

Advancing Sustainable-Smart Innovations Through a Transdisciplinary Learning Intervention: Insights From The Quintuple Helix Model

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Abstract: The urgent need to shape the future of societies necessitates complex collaborative partnerships that co-create sustainable solutions. This whilst maintaining a balance between ecological, economic, and sociocultural concerns. The aforementioned creates complexity, calling for a transdisciplinary focus to circumvent the narrow lenses of disciplinary boundaries to develop new systems for educating young professionals. Within this context, we explore how a transdisciplinary learning intervention can result in sustainable-smart innovations that address real-world community challenges. To engage this question, we draw on findings from a longitudinal Design-Based Research (DBR) study that commenced in February 2020. Two iterations of this study have been completed and the third iteration commenced in 2023. Data is drawn from student project artefacts and reflections. This study utilises the potential of transdisciplinary student projects, between urban planning and information system students, and other stakeholders, to develop sustainable-smart innovations. It focuses on community challenges related to SDG 11 as experienced by marginalised township communities in Cape Town, South Africa. The study is founded on key concepts: Education for Sustainable Development, Transdisciplinary, Digital Social Innovations, Society 5.0, and Inclusive collaborative partnerships. These concepts allow the interrogation of the complexities that reside in wicked problems related to the localisation of SDGs. The introduction of the quintuple helix model during the project's third iteration to analyse the wider contribution from different stakeholders and the shift to Mode 3 knowledge application in innovation is of special value. This model lends itself to transdisciplinary methodologies specifically to merge many voices toward sustainable-smart innovations. The co-creation of sustainable-smart innovations involves unifying various stakeholders from academia, industry, government and the community, to jointly develop and implement sustainable and technology-enabled solutions. The contribution of this paper lies in the expansion of discourse on innovations for sustainability through our engagement with the quintuple helix model in a transdisciplinary learning intervention.

Keywords: sustainable-smart innovations, design-based research, transdisciplinary learning, quintuple helix model, collaborative partnerships

1. Introduction

There is an urgent call on universities to create an inclusive environment that fosters sustainable-smart innovations to tackle socio-ecological and cultural challenges. In particular, the paper highlights the need for South African Higher Education to demonstrate social responsibility and contribute to social and community value given its resource-limited context.

Although the importance of education for sustainable development is widely acknowledged, there is limited knowledge of how to design curricula that support the development of the competencies required for interdisciplinary and transdisciplinary learning (Horn *et al.*, 2023). In this paper, we explore this challenging task and ask the question of how a transdisciplinary learning intervention can result in sustainable-smart innovations that address real-world community challenges. We draw on findings from a study that commenced in 2020 between two universities in Cape Town, South Africa. The focus is to explore the value of co-creating digital social innovations in interdisciplinary and transdisciplinary student projects between Information Systems (IS) and Urban Planning (URP) students and other stakeholders. Data is drawn from the third iteration that commenced in 2023.

The paper commences with a review of the literature to explore a number of foundational concepts that frame and influence the student project. This includes a discussion on the Quintuple Helix model as an analytical framework. Subsequently, the methodology, results and findings are discussed to highlight the significance of transdisciplinary approaches to facilitate the convergence of diverse perspectives and fields of knowledge to enable sustainable-smart innovations.

2. Literature Review

2.1 Education for Sustainable Development through a Transdisciplinary Focus

Education for Sustainable Development (ESD) represents a significant approach that endeavours to embed sustainability and Sustainable Development Goals (SDGs) at all levels of education (Rieckmann, 2018). The overarching objective of ESD is to cultivate a cohort of learners who possess the necessary tools and competencies to effectively respond to intricate socio-ecological or wicked challenges. By fostering agency, ESD aims to empower students, as future decision-makers, to become catalysts for change, capable of addressing the threats to the sustainability of our planet (Sinakou et al., 2019).

