Interdisciplinary and multi-institutional higher learning: reflecting on a South African case study investigating complex and dynamic environmental challenges

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Highlights

- A 4-year program, in a developing country context, followed an interdisciplinary research mode.
- Conscientious program design is key to catalyzing interdisciplinary learning in academia.
- Focus disciplinary studies around a theme but build in an integrative component.
- Seek boundary concepts/objects to facilitate communication across disciplines.
- A broker organization removed transaction costs; funders should consider this investment.

Abstract

Complex social-ecological problems need sustained interdisciplinary engagements across multiple disciplines, yet academic offerings continue to reflect disciplinary silos. To address this, a five-year program, within a developing country context, was conceived to follow an interdisciplinary research mode using a team of students and supervisors from various institutions across the disciplines of ecology, hydrology and economics. By using a flexible student training model, regional/site specific knowledge was developed while simultaneously developing a shared vision and a model to combine information from each student project. Graduates felt enabled by the program that actively

encouraged interdisciplinary interactions and engagements while simultaneously furthering disciplinary development. Cross disciplinary communication, was achieved through multiple engagement opportunities and common research outputs, all facilitated by an external boundary organization. While lengthy time frames are required for such collaborative interdisciplinary programs, researchers, higher learning institutions and funding agencies should not avoid this type of program and investment.

Introduction

Persistent gaps between knowledge and action have been highlighted in a range of environmental science disciplines such as resource management [1, 2], restoration [3], conservation planning [4], and invasion management [5]. Typically, challenges (and their solutions) are social-ecological in nature as they cover large spatial scales, involve multiple, interacting drivers of change, and include many stakeholders with different values and expectations [6]. Disciplinary depth of knowledge is needed [7], but single disciplines do not typically provide the skills or the tools required to find effective solutions to such issues [8]. Diverse perspectives enhance understanding of complex social-ecological challenges and are increasingly advocated as a way to bridge the "knowing-doing gap" for sustainable actions [8]. This requires the spanning of knowledge boundaries, or "boundary work" [9] which involves collaboration and integration across disciplines, beyond academia and (frequently) over large geographical areas (but see Gieryn [10] for the original use of the concept).

Boundary work is needed on many fronts, including graduate training at higher learning institutions. Graduates need to be endowed with the necessary conceptual knowledge and both technical and social integration skills to undertake research and inform decisions about our environment and society [11,12], yet study programs and curricula largely continue to reflect disciplinary silos. In South Africa, like many parts of the world, academia is dominated by a highly competitive, disciplinary approach [13, 14] which tends to separate research and training from problems and issues of every day practice [15, 16], although this is changing [17]. It is not common to have teams of students, who while pursuing their individual studies, participate in programs beyond disciplines and institutions. The situation in South Africa is exacerbated by increasing pressure on financial resources and research allocations [18, 19] and pressure to take on more graduate students [20]. This favors straight forward, disciplinary research leading to less "hands-on" supervision, limited understanding of the societal context of the research, and general avoidance of complex social-ecological challenges [21]. The disciplinary divide in universities, especially between the natural and

social sciences therefore persists [22], leaving graduates unprepared for a complex and dynamic world [23, 24] where sustained interdisciplinary engagements are needed among scientists, decision makers and broader society [25, 26].

We report on a higher learning program that sought to follow an interdisciplinary mode of research involving senior and junior researchers from various institutions. The primary aim was to explore linkages between ecological restoration and economic development, an emerging field in academic literature, because restoration ecologists and social economists mostly work in mutual isolation [3, 27]. We therefore carefully designed our educational research program to actively connect a team of postgraduate students and their supervisors across the disciplinary fields of ecology, hydrology and economics. Interactive learning experiences, which included stakeholders from industry and civil society, facilitated primary data collection and systems understanding at a range of sites; these data were then synthesized [28], as discussed below. We document this process and reflect on the method of interactive learning used as a contribution to the design of multi-institutional and interdisciplinary studies worldwide. First we provide general background on bridging disciplines, inter-disciplinarity in graduate education, and the theory behind our approach. Next we describe the establishment and contribution of this project, key elements that enabled student learning "on-the-job". We close by placing these findings into context and draw some conclusions.

Bridging disciplines

Several terms are used for disciplinary bridging, depending on the nature of the interaction. In brief, a multidisciplinary study takes place when information from several disciplines is used in an additive way with a low degree of exchange and no real knowledge integration taking place between the disciplines [29]. Interdisciplinary research goes a step further by integrating and synthesizing information across different disciplines to produce a more complete understanding or conceptual advancement that would not be possible from individual disciplines [30, 31]. Trans-disciplinarity represents a distinct next step along this continuum, implying problem framing, exchange and co-production of knowledge not only between scientific disciplines but also between science and stakeholders from a variety of non-scientific knowledge domains [32]. While our program involved exchange with non-academic stakeholders, problem framing and knowledge production was largely within and across academic disciplines, so we define it as interdisciplinary rather than transdisciplinary in nature.

