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Sharma, A., 2009. Interdisciplinary industrial ecology education: recommendations for an inclusive pedagogical model. *Asia Pacific Journal of Education*. Singapore: Routledge publishers, March 2009 Vol 29: 1 pp 75-86

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Publisher Routledge

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Asia Pacific Journal of Education

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title-content=t713724324>

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Online Publication Date: 01 March 2009

To cite this Article Sharma, Archana(2009)'Interdisciplinary industrial ecology education: recommendations for an inclusive pedagogical model',Asia Pacific Journal of Education,29:1,75 — 85

To link to this Article: DOI: 10.1080/02188790802655056

URL: <http://dx.doi.org/10.1080/02188790802655056>

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Interdisciplinary industrial ecology education: recommendations for an inclusive pedagogical model

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(Received 25 March 2008; final version received 5 August 2008)

Industrial ecology education is being developed and delivered predominantly within the domains of engineering and management. Such an approach could prove somewhat limiting to the broader goal of developing industrial ecology as an integrated knowledge base inclusive of diverse disciplines, contributing to sustainable development. This paper hypothesizes that industrial ecology could be optimally delivered across broader disciplines if it were to be delivered as a supplemental knowledge among disciplines that engage with sustainable development education. Based on this hypothesis, a pedagogical experiment was devised and is presented here. This paper is descriptive, reflective and exploratory in approach, highlighting the challenges embedded in an interdisciplinary industrial ecology education, and recommending an inclusive pedagogical model to address the challenges. The intention is binary, to contribute towards the advancement of industrial ecology as an integrated knowledge base, and to introduce the concept of industrial ecology to the discipline of landscape architecture.

Keywords: interdisciplinary education; industrial ecology; design; landscape; architecture; pedagogy

Introduction

The field of industrial ecology focuses particularly on the role of industry in reducing the environmental burdens through optimization of the material life cycle, design for environment, industrial metabolism, symbiosis, and ecological as well as economic efficiency, among other measures. The underlying motivation of industrial ecology could therefore be accurately interpreted as the sustainability of both industry and the environment.

The field of industrial ecology clearly exists as an interdisciplinary collaboration between variant schools within the educational community, and is thus burdened by a need for its own unique and innovative approach with regard to education. The colloquium on industrial ecology held at the National Academy of Sciences in 1991, the proceedings of which were published in 1992, created the impetus needed to initiate valuable discussions on the educational approach required. The colloquium succeeded in generating a debate on developing industrial ecology as a multidisciplinary knowledge base through the instrument of education; key issues included curriculum design (Troxell, 1992), academic structure (Starr, 1992) and defining agents of action (Patel, 1992).

Troxell and Starr both sought to explore the intellectual content of the industrial ecology knowledge base, as well as determine the overall means for the administration

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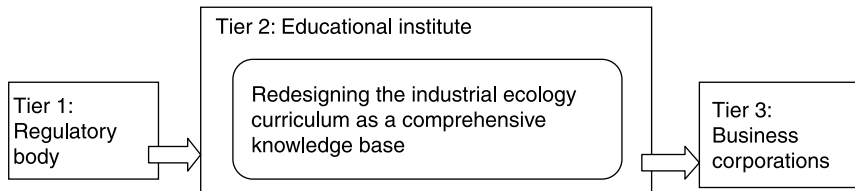


Figure 1. Diagrammatic interpretation of Troxell's approach.

of this knowledge to its students. Troxell (1992) outlined a more linear approach to this issue, as shown in Figure 1. He proposed three tiers of action, where the fundamental tier exists as a regulatory body that sets the education process in motion. The second tier is the educational institute that disseminates knowledge to the student body, and the third tier is comprised of business corporations that apply the knowledge. Troxell's approach to the establishment of a fundamental framework for the academic pursuit of industrial ecology education clearly reflects a moderate approach of least resistance to the currently existing ties between education and practice.