Addressing such complex challenges demands competencies that transcend individual disciplinary boundaries (Mauser et al., 2013). An interdisciplinary approach, as opposed to a mere multidisciplinary approach that amalgamates contributions from various disciplines without integrating them, is vital for acquiring the knowledge to tackle current and future challenges (Bernstein, 2015). Furthermore, the range of knowledge required to address these challenges extends beyond the domain of science, necessitating a transdisciplinary focus (ibid, 2015). This underscores the significance of transdisciplinary learning in both education and collaborative innovation. To effectively address societal issues and facilitate collaborative knowledge co-creation, a comprehensive understanding of the implications of transdisciplinary learning for present and future sustainability challenges is indispensable. Thus, adopting transdisciplinary approaches is essential for addressing sustainability issues by means of collaborative knowledge co-creation involving multiple stakeholders from academia, government, and civil society (Horn et al., 2023).

Implementing inter and transdisciplinary learning practices is a complex endeavour that requires meticulous planning. Equipping students with the ability to operate in conditions of high uncertainty and encouraging them to approach challenges experimentally and iteratively are vital aspects. The focal point should be on generating unforeseen possibilities rather than incremental approaches that merely enhance performance (Baumber, 2022). The application of a design thinking methodology that incorporates reflexivity, continuous feedback, and scaffolding constitutes key elements in enabling the integration of knowledge among diverse participants (van den Berg and Verster, 2022).

2.2 Digital social innovations and Society 5.0

Digital social innovation refers to the use of digital technologies to improve social challenges related to marginality, inequality and social exclusion (Qureshi et al., 2021). It applies to projects that use digital technologies in conjunction with community engagement and collaboration, co-creation strategies and bottom-up approaches to address societal needs.

The concept of Society 5.0 is a vision first proposed by the Japanese government where the benefits of technology and innovation are applied in a human-centred way to solve social problems and enhance the quality of life for all citizens (Fukuyama, 2018). This concept envisions a super-smart society that merges the virtual with the real world and emphasises social development, quality of life, economic growth and social justice whilst respecting sustainability (Sá et al. 2022). It seeks to integrate evolving technologies used in Industry 4.0 for business purposes into the everyday lives of ordinary people to improve the quality of life for individual human beings and benefit society as a whole (Gladden, 2019). This super-smart society represents a balance between human and technocentric approaches to development and innovation and is considered a crucial step in ensuring a sustainable future (Carayannis and Morawska-Jancelewicz, 2021).

The two concepts are incorporated into the learning environment by sparking the vision of Society 5.0 in the co-creation of sustainable-smart innovations. The design of the interventions continuously balances the innovation process, the social world and the digital ecosystem within an iterative process. It is emphasised that the focus of innovation is not on the technology but on the process of working together with different stakeholders to co-create a more sustainable and equitable society, where everyone has access to the resources and opportunities they need to thrive.

2.3 Inclusive collaborative partnerships

This refers to partnerships that intentionally include individuals and groups who may have historically been excluded or marginalised. These partnerships seek to ensure that all voices are heard and valued and that all

parties involved have an equal opportunity to contribute to and benefit from the collaboration (Gupta et al., 2017). This type of partnership is critical in contexts where power dynamics may be unequal, such as between institutions and community groups, or between individuals from different socio-economic backgrounds. Inclusive collaborative partnerships, as opposed to collaborative partnerships, thus prioritise both inclusivity and power dynamics that can have a major impact on the success of partnerships.

Our focus is also on empowering marginalised communities by incorporating the insights and experiences of community members in the design of sustainable-smart innovations. The value of their "local lived knowledge" is emphasised to recognise the value of practical, experiential, and contextual knowledge that individuals and communities possess within a specific geographic area. By tapping into this knowledge, learners can gain a deeper understanding of the issues and challenges faced by people in that area and the unique perspectives and solutions that have emerged from their experiences. This approach also fosters a sense of community engagement and collaboration, as learners work alongside local residents to co-create knowledge and solutions. In the context of ESD, this knowledge can serve as a rich source of real-world information, enabling the development of curricula and learning experiences that are relevant and responsive to the needs and aspirations of local communities. This is especially powerful within the South African context with its limited availability of resources to both communities and education.