Interdisciplinary research integrates approaches, methods and concepts to produce novel understanding or capability. Moreover, interdisciplinary research is problem driven, as opposed to being driven by academic interest, and sensitive to the problem context. Often the scientists do the problem framing while explicitly considering societal needs in the process [33]. Benefits associated with interdisciplinary research include an ability to view issues from different conceptual frames, formulate novel perspectives, stimulate transformative learning that advances science [34] and formation of new networks to enable broad knowledge sharing. The problem oriented nature of inter-disciplinarity tends to increase the relevance of research endeavors [35]. Inter- and transdisciplinary approaches to environmental science research are supported by prominent funding programs such as the International Social Science Council and the Belmont Forum, and encouraged by international science platforms such as FutureEarth [36] and the Program for Ecosystem Change and Society [37]. This has led to renewed political will [38], awareness of the ways in which biodiversity and ecosystems underpin human development [39], and increases in coursework opportunities. From 2000 there has an explosion of University level programmes introducing interdisciplinarity to graduates [21, 40, 41). The vast majority of these programmes and examples have come from developed countries or 'large-scale science' contexts and have often focused on a single university programme, integrating academic disciplines to expose students to a variety of perspectives.

Several challenges to inter-disciplinarity have been listed in the literature, in particular that it 'strains communication bandwidth' [42]. It is simpler to work with colleagues in your own area of expertise who share the same vocabulary and ingrained conceptual understanding. Interdisciplinary collaboration also requires a relatively large time investment to allow for relationships to establish and for teams to evolve past initial differences in perspectives, cultures, methods, theories and approaches. Institutional barriers include: difficulty in publishing the interdisciplinary research because of an uncomfortable fit within traditional disciplinary journals; finding the right trade-off between disciplinary depth and interdisciplinary breadth might be problematic for individuals and departments; perceptions that interdisciplinary research is academically inferior to disciplinary research; giving insufficient academic rewards for interdisciplinary activities; and interdisciplinary researchers can experience career limitations in academia [35, 43, 44].

Growing interdisciplinarity in graduate education

The past fifty years have also seen a pronounced shift from individually orientated research towards team-based, collaborative research initiatives [45], many of them within university education programs [21, 46, 40, 41]. University students and their training programs are recognized as central to increasing interdisciplinary research capacity [47]. The need for innovative approaches to graduate training has also come from recognition that complex environmental problems require solutions that draw from varied disciplines and stakeholders and so requires collaboration [46, 41, 47]. University education should explicitly prepare students for an increasingly interdisciplinary, collaborative, and global job market and should not be solely a by-product of immersion in an intensive research experience [48]. Graduate students who are well-prepared to tackle complex and dynamic interdisciplinary questions are more likely to succeed in today's increasingly competitive job-market [49].

Theoretical approach

Our program was informed by three key theoretical approaches. Firstly, we recognized the importance of action learning as "concrete experience and critical reflection on that experience, through group discussion, trial and error, discovery and learning from one another" [50]. Secondly, we situated our program's focal activities within the research-teaching nexus [51], with emphasis on the students as participants and on the research process (problem solving approach). Finally, we acknowledged, along with others [see e.g. 52, 53, 54, 55, 56], that knowledge co-production and "boundary work" are important ways to tackle complex social-ecological challenges. These approaches encourage meaningful participation across different knowledge communities, thereby ensuring accountability to relevant stakeholders. This is achieved through the production of "boundary objects" that provide a common platform through which different types of knowledge can be viewed [53]. The facilitation role played by individuals, groups or organizations, referred to as boundary spanners [52], boundary organizations [57] or bridging organizations [58] is central to the process and indispensable. They mobilize resources and provide opportunities for building trust, mustering collaboration and bridging disciplines.