In contrast, Starr (1992) chose a more diverse approach to the issue of industrial ecology education, suggesting a combination of lateral and iterative approaches (see Figure 2 for a diagrammatic interpretation). Starr advocated widespread educational retrofitting within the current context of both the knowledge and administrative structures. He further explained the idea for an educational retrofit through the use of an interdisciplinary educational approach, which by definition needs to be nurtured by both regulatory bodies and business corporations. For instance, the technical knowledge base of engineers can be enriched through the inclusion of a strong social science education. The enrichment and diversification of the engineering knowledge base was thus proposed, through tapping into the knowledge offered by other departments of the same educational institute. Starr also emphasized simultaneous co-operation across different subjects and disciplines, and advocated a strong interaction between academics and practitioners in the field in order to promote a positive and productive mutual learning process for all parties.

It is noteworthy that the target student community referred to both by Troxell and Starr belongs to an engineering or affiliated background. The broadening of this target student community to include business administration students was proposed by Ehrenfeld (1994) and Piasecki (1992). These insightful proposals were indicative of long-standing efforts to expand the delivery of industrial ecology education into other related disciplines for the enrichment of participating disciplines. To this end, an attempt to further broaden the

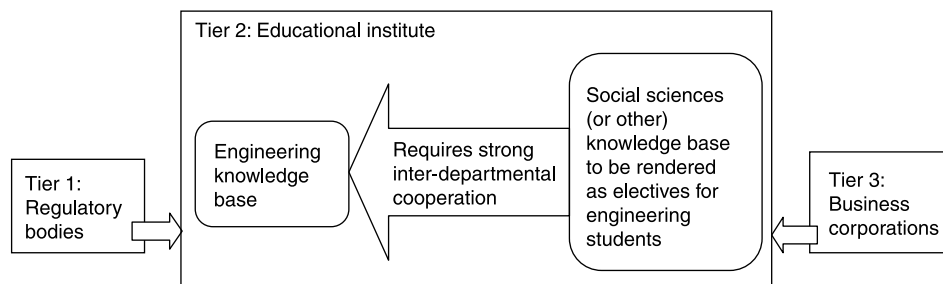


Figure 2. Diagrammatic interpretation of Starr's approach.

horizons of industrial ecology education into the discipline of landscape architecture is presented through this paper.

Since the standardization of industrial ecology education is still in its formative stages, this paper assumes and builds on the hypothesis that the inherent structure of a well-established industrial ecology education needs to be perceived as one with a dual order: the first order delivering the industrial ecology knowledge base as core knowledge, and the second order delivering industrial ecology as supplemental knowledge to other related fields, both aimed at sustainable development. This paper presents an account of experimentation in the second order; that is, delivering industrial ecology as supplemental knowledge in landscape architecture discipline.

The term “experiment” is used rather indicatively here to represent the novelty of this particular interdisciplinary educational initiative, especially for an early career academician. The experiment was not constructed prior to its application but, rather, organically evolved under the dynamic influences of time, students’ responses and the management’s position. Reference to the word “interdisciplinary” corresponds most closely with Rosenfeld’s explanation of interdisciplinarity as synthesized by Aboelela et al. (2007, p. 337) suggesting joint discipline-specific attempts to address a common problem. Industrial ecology is yet to be widely established and accepted as an independent discipline therefore the term “interdisciplinary” is used to highlight the introduction of the diversified knowledge associated with industrial ecology into a separate, autonomous discipline. The term “sustainable development”, as used throughout this paper, largely refers to minimum-impact development maximizing the use of available resources and minimizing the disruption to the environment.

This paper is based on elective (Bridging Landscapes) and design studios (Networks and Urban Eco-constructs) offered at RMIT University, Australia, over a period of two academic years. Electives are seminar-style courses, while design studios are intensive courses on problem solving through design in a studio environment. The courses were structured with the particular intention of introducing the concept of industrial ecology to landscape architecture students, in addition to advancing their landscape design skills for sustainable development. The pedagogical experiment is described below.