Recognising the essential contribution of inclusive collaborative partnerships to solve wicked problems has led our research to the potential of the quintuple helix model (Carayannis and Campbell, 2010; Carayannis and Morawska-Jancelewicz, 2021). The application thereof to balance techno and human-centric approaches to innovation and integrate knowledge, innovation and the environment are discussed in the following section.

2.4 The Quintuple Helix Model as an analytical framework

The triple helix model (Etzkowitz and Leydesdorff, 2000) incorporated the intersection of universities, industry and governments. In contrast, the quadruple helix (Carayannis and Campbell, 2009) added the perspective of civil society to highlight the importance of a social dimension to innovation. The quintuple helix (Carayannis and Campbell, 2010) expands on this by adding the context of the environment to frame knowledge and innovation. This emphasises that environmental sustainability must be integrated into the innovation process and that all five helices must work collaboratively to achieve this goal.

Moreover, the concepts of Mode 1 and Mode 2 knowledge production occur in the triple helix model. Mode 1 is a linear model of innovation through basic research produced by universities in a disciplinary manner (Carayannis and Campbell, 2010). Mode 2 includes the execution of knowledge where knowledge is applied and put into practice. Mode 3 is aligned with the broader perspective of quadruple and quintuple helix innovation systems that support the co-creation of several knowledge and innovation modes that support non-linear innovation processes (Kitsios and Kamariotou, 2021).

Including the quintuple helix model as an analytical framework for reviewing the outcome of student projects during the third iteration in 2023 has the benefit of including a transdisciplinary focus to integrate different perspectives. It can be applied as a framework for understanding the complex relationships and interactions between different stakeholders involved in innovation processes. It furthermore supports the conceptualisation of Society 5.0 as it relates to the digital social innovations generated by student teams as well as the inclusion of local lived knowledge within collaborative partnerships. It can also help to identify gaps or areas where collaboration or intervention may be needed to achieve the desired outcomes.

3. Method

The paper represents the analysis of findings from the third iteration of a longitudinal study where the method of Design-Based Research (DBR) was used. Two iterations of this study have been completed in 2021 and 2022 and the third iteration in 2023. In a DBR study, researchers gain an in-depth understanding of a problem before testing and refining solutions over several iterations (Mckenney and Reeves, 2020). DBR develops both theoretical insights and practical solutions, together with stakeholders within authentic settings (ibid, 2020).

The first two iterations had an interdisciplinary focus as wider representation was limited due to the COVID-19 pandemic (Verster and van den Berg, 2022). In the third iteration, additional stakeholders from the local government, industry, and Dunoon's community could be included, opening up the potential for a transdisciplinary focus. This prompted the research question: How can a transdisciplinary learning intervention result in sustainable-smart innovations that address real-world community challenges? To explore the research

question, we apply the quintuple helix framework as a lens and draw on Mode 3 knowledge application (innovation networks and knowledge clusters) in the student projects (see Table 1). Data is drawn from student project artefacts and reflections from students and researchers. A thematic data analysis was done to review the contribution of the different stakeholders within each of the five helixes. Examining the stakeholder groups' interactions and their overall impact enabled us to identify gaps and develop interventions for future iterations as well as propose theoretical and practical possibilities (see Section 5).

Table 1: Stakeholder groups in the Quintuple Helix and their contributions to innovation.