How we established the South African programme

Nel et al. [56] provide a developing country's perspective and approach to dealing with complex and dynamic social-ecological systems through a collaborative and interdisciplinary program. Our Restoration of Natural Capital (RNC) project provides another example. Initiated by ASSET Research (www.assetresearch.org.za; a not-for-profit for the public benefit research and development organisation), the project was initiated to address the complex and dynamic problem of combating land degradation and foster knowledge development across academic disciplines and institutions of higher education with respect to multi- and interdisciplinary and multi-institutional learning. The aim was to "*determine the economic risk/return parameters for developing a market for ecosystem goods and services following the restoration of natural capital [by utilising] a system dynamics approach"* [59] (Table 1). Designed by a core leadership team with prior ~~cross-~~interdisciplinary collaborative work experience (Table 2), the program focused on a meta-analysis of the hydrological, ecological and socio-economic impacts of eight different ecological restoration projects across South Africa [28]. The sites were selected to represent large scale restoration trials dealing with real-life degradation issues and involving various stakeholder communities (e.g. business and farming communities). At each site, at least two masters students from different disciplines were teamed together to conduct ecological, hydrological and socio-economic assessments of the impacts of restoration at these sites that were embedded in different social-ecological contexts (Figure 1). A doctoral candidate then aggregated and synthesised the site-specific information into an overarching systems-based framework aimed at supporting better decisions by identifying risks and rewards of restoration activities. Prior to this project, a meta-analysis of restoration had not taken place and previous site-specific research was largely disciplinary. Work not only addressed the RNC program aim, but also stimulated interdisciplinary learning across distances and contributed to capacity-building (Table 1). The RNC program was therefore an active and deliberate attempt to facilitate learning and knowledge development in a world comprising complex and dynamic challenges. (Table 3)

Capacity-building (primarily of students, but also of the team) in the RNC program was not a single event but rather a process comprising a variety of interactive facets, including formal training in the form of teaching and research, learning events and discussions through colloquia, information dissemination, communication with stakeholders, engagements with peers, and the compilation of five policy briefs in 2012 in conjunction with a policy advisory think tank (http://www.tips.org.za/research/briefs) (Table 1, Appendix 1). In this regard, the program made

Table 1. Timeline of key events over the program life-span and their relevance to the integrative learning experience

Year	Month	Activity	Integrative experience
2008	June	Inception report	
	July	Inaugural Water Research Commission (WRC) Steering Committee meets	Stakeholder involvement
	August	Core team program planning meeting, Oudtshoorn	Planning for integration. Project co-design. Catalyze stakeholder involvement.
	August	Student adverts distributed for Phase 1	Advertised nationally. Supervision not restricted to core team institutions to leverage capacity and to draw on regional expertise.
	October	Core team workshop to finalize site selection De Hoop Nature Reserve	Project co-design and co-management
	December	Draft literature review completed	Collate and review existing knowledge. Transformative learning through generation of common definitions of integrative concepts. Identify emerging issues.
2009	January	Phase 1 students register Orientation meeting for Phase 1 students (7 Masters, 1 PhD)	Catalyze student involvement. Generate common language. Initiate cross disciplinary learning.
	May	Student colloquium, Stellenbosch University Phase 1 student proposals & feedback	Coordination of work across and within sites. Advance mutual understanding
	August	Student adverts distributed for Phase 2	Advertised nationally. Supervision not restricted to core team institutions to leverage capacity and to draw on regional expertise.
	October	Student colloquium, Sustainability Institute Phase 1 student progress, Phase 2 students, orientation	Coordination of work across and within sites. Advance mutual understanding.
2010	January	Phase 2 students register	
	March	WRC steering committee and student colloquium, Oudtshoorn	Stakeholder involvement. Coordination of work across and within sites. Advance mutual understanding.
	May	Student colloquium, Drakensberg Phase 1 students present progress, Phase 2 students present proposals	Coordination of work across and within sites. Advance mutual understanding.
	Sept	Student colloquium Phase 1 students present final drafts, Phase 2 students present progress	Coordination of work across and within sites. Advance mutual understanding
2011	July	PhD student presentation at International Conference of System Dynamics Society, Washington DC.	Presentation of poster with opportunity for inputs in modeling process
	May	Student colloquium Model building workshop	Six of eight case study models presented and

			discussed.
	Oct/Nov	Student colloquium Phase 2 students present final drafts. Development of outlines for policy papers, in collaboration with policy "think-tank", TIPS	Coordination of work across and within sites. Advance mutual understanding. Stakeholder engagement. Policy engagement.
2012	March	"Write shop" retreat. Synthesis report planning involving key Phase 2 students	Co-production of final report. Co-develop boundary object
	March	Stakeholder workshop	Knowledge dissemination to stakeholders.
	November	Final report submitted	Knowledge dissemination to funders

