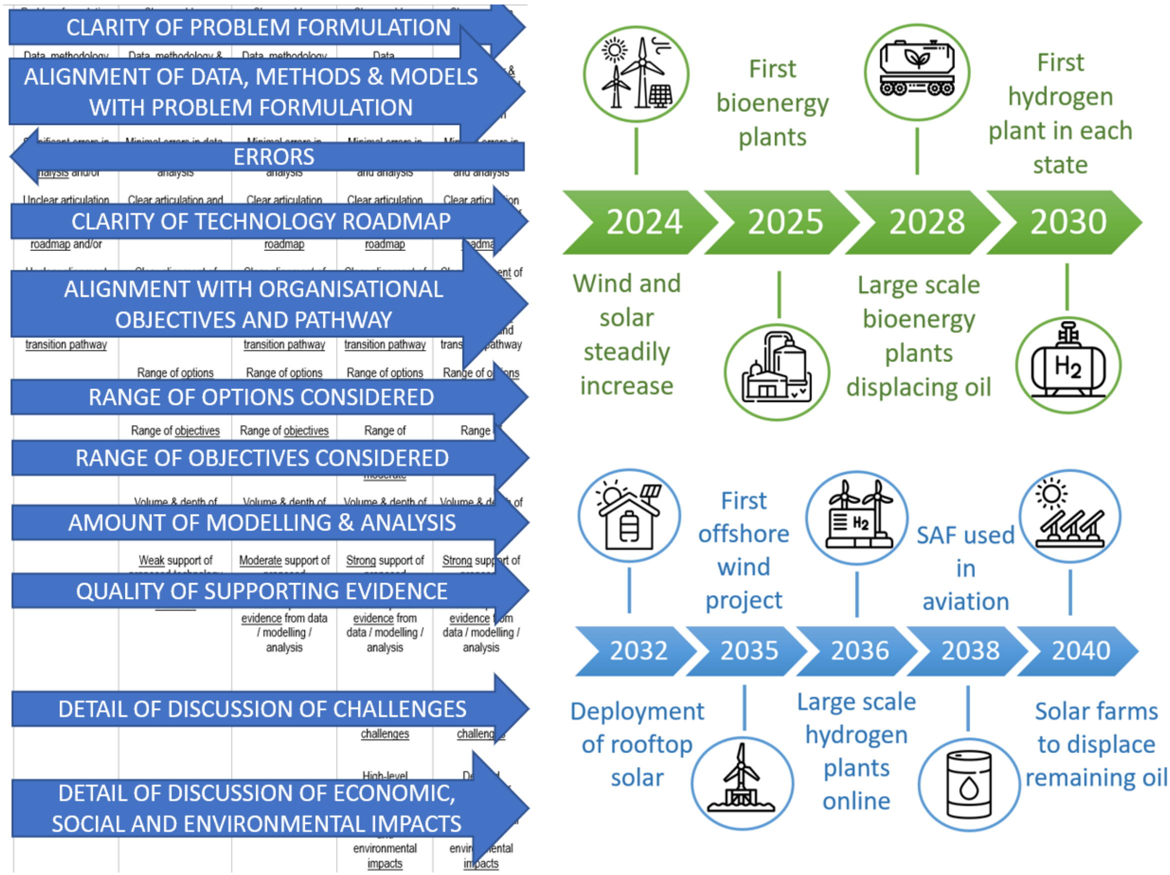

Figure 5. High-level summary of assessment rubric for questions related to the presentation and discussion of the developed technology roadmaps

(a) Reflect on how previous tasks have assisted with development of understanding of:

1. Complexity of engineering decision-making, including the need to consider (i) multiple perspectives; (ii) trade-offs
2. Sustainability, including (i) need to balance economic, environmental and social factors over time; (ii) impact of engineering projects on the sustainable development goals
3. Importance of at least two of (i) using models, data and other lines of evidence to support arguments, (ii) teamwork and communication, (iii) research, critical thinking, negotiation and decision-making skills, (iv) appreciation of cultural differences and approaches; (v) acting ethically and responsibly

(b)

FAIL < 50%	PASS 50-64%	CREDIT 65-74%	DISTINCTION 75-84%	HIGH DISTINCTION 85-100%
Prestructural: no relevant response, task is not tackled appropriately	**Unistructural:** i.e. one strategy/view used in the interpretation of the problem, focus on one relevant aspect (technique, discipline, socio-technical dimension) only, low level of concept differentiation, retelling of source materials with minimal transformation.	**Multistructural:** i.e. several strategies/views used to interpret the problem, focus on several relevant aspects but these are not integrated, some tolerance for ambiguity or complexity, there is some evidence of understanding, coverage and effort. Typically characterised by assimilation of knowledge rather than its integration.	**Relational:** alternate aspects of the problem are clearly represented and there is a clear recognition of a dynamic/linkage between them, selectivity and judgement used in incorporating what is more and less important for the argument.	**Extended Abstract:** use of outside references (bring new phenomena under existing concepts), conclusions are related to a broader set of issues outside discipline (generalise to new context), clear depiction of all aspects of the problem (differentiation) and their interactions (integration)