Quintuple Helix	Project Stakeholders	Data Analysis
Civil Society Helix Emphasises the importance of public engagement and social responsibility in innovation	Community members, informal businesses and NGOs in Dunoon, Cape Town	The project can be evaluated based on its ability to engage with civil society and promote social inclusion and equity.
Academic Helix: Emphasises the importance of academic research and knowledge transfer in driving innovation	Academic staff and students from UWC and CPUT universities	The project can be assessed based on knowledge creation and dissemination, subject matter expertise, the research process, and skills development
Government Helix The role of government policies and regulations in promoting innovation	City of Cape Town Local Government stakeholders in the Urban Sustainability and IS Units	The project can be evaluated based on its alignment with government policies and regulations, and its ability to influence government policies through its innovative approaches.
Industry Helix The role of businesses and industries in driving innovation	Guest Lecturers from NGOs, Technology Consulting Organisations and Entrepreneurs	The project can be evaluated based on its ability to attract and involve businesses and industries, and its potential to promote economic growth and development.
Natural Environment Helix The role of the natural environment as a driver for further knowledge creation and innovation	Sustainable Development Goals – focus on SDG 11 (sustainable cities and communities) in Dunoon, Cape Town	The project can be evaluated based on its ability to promote sustainability and its commitment to sustainable development goals and well-being.

3.1 Project Brief

Eight student project groups were selected comprising four students from IS and three students from URP. Each group had a thematic area or problem that was randomly assigned after an icebreaker activity. The themes included challenges related to the informal economy, lack of public services and facilities, informal housing, unemployment, lack of sanitation, lack of recreation opportunities, challenges to the natural environment and food security.

The three project iterations conducted in 2021, 2022, and 2023 were preceded by a preliminary pilot study in 2020. Each of the three iterations followed the same design phases, as documented in Table 2.

Table 2: Project design phases and activities

Design Phases & Learning Activity	Output
Pre-Production Phase: Discussion topics: Digital Social Innovation, Human Centered Design, Society 5.0 and SDGs	Submit a draft problem statement and literature review. Determine a potential target population within Dunoon.
Phase 1: Empathize Discussion topics: Interview techniques, Personas and Digital Stories Group: Prepare questionnaires: use the IDEO interview toolkit as a base.	Develop a questionnaire for interviews with the community.
Phase 1: Define Group: Group members participate in the site visit to Dunoon and conduct interviews.	Complete questionnaires with seven or more members of the target population. Develop two personas from insights obtained Finalise the storyboard for the digital story.

Design Phases & Learning Activity	Output
<p>Phase 2: Ideate and Prototype</p> <p>Discussion topic: Value of community voice and street-smart local lived knowledge to explore the feasibility and viability of potential solutions.</p> <p>Group: Brainstorming, ideation, decision matrix and selection of potential prototypes.</p>	<p>Present personas to other stakeholders</p> <p>Present ideas from brainstorming</p> <p>Apply a decision matrix to determine ideas that can be prototyped.</p> <p>Pitch ideas and blueprints of prototypes to other stakeholders.</p> <p>Select four potential prototypes to develop</p>
<p>Phase 3: Testing and Production</p> <p>Group: Test prototype for viability and feasibility by other practitioners and stakeholders in Dunoon.</p> <p>Finalise prototype design specifications</p> <p>Conduct commercialisation feasibility report</p>	<p>Project presentations.</p> <p>Finalise Group Project portfolios.</p> <p>Present prototype design specifications to Local Government and Industry representatives.</p> <p>Determine implementation strategy</p>

4. Findings

Table 1 was used for the analysis of the data and the identification of gaps that can be addressed in subsequent iterations of the project.

Civil Society Helix: In the third iteration in 2023, the project was designed to focus on Dunoon, a severely under-resourced and over-populated community where people largely live in informal structures. Each student group was assigned a problem to investigate in collaboration with community members, informal businesses and NGOs in the area. The emphasis was on their local lived knowledge of the problem and the capturing of their voice to define potential sustainable-smart innovations that promote social inclusion and equity. Student groups interviewed community members and engaged with them to clearly understand the problem from their perspective and the outcome was to develop personas and digital stories to collectively generate new insights, perspectives, and potential solutions. See reflection:

It allowed us to understand how the people of Dunoon feel, not from our perspective, but from theirs in their own words. This allowed us to know exactly what their thoughts are and how they genuinely feel about their situation and the harsh realities they face.