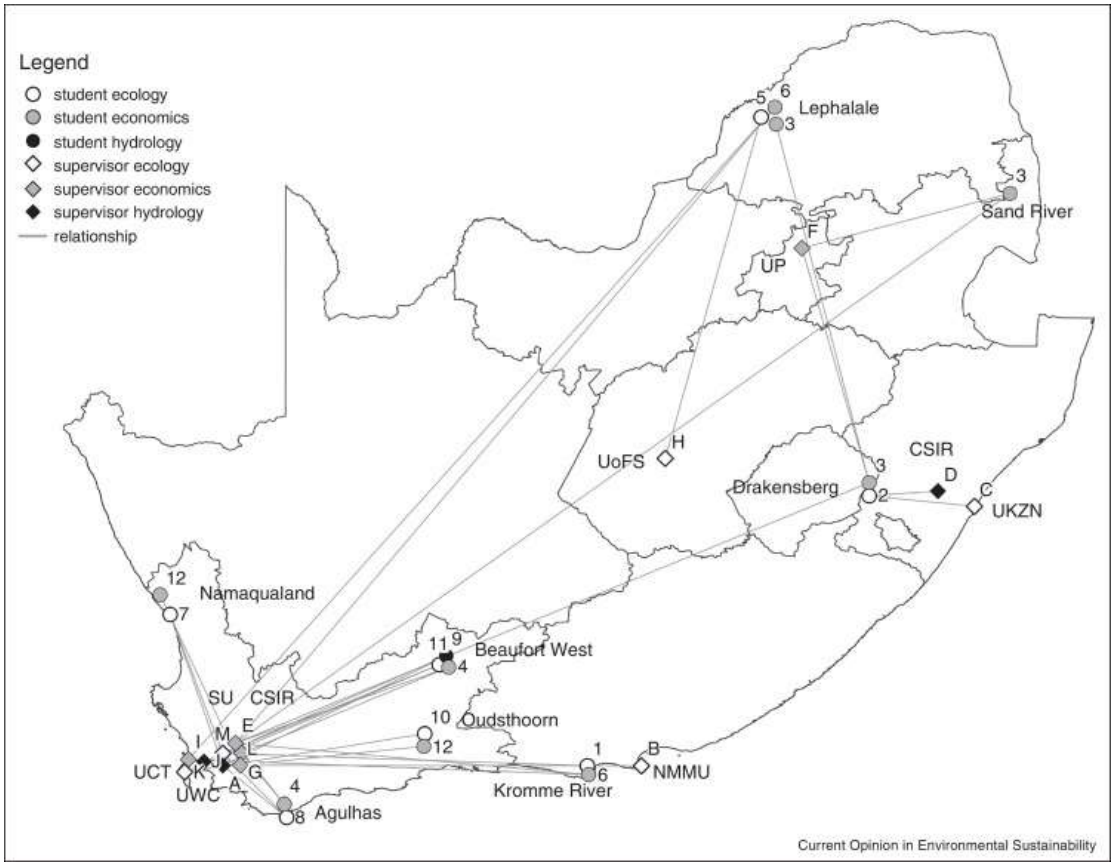

Figure 1. Map of South Africa showing Provincial boundaries and indicating the large scale (National), collaborative network of students (numbers; circles) and their supervisors (letters; diamonds) in the RNC program. Symbol colours indicate disciplines; Black = hydrologist; Grey = economist; White = ecologist. Students are positioned at the sites (Agulhas, Beaufort West, Drakensberg, Kromme River, Lephalale, Namaqualand, Oudtshoorn, Sand River) where they worked (note that most economics students worked at more than one site) and are linked to their supervisors; supervisors are positioned at their institutions. CSIR = Council for Scientific and Industrial Research (Stellenbosch and Pietermaritzburg offices); NMMU = Nelson Mandela Metropolitan University; SU = Stellenbosch University; UCT = University of Cape Town; UoFS = University of the Free State; UWC = University of the Western Cape. The PhD (supervised from SU) is not indicated completely on the map, as he integrated work across all sites, although he also did site-specific work at Drakensberg and Sand River (indicated).

Table 2. Organizations involved in the RNC program

Organization	Core Team[1]	Student Supervision[2]	Collaborators
ASSET Research	X		
Aghulas Biodiversity Initiative			X
Council for Scientific and Industrial Research	X		X
Department of Water Affairs			X
Exxaro Namaqua Sands			X
Flower Valley Conservation Trust			X
Gamtoos Irrigation Board			X
Living Lands			X
Nelson Mandela Metropolitan University		X	
Ostrich Business Chamber			X
Stellenbosch University	X	X	
Trade and Industrial policy Strategies (TIPS)			X
University of Cape Town		X	
University of Free State		X	
University of Kwa Zulu Natal		X	
University of Pretoria	X	X	
University of Western Cape		X	
Water Research Commission			X
Western Cape Department of Agriculture, Elsenberg			X
Working for Water			X

[1]The core team consisted of 6 members; [2]the total supervision team consisted of 12 members

Table 3. Features and outcomes of the RNC program in relation to theoretical context