Figure 6. Details of the assessment related to the sense-making / reflection task, including details (a) of the assessment task and (b) of the marking rubric, which is based on the SOLO criteria

The key questions to be answered in the reflection report as part of the sense making stage (Figure 4) are summarised in Figure 6a and the corresponding assessment rubric is given in Figure 6b. The rubric is based on the SOLO (Structure of Observed Learning Outcomes) taxonomy (Biggs and Collis, 1982). A key feature of the reflective report is that it needs to be based on actual experiences or events from the roleplay, which students need to refer to explicitly. This not only encourages reflexive practice, but also minimises any potential for plagiarism.

4. STUDENT EXPERIENCE

The summary results of the Student Experience of Learning and Teaching surveys for the course the first year it was taught (2022) in terms of average student responses on a 7-point Likert scale are given in Table 2. As can be seen, overall, students felt very positively about the course, with average scores ranging from 6.3-6.4 out of 7 across a range of questions, covering the development of understanding, degree of intellectual stimulation, assessment and feedback, course organisation and overall satisfaction.

Table 2. Average student evaluation scores on a 7-point Likert scale

Question	Average Score out of 7
This course helps me build my understanding of key concepts	6.4
Overall, this course is intellectually stimulating	6.4
In this course, I receive useful and timely feedback on my work	6.4
The assessment tasks in this course help me to learn	6.4
This course is well organised	6.4
Overall, I am satisfied with the quality of this course	6.3

The following student comments also highlight different elements of student satisfaction with the course:

"*Really interesting concept for a course that encourages thinking from a very different perspective than we are used to. Resources such as exemplars were very useful to support that transition into the role of being a representative of a company. Active class participation was encouraged and made the experience a bit more 'real'.*"

"*There are a lot of good things about this course. The assignments are well crafted, each with their own exemplars attached, so you can see the right process to follow to achieve high grades. The rubrics are carefully stepped out so the students can see exactly what they need to cover in their work to score highly, and the feedback was very constructive, helping in improving the grades from previous assignments. There is a broad range of learnings in the course from effective modelling, teamwork, presentation skill and communication that most other classes do not have.*"

"*Best aspect is the organization of the coordinators and the role play. Specifically, conducting role play for the entire semester gives students enough time to properly align with a company.*"

"*The assignments are some of the best aspects of the course. Assignments are interesting and fun to solve:*

- *Getting into the role of a company within the energy industry and form a solution that deal with company interests and government objectives. It was good to practice considering conflicting interests in developing a solution.*
- *Working on a supporting model to back up the transition plan while having to consider the connection between transition pathway and technology roadmap.*
- *Good mix between report writing, research, and presentation work*."

It was particularly pleasing to see that students felt that the course (i) highlighted the importance of using models to provide the evidence needed to support decision-making for wicked problems, (ii) provided practice in considering conflicting interests when developing a solutions, (iii) encouraged divergent thinking and the consideration of different perspectives and (iv) facilitated the development of a range of generic skills. It was also satisfying that the rubrics and exemplars were helpful and assisted students with achieving to their full potential and that students appreciated the variety of assessment tasks.

5. CONCLUSIONS

The world is full of wicked problems. Consequently, there is an increasing need to develop the capacity to deal with such problems in a sustainable manner. This requires the development of skills in stakeholder engagement, system mapping, modelling and analysis, the ability to see different perspectives on an issue, the ability to deal with competing objectives and trade-offs and the ability to communicate and negotiate to mention a few.

In order to equip environmental engineering students at the University of Adelaide with these skills, the final year capstone course Decision Making for Sustainable Solutions was developed in 2022. The course achieves this by providing students with an authentic and immersive learning experience that is centred on developing transition plans and technology roadmaps for the renewable energy transition.

Decision Making for Sustainable Solutions is structured as a roleplay, as part of which groups of students adopt the roles of organisations that have different goals and interests in the renewable energy transition. By first developing solutions from the relatively narrow perspective of their organisation, then being exposed to the range of solutions developed by other organisations and finally working together to develop a negotiated compromise solution, students are able to experience what is involved in trying to "solve" a wicked problem in a sustainable manner first-hand. A key component of student learning is their reflection on their experiences of the roleplay and how they assisted them with developing a range of relevant skills.

ACKNOWLEDGMENTS

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