The pedagogical experiment

Retrofit opportunities

RMIT University signed the Universities of Australia Ecological Development Charter in 1999, thus formally proclaiming the accountability of teaching and research communities to ecological and sustainability education (RMIT University, 2006). Most academic programmes offered at the university were directed to support the global concerns of ecological sustainability, as proclaimed by the charter, through education. The introduction of industrial ecology as a new body of knowledge largely complied with the general ecological education agenda at RMIT University, as part of its accountability towards sustainable development. The challenge, however, was to find an appropriate avenue to offer this new knowledge base to students in its landscape architecture programme.

The landscape architecture programme is one of the five programmes offered at both the undergraduate and postgraduate levels, and is administered by the School of Architecture and Design at RMIT University. Subjects related to the fundamentals of ecology and contemporary environmental theory are precursors to education in sustainable

development and occupy the slots of core theory subjects, design studios and electives; this is indicative of the landscape architecture programme's intention to deliver knowledge on ecological and sustainable development. Design studios and electives are open to exploratory and experimental teaching and thus offered the most suitable opportunity to disseminate introductory knowledge on industrial ecology to the landscape architecture student community.

Content development

Inspired by the natural ecosystem (the food web, to be specific), where the waste of one organism is a resource for another, industrial ecology advocates the development of the industrial system as a true component of the surrounding system. It is not clear, however, whether the "surrounding system" should include constructed systems or biophysical systems or both.

Deciding upon the content of the course in view of the evident lack of relevant precedents was indeed challenging. Troxell's (1992) discourse on industrial ecology education is premised around the understanding of industrial ecology as a system seeking to integrate all aspects of an industrial process subsequently aiming to optimization of the total system, through maximization of resource recycling and minimization of resource consumption and waste emission. After over a decade, the definition, approach, scope and application of industrial ecology continues to be formulated, contested and refined by researchers around the world.

Seminal literature on the subject was reviewed for an idea on the content of industrial ecology knowledge base. Basic principles of industrial ecology selected for the course are outlined below:

- Maximum resource efficiency and waste minimization can be achieved by optimizing inter-industrial material and energy exchanges, and using cleaner production processes. Industrial production processes could be optimized at each stage by delineating and ramifying the pollutive production stages (Allenby & Cooper, 1994; Socolow, Andrews, Berkhout, & Thomas, 1994).
- The selection of raw materials to be used in the industrial manufacturing process should be guided by the end-of-life recycling potential of raw materials and the disposability of materials, with minimal environmental damage (Ausubel, 1992; Graedel, Allenby, & Linhart, 1993).
- Multiple recycling loops of raw materials should be identified (Cohen-Rosenthal, 2004; Cote & Plunkett, 1996).

That the interactions between the component organism and the ecosystem contribute towards the overall stability of the component as well as the composite natural ecosystem should also be acknowledged as one of the key principles of industrial ecology.

Key players

In the development of any new curriculum, it is the educator who foremost influences the manner in which the content is disseminated to students. Even the prominent discourse on industrial ecology education by Troxell (1992), Starr (1992), Piasecki (1992) and Ehrenfeld (1994) is very much oriented towards the disciplines of engineering, systems and management sciences – the subject areas of the authors' own proficiencies and interests. In this case also, the personal motivations, intentions and teaching practices of

the educator influenced the design of the curriculum. The course was, therefore, strongly influenced by the author's personal position and hypothesis on the significant role that landscape design can play in activating a symbiotic network of industrial systems with surrounding residential and biophysical system in support of sustainable development; the position is partially shared with contemporary researchers, who advocate the development of industrial ecosystems with due attention to the protection and restoration of sensitive ecosystems, indigenous plantings and natural resources; the protection and preservation of water flows; and the maintenance of natural topography and drainage-ways (Grant, 1997, 2000; Lowe, 2001; Lowe, Moran, & Holmes, 1998).