Theoretical context	**Project action**	**Outcome[1]**
Knowledge co-production [64] **Knowledge is produced by involving scientific method and social context.**	Diverse knowledge sources (across disciplines of ecology, hydrology, economics) drawn together to address a defined problem. Integrated, systems orientated understanding of the problem generated.	Fresh understanding of an old problem, leading to innovative solutions. Transformative learning. Joint publications, joint research reports, graduates and supervisors with interdisciplinary experience.
Boundary organization [9] **Organization that facilitates collaboration and information sharing across knowledge boundaries.**	ASSET research (boundary organization) identified, communicated with and involved stakeholders, ensured continued interaction between project participants (Table 2), provided a "collective" memory	Continuous interaction throughout program life span. Built trust. Engaged approach facilitated boundary work and boundary objects described below. Maximised on partner institution capacity by removing time-consuming responsibilities
Boundary work [52] between research disciplines [53] **The act of working across knowledge boundaries.**	Interdisciplinary student teams participate in site-specific working groups and joint field trips. Joint participation of core team members and students in collaborative literature review Regular student colloquia. "Write-shops" with interdisciplinary core team	Clarity on disciplinary jargon. Mutual respect. Coordination of work within and across sites. Development of common research protocols and conceptualization of "boundary object" (see below). Joint publications, joint research reports, graduates with interdisciplinary experience.
Boundary work [52] between science and policy makers [53]	Policy advisory "think tank" organization invited to student colloquia to provide input on tailoring to policy maker needs. Students and core team encouraged to engage with policy-related implications of their research	Five policy briefs produced and distributed policy makers.

Boundary work [52] between context-specific and generalizable research [53]	MSc students focused on local, site-specific needs and solutions while core team and PhD developed "boundary object" to integrate research across sites and to produce generalizable results	Site-specific research outputs generalized to nationally relevant outputs.
Boundary work [52] between scientists and stakeholders [53]	Stakeholders and collaborators invited to participate in meetings, field trips and site visits. Students tasked to report back to stakeholders and collaborators.	Stakeholder participation.
Boundary object [9] **The use and adaptation of concepts or objects that facilitate communication across knowledge boundaries.**	PhD tasked to develop, in collaboration with core team, a consistent methodology for economic evaluation and visualization of ecological restoration projects. Developed a system dynamics model that evaluates risks and rewards to inform a decision-making framework.	First-known application that couples ecological restoration with systems dynamics and portfolio mapping to guide decisions on when markets for restoration activities are feasible [19]
Action learning [50] **A structured process of peer learning while working with real-life challenges**	Interdisciplinary student teams participate in site-specific working groups, joint field trips and co-generation of policy briefs	Students given concrete interdisciplinary experience. Learning by working on a real issue, and carrying responsibility in real conditions.
Research-teaching nexus [51] **Integrating teaching with research**	Student training model was carefully considered as an integral part of the research process	Students motivated to learn and participate in real-world research

[1] Guided by questionnaire feed-back

explicit the need "to offer students the opportunity to work in multi– and interdisciplinary teams on projects and in the process, innovate, learn and contribute to the knowledge base of the country". Based on the core research team's prior interdisciplinary research experience, knowledge of RNC, and strong interest in fundamental research, this specific approach was chosen.

To achieve the two-fold objective of scientific enquiry and capacity building, the program was widely advertised in two rounds, clearly stating the program hypothesis and offering bursaries to ten masters students and one PhD to undertake research in three areas: economics, ecology and hydrology. The objective was to locate the best students available, and to match them with appropriate supervisors based on the applicant's background and situation, thereby tapping into regional, site-specific supervision expertise and ensuring that relevant data were collected. Candidates in the three distinct disciplines were registered at four South African Universities, while their supervision team spanned seven higher education and research institutions (Table 1). The core researchers were chosen because of i) their knowledge and expertise, and ii) because of existing researcher networks. The universities involved were a consequence of the successful students chosen to become part of the programme.

Students and supervisors were encouraged to interact through joint field trips and regular meetings. Concurrent to the masters case studies at each of the eight sites, a PhD candidate (with input from the core, interdisciplinary research team), was tasked to develop a system dynamics model for economic evaluation of each case study which allowed for integration across all sites [28]. The system dynamics model provided a platform for shared data collection protocols and a vehicle to integrate different data types and sources, and can be viewed as a "boundary object" in this work.

The large-scale, complex, collaborative, networked design of this program (Figure 1) required close management to achieve its objectives, helped by the fact that core team members had positive prior experience working together in a collaborative research network and were ably led. ASSET Research was core to the process, channelling funding and playing a key integrative, management and intellectual role in the program, specifically, ASSET Research prepared the proposal and provided project management services, including coordination of researchers and compilation of reports. The organization's focus is strictly on collaborative research and capacity-building in relation to the economy/environment interface in sub-Saharan Africa. It further distinguishes itself as being a catalyst for knowledge at the interface between the subject matters of economy and ecology, acknowledging that challenges in these two complex, dynamic and overlapping systems can only be addressed in an integrated way. ASSET research can therefore be viewed as the "boundary organization" in this work.