We experienced the actual problem and not just what we initially thought the problem was. Seeing how the people of Dunoon lived created a sense of urgency to want to improve these conditions with them. It also helped to create prototypes that were human-centred and would benefit the community.

The full impact from the community's perspective cannot fully be measured yet as the projects are still being rolled out. However, the quality of prototypes created far exceeds previous years due to the active engagement from the community. Students continuously mentioned engagement with the community as one of the biggest 'value-adding' experiences in the project. The gaps that we can identify are the lack of community representation in the identification of potential themes or community problems. It would be more beneficial to involve the community from the start and to get their insights and input in problem definition as well as more community participation during the ideation phase in the form of co-creation workshops.

4.1 Government Helix:

Since the beginning of the 2023 project iteration, we had active participation from local government representatives in the project through a series of guest lectures, guided site visits and as respondents to student project development.

Further, the local government's contribution to the project includes providing local policy documents to guide the literature review aspect of the student project. Policy documents such as the Cape Town Municipal Spatial Development Framework and the Environmental Strategy played a key role in shaping the students' understanding of the development trajectory within which their projects are located. Understanding the context, particularly the policy context, is a significant determinant of the relevance of the sustainable-smart innovations that the groups develop.

The impacts of this student project can be directly linked to the meta objectives of the provincial and local governments as the following: "Resilience for Inclusive Development" aligns strategically with the project objectives of foregrounding the community voice (inclusivity) and unpacking and responding to local

environmental challenges through sustainable-smart innovations (resilience). Further “Infrastructure, new technologies and sustainability” and “citizenship and democracy” have specific and direct relevance with active citizenship being a central aim of the project both as it applies to the local community voice and the location of our students as active and responsible community members.

A concerning gap that currently exists is the presence of a power imbalance between local government and civil society (communities) because of political influences that shape relationships. Academics need to be aware of these and be able to negotiate the contested space between academia, government and civil society, which is especially burdened by the South African Apartheid legacy. A further gap that was highlighted by student reflections is the difficulty students experienced on-site to gain access to community members willing to participate. This is in part due to what was mentioned previously as the political influence that manifests as mistrust by civil society. To address the above concerns, we will in future partner with community champions to gain the trust and cooperation of community members.

4.2 Industry Helix:

Stakeholders from the industry include representatives from the Industry Board at one of the participating universities and external moderators from the other university. They play an advisory role as guest lecturers and reviewers primarily. There is more active participation in the projects by local entrepreneurs within the area of Dunoon.

A lack of understanding about the potential value and economic incentives linked to social innovation in the informal economy as well as the complex political situation within the area are deterrents to active participation. More active collaboration to share the project outcomes and success stories with the industry partners and their participation in co-creation workshops needs to be encouraged. Industry partners can also be more active in the further development and implementation of sustainable-smart innovations and use this as an opportunity to build their reputation as socially responsible organisations. This could include branding and marketing opportunities, as well as networking events.

4.3 Academic Helix:

The stakeholders include academics and students from two universities in Cape Town, South Africa. The project has been highly beneficial in shifting knowledge creation from Mode 1 to Modes 2 and 3. The students have cited the shifting of their perspectives and the development of new skills and competencies for example:

The different perspectives influenced my learning by enabling me to view situations from other people's positions and to consider other people's views, experiences and beliefs. This provided me with a deeper understanding and empathy which decreases prejudice, judgment, and conflict, within the area and among my group.

I never thought that we will get a chance to engage with the community and interview them, and share the issues that they experience. I am also surprised by the skills that I developed from this project like creating digital stories and designing prototypes.