Key aspects of learning during the project

How we evaluated "on-the-job" learning

An independent monitoring team was established (co-authors of this paper, Downsborough and Roux, based on prior work with respect to interdisciplinary research) to document some of the learning and sharing opportunities created by this program and its overall effectiveness. They attended most colloquia and administered two questionnaires aimed primarily at the students (N=11), but including their supervisors, some of whom were also program members. An introductory questionnaire was administered six months into their studies, which examined students' understanding of interdisciplinary research. A second, administered after 18-24 months of study investigated student's overall experience of the RNC program and how it contributed towards the successful completion of their research.

Nine students completed the introductory questionnaire and seven completed the second questionnaire. The first questionnaire showed that the majority of students (7; 78%) were familiar with multi- and interdisciplinary research and understood collaborative research work in collaborative teams. Most students identified their own projects as multi-disciplinary (7, 78%), but would feed into a larger interdisciplinary program on restoring South Africa's natural capital (9, 100%). The second questionnaire provided insights which have been distilled into lessons learned, as described below.

Collaborating across disciplines

Students reflected on undertaking collaborative research and more than half indicated that they experienced it to be worthwhile in the end, but the process was quite challenging. One student remarked, among others:

> *"Collaborating across different disciplines is definitely not an easy task. It is time consuming and the researcher needs to familiarize themselves about aspects which they are not familiar with and without which, wrongful assumptions could easily be made. It allows the opportunity to regard the discipline with which one is familiar as part of the broader structure of society: a fact one can easily lose sight of when working only within a specific field."*

Another student reflected,

> "*The first step in collaborative research is to learn the language of both disciplines and the second step is to find common ground between the two*".

This student was particularly referring to the languages used in ecology and in economics; the steps reflect a "group model building" approach similar to that used by Hovelynck et al. [60]. A feature of the RNC program was that it developed a collaborative and evolving glossary of terms, driven by the students to aid interdisciplinary communication. This activity was initiated at the first colloquium, which established itself as a critical forum and platform for the program (Table 1).

Learning and sharing opportunities

Students were asked to identify and reflect on the learning and sharing opportunities created by the program. When asked to identify the key individuals, groups, partners or institutions from whom they learned the most, students highlighted the input of subject experts (their supervisors) (9, 100%), interactions with fellow students (5, 56%), colloquia (5, 56%) and stakeholders (4, 44%). A core cohort of seven students was based at Stellenbosch University and this provided a small hub for regular interactions and learning to take place. Students were encouraged and supported to attend

and present their work at conferences and this provided broader context for them. Regular colloquia were organized where the students and the broader program team interacted for several days. Colloquia and informal discussion groups served the dual role of providing a relaxed atmosphere for the team to gather and socialize, while creating opportunities for academic engagement and dialogue. Stakeholders from key organizations (Table 2) were also invited to these events to provide a wider network for interaction, discussion and learning to take place. In total, seven colloquia were held over five years and each one focused on student interactions, individual project updates and how individual projects became integrated into the overall program through the collaborative development of a model (Table 1). These learning and sharing opportunities were well regarded, as some students remarked:

> *"The regular colloquiums provided a structured opportunity for me to get a good understanding of how my project fits into the bigger whole";*
>
> *"Social activities bring people from different backgrounds together whereas I might have stuck to people from my own department if I hadn't been put in a relaxed and easy atmosphere like the colloquia, where you don't need to talk about work all the time. Of course, I also made some lifelong friends".*

One student noted that masters degrees are still conducted within the boundaries of a university in a specific discipline and therefore one still has to comply with certain disciplinary expectations.

Knowledge generation and knowledge sharing

Most students noted that they learned and shared more through this program than if they had been focusing only on obtaining a research degree within a single discipline. These observations are valid since the senior MSc-level students who participated in the program had experienced silo-type learning in their early degrees and were well informed about the differences. Students were also kept motivated by the 'bigger picture' of the program, as one noted:

> *"being part of the team kept me motivated and inspired throughout my research project. It became obvious that the student projects were playing a central role in generating new knowledge to contribute to the bigger picture as many students can get bogged down wondering if their research is really contributing to scientific literature or society".*

Because the program integrated three disciplinary perspectives, many students reflected that they acquired greater depth of knowledge in their own discipline, but that it also broadened their knowledge into other disciplines, stating, among others:

> *"Generally student projects are focused on one topic within one particular field. Working together with other students from economics has forced me to open my view of natural*

resource management to include resource economics, a field I am unfamiliar with. Although my project was in ecology, I was assigned a hydrology supervisor and I have gained extensive experience in another new field".

Powerful role of peers and supervisors

Students reflected on the powerful roles of their peers and supervisors in keeping them motivated and on track with their research. Several students echoed the sentiment that:

"*I would say my peers had the biggest influence, I have learned a lot from them both personally and within my study*".

Many also indicated that their supervisors were readily available to them which is critical to student success but often not achieved in large university settings where supervisors have many other commitments [61].

Overall, all students concluded that being part of the RNC program had helped them develop both personally and professionally and provided a supportive environment in which to complete their projects, as one remarked:

"*The program helped me complete my research by providing structure to work towards deadlines and deliverables, professional administrative support and a wide range of mentoring and peer support. As a result, unlike the other students around me who are doing their research in the traditional isolated way, I did not find my work as daunting, confusing and lonely".*

Discussion: putting the project learning into context

Evidence suggests that this programme with its design elements of team-based student-driven research, cross cutting research projects, spanning many sites with input from numerous institutions, and inclusion of multiple co-learning opportunities makes it among the first of its kind in South and southern Africa. In particular, the capacity building model was deemed highly successful, with all but two of the masters students and being ready for advanced studies or employment. This pass rate is high for South Africa, where students struggle to complete their degrees, and often take longer than the allocated time to do so [62]. Four of the masters students continued on to register for a PhD in a related topic, while three found immediate employment in the sector. The funding organization, the Water Research Commission (WRC), recognized this achievement in presenting a capacity-building award to the core team in 2013. The funding structure provided by the WRC

facilitated the interdisciplinary and multi-institutional type research discussed by allowing student products to be deliverables, and for financially supporting ASSET research in its facilitation role.

Although the planned interactions facilitated interdisciplinary learning among the masters students, the majority of students learned the most from disciplinary experts (supervisors). The program was specifically designed to exploit existing academic structures in which most masters degrees are severely time-restricted (1-2 years) and formalized around disciplines and departments. So, while we provided an interdisciplinary learning experience through the placement of students and structure of the program, we simultaneously navigated negative perceptions associated with "lack of depth", a commonly reported obstacle to interdisciplinary research [35]. Student success was ensured through low-risk disciplinary projects that could be achieved in the allocated time but interdisciplinarity was still an outcome.

The primary task of the dedicated interdisciplinary PhD candidate was to integrate the site-specific economic evaluations and ecosystem knowledge generated by the disciplinary masters students. The supervisors and the PhD candidate worked closely with the masters students to develop a system dynamics model, which acted as a "boundary object" [53] in this program. Towards the end of the program the model, which captured biophysical variability as well a measure of risk in restoration investment decisions [28], allowed the program team to co-develop a shared understanding of how to achieve the overall program goal.

As a boundary organization [9], ASSET played a critical role in the program's success by removing many challenges associated with interdisciplinary research [63]. Communication difficulties were overcome through regular, iterative ASSET facilitated co-learning opportunities, freeing up time for academics to focus on the research. Funding and institutional barriers were removed through the leverage of additional funds. We acknowledge the far-sighted decision of the funding agency to support ASSET in its role, as many funders regard such brokers as an additional, unnecessary expense. Although a comparative financial-economic analysis is beyond the scope of this paper, a simple calculation of the direct subsidies generated (Appendix 1) amounted to R2 730 000, excellent leveraging for a program grant of R3 000 000.

Conclusion

Achieving interdisciplinary research within Universities is possible, but challenging because of the strong disciplinary focus. The organizational model described here is to outsource the coordinating

role to a third party that specializes in interdisciplinary research and has the capacity to support it. University departments can still deliver disciplinary degrees within expected time frames, while longer interdisciplinary time frames are guaranteed. The measures of success described here testify to good outcomes for universities, students, supervisors and stakeholders alike. Several elements must be in place to support such research programs and for them to succeed:

- While maintaining disciplinary strengths through well-designed and executed studies, interdisciplinarity can be simultaneously achieved through planned engagements involving students and supervisors.
- Focus the disciplinary studies around key elements of a single theme and build in an integrative component, preferably at a higher academic level (PhD).
- Seek concepts to facilitate communication across disciplines. In our program a system dynamics model drew together essential features of site-specific projects into a common approach.
- Broker organizations are invaluable to assist with the time-consuming aspects of collaborative interdisciplinary programs; funding agencies should not shy away from this type of investment.

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Appendix 1: List of paper published and students graduated under the RNC program

Peer reviewed publications - Total direct subsidy generated: R2 730 000.00; 9 x ISI publications = R130 000x9 = R1 170 000

Aronson, J., Blignaut, J.N., Milton, S.J., Le Maitre, D., Esler, K.J., Limouzin, A., Fontaine, C., De Wit, M.P., Mugido, W., Prinsloo, P., Van der Elst, L. & Lederer, N. (2010) Are socioeconomic Benefits of Restoration Adequately Quantified? A Meta-analysis of Recent Papers (2000–2008) in Restoration Ecology and 12 Other Scientific Journals. Restoration Ecology, 18(2):143-154.