To date, the impact from an academic perspective has been positive resulting in a number of research publications and wider collaboration with other academics, government and community stakeholders. This is an ongoing project and the largest present gap is to establish continuity from one year to the next and build on the results of previous iterations. The focus on a single community is recommended and also to increase the participation by other stakeholders through more formalised agreements on project scope and outcomes. The results should also be widely showcased on a project platform which is currently being developed.

5. Natural Environment Helix:

The project is based on the "Education for Sustainable Development" (ESD) approach, which prioritises the promotion of constructive and sustainable changes within society. ESD is typically found at institutional and educational policy levels with limited curriculum uptake. By embedding the sustainability principles within every aspect of this student project, we sensitised students, as future leaders, to concepts such as the sustainable development goals (SDG) and specifically SDG 11, sustainable-smart cities and Society 5.0. Further, as the environment is usually the most vulnerable stakeholder in the quintuple helix, the themes, as mentioned under the Project Brief section, all have an environmental footprint.

One of the major impacts was the focus on a sustainable-smart approach as a single, entangled concept. We propose sustainable-smart to refer to smart, technology-driven innovations underpinned by a sustainability mandate. A further medium to longer-term impact is the contribution to the Dunoon sustainability campus (in partnership with international and local donors) that is in the formation phase. The sustainability campus is intended to upskill the local community as well as disseminate practical information that can contribute to all aspects of better living.

The gap currently is to be able to track the real-world environmental impacts of this project as this is the first engagement within this community. In the past students worked in the communities in which they reside as we were not able to access communities under lockdown restrictions.

6. Discussion: Theoretical Insights and Practical Solutions

The analysis of the transdisciplinary learning intervention through the lens of the quintuple helix model of innovation provides valuable theoretical insights and practical solutions.

Two main considerations for theory were highlighted by the above project findings, as first, the concept of shifting "Mode 1" to "Modes 2 and 3" knowledge creation as a move in the academic helix towards more collaborative and applied research. The potential role of universities to take on a more significant role in fostering innovation, not only by promoting technology and knowledge transfer but also by acting as intermediaries and facilitators among the various components of the ecosystem through interdisciplinary and transdisciplinary approaches (Ferraris et al., 2020). Secondly, the significance and promotion of sustainability principles within all aspects of education, as emphasised in the ESD approach. What flows from this is our proposal to recognise technology as a main driver of innovation, thus the identification of the sustainable-smart approach as a single, entangled concept, combining smart, technology-driven innovations with a sustainability mandate.

The practical recommendations are to first establish an iterative approach to ensure that the project's impact is cumulative and sustainable. Second, focus on a single community, which allows for deeper engagement and understanding of the local context, traditions, and values. Following on from this, thirdly, to establish partnerships with community champions to gain trust and cooperation from community members. This is of particular importance in societies where political influences and historical legacies have contributed to mistrust. Fourthly, to encourage industry partners to actively participate in the further development and refinement of the student project and future implementation of sustainable-smart innovations within communities.

7. Conclusion

This paper posits that for university programs to make meaningful contributions toward addressing the multifaceted socio-eco-cultural challenges of society, a sustained emphasis on sustainable-smart innovations is necessary. Pursuing sustainable-smart innovations requires a holistic understanding of the environmental, economic, and social factors shaping contemporary challenges.

For this reason, we argued for the integration of concepts such as education for sustainable development, SDGs, Society 5.0, digital social innovations, street-smart local lived knowledge, and collaborative partnerships, through the lens of the quintuple helix model. To achieve this integration, the paper emphasises the importance of transformative and experiential learning approaches that expose students to real-world challenges and enable them to engage in collaborative problem-solving. Furthermore, it underscores the significance of transdisciplinary approaches that facilitate the convergence of diverse perspectives and fields of knowledge by adding the Quintuple Helix Model as a barometer for reflection on the impact and gaps of the intervention.

We envisaged the next phase of this research project to develop a learning theory that focuses on sustainable-smart thinking: learning for sustainable-smart innovations.

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