Blignaut, J., Esler, K.J., de Wit, M.P., Le Maitre, D., Milton, S.J., Aronson, J. (2013) Establishing the links between economic development and the restoration of natural capital Current Opinion in Environmental Sustainability, 5:94-101

Crookes, D.J., Blignaut, J.N., de Wit, .P., Esler, K.J., Le Maitre, D.C., Milton, S.J., Mitchell, S.A., Cloete, J., de Abreu, P., Fourie (nee Vlok), H., Gull, K., Marx, D., Mugido, W., Ndhlovu, T., Nowell, M., Pauw, M., Rebelo, A. (2013) System dynamic modeling to assess economic viability and risk trade-offs for ecological restoration in South Africa. Journal of Environmental Management 120:138-147.

Crookes, D.J., de Wit, .P. (2014). Is system dynamics modelling of relevance to neoclassical economists? South African Journal of Economics 82: 181-192.

Ndhlovu, T., Milton, S.J. Esler, K.J. (2011) Impact of Prosopis (mesquite) invasion and clearing on the grazing capacity of degraded semi-arid Nama Karoo rangeland, South Africa. African Journal of Range and Forage Management, 28(3):129-137

Rebelo, A., Le Maitre, D., Esler, K., Cowling, R.M. (2013) Hydrological responses of a valley-bottom wetland to land-use/land-cover change in a South African catchment: making a case for wetland restoration. Restoration Ecology, In Press

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Popular articles

Blignaut, J., de Wit, M., Esler K.J., le Maitre D., Milton S., Mitchell, S., van der Elst, L.(2010) Restoration in South Africa. Quest 6(1): 14-18.

Kotze, P. (2013) Study proves the economic worth of biodiversity rehabilitation projects. Water wheel, 12(6): 20-27.

Rebelo, A. (2013) Palmiet wetland conservation. Farmers Weekly 7 June: 28-29

Policy Briefs

Pauw, M. 2012. Policy brief: Implications of the regulatory landscape for the restoration of natural capital. Pretoria: ASSET Research & TIPS.

Rebelo, A., Gull, K. 2012. Policy brief: Urban water use. Pretoria: ASSET Research & TIPS.

Crookes, D., Blignaut, J. 2012. Policy brief: Market challenges for the restoration of the natural environment. Pretoria: ASSET Research & TIPS.

Cloete, J. 2012. Policy brief: Bush thickening and indigenous woody plants as a source of renewable energy. Pretoria: ASSET Research & TIPS.

Fourie, H., Le Maitre, D. 2012. Policy brief: Supporting livelihoods through the protection of natural capital: A case study of the Agulhas Plain. Pretoria: ASSET Research & TIPS.

Theses and dissertations

1x PhD = R130 000x3 = R390 000; 9x MSc = R130 000x9 = R1 170 000

Crookes, D.J. 2013. Modelling the ecological-economic impacts of restoring natural capital, with a special focus on water and agriculture, at eight sites in South Africa. Ph.D thesis. Department of Economics, Stellenbosch University.

De Abreu, P. 2011. The effect of rehabilitation on ecosystem services in the semi-arid Succulent Karoo lowlands of the Little Karoo, South Africa. M.Sc Thesis, Department of Zoology, University of Cape Town.

Gull, K. 2012a. Water Supply in the Eastern Cape. An economic case study of land rehabilitation in the Kromme River Catchment. M.Com thesis, Department of Economics, University of Cape Town.

Marx, D.L. 2012. An assessment of ecological impacts of community-based restoration on communal grasslands in the Drakensberg foothills. Masters' thesis, Department of Zoology, University of Cape Town.

Mugido, W. 2011. A financial cost-benefit analysis of the implementation of a small-camp system in ostrich farming to allow veld restoration. M.Sc. Thesis, Department of Agricultural Economics, Stellenbosch University.

Ndhlovu, T. 2011. Impact of *Prosopis* (mesquite) invasion and clearing on ecosystem structure, function and agricultural productivity in semi-arid Nama Karoo rangeland, South Africa. M.Sc. Thesis, Department of Conservation Ecology & Entomology, University of Stellenbosch.

Nowell, M. 2011. Determining the hydrological benefits of clearing invasive alien vegetation on the Agulhas Plain, South Africa. M.Sc Thesis, Department of Conservation Ecology and Entomology, University of Stellenbosch.

Pauw, M.J. 2011. Monitoring Ecological Rehabilitation on a Coastal Mineral Sands Mine in Namaqualand, South Africa. Master's thesis, Department of Entomology and Conservation Ecology, University of Stellenbosch, Stellenbosch.

Rebelo, A.J. 2012. An Ecological and Hydrological Evaluation of the Effects of Restoration on Ecosystem Services in the Kromme River System, South Africa. M.Sc Thesis, Department of Conservation Ecology and Entomology, University of Stellenbosch.

Vlok, H. 2010. The Value of Natural Capital Restoration – A Case Study of the Agulhas Plain. M.Comm. Thesis, Department of Economics, University of Stellenbosch.