Aspirations and objectives for the course were multi-fold, ranging from the desire to explore the role of landscape architecture in improving the ecology of urbanized contexts, to contributing to the advancement of industrial ecology as an integrated body of knowledge and skills. Further, a strong desire to make students aware of the multitude of possibilities available for pushing the boundaries of conventional frontiers of landscape architecture practice was a key impetus. Teaching was largely based on the tenet that problems – whether theoretical or design-based – inherently hold within them a clue to the solution, and thus critical analysis of the problem is imperative. This author agrees with Steiner and Posch's observation that "interdisciplinary teaching does not focus primarily on detailed factual knowledge; rather it focuses upon the development of core competencies for solving different kinds of problems" (2006, p. 880). The structure of this experimental course was thus influenced by the "teaching and learning" approach, as a guided collaborative exploration in which students were equipped with selective tools and techniques to enable them to be contributors to the larger body of knowledge, and not only be the consumers of given knowledge.

Teaching the course

The structure of the elective and design courses offered over two academic years, from 2005 to 2007, was largely consistent in its approach and involved a critical study of precedents, problem-based tasks, site-responsive exercises, community engagement initiatives, and even intuitive responses to a certain extent. The courses were partly descriptive and partly exploratory in nature; the teaching approach utilized was distinctive in both years.

In the first year of teaching, industrial ecology knowledge was offered through an elective called "Bridging Landscapes". This elective course attempted to spatially bridge the gap between the opposing and cohabiting domains of industrialized and biophysical contexts through subtle manipulations using landscape design as a tool. Besides introducing the basics of industrial ecology, the course sought to impart basic knowledge on designing remediation and vertical landscapes. The course was delivered through a combination of workshops, discussion forums, design reviews and field visits.

The structure of the course was linear and compartmentalized. To elaborate, the first compartment was teacher-centric, whereby the basic knowledge of industrial ecology and its principles were delivered by the author and supported by invited lecturers in a classroom environment. The second compartment was learner-centric and was based on the author's pedagogical tenet that theoretical knowledge is best understood through personally engaging or translating it into action. This component was run as an experimental lab, wherein students were asked to address one major issue addressed by industrial ecology, such as closing the material loop, through a landscape design intervention. The landscape design interventions proposed by students reflected a partial

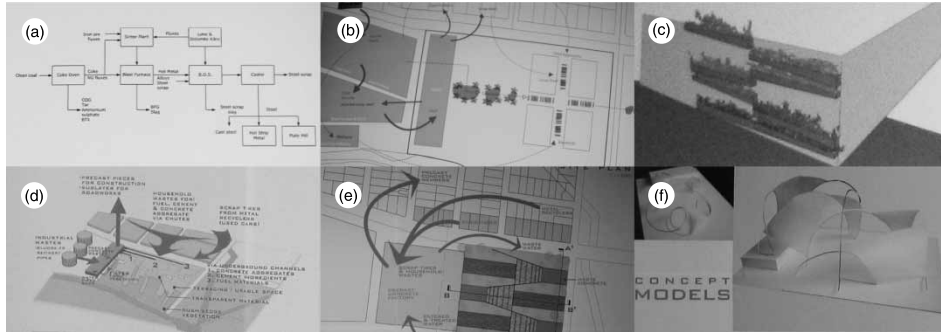


Figure 3. Design development and resolution drawings for industrial ecology education as part of the elective on Bridging Landscapes by landscape architecture students at RMIT University: Andrea Scyzmanski (a); Caitlin Perry (a); Dimitri Dimoukopolos (a, b); Adrian Napolean (a, c); and Eva Yapit (d, e, f).

and inflected understanding of the overall principle – a promising start as measured against the course objectives. Figure 3 shows a sample of the students' design resolutions.

As one would expect, the course had its shortcomings. The use of real-world case studies, developed through co-operation and interaction among students, teachers and regional stakeholders, is widely recommended for refining the critical thinking approach of students (Alvarez & Rogers, 2006), and for a better appreciation of the relevance and value of interdisciplinary education (Steiner & Posch, 2006), besides others. However, the lack of established industrial ecosystems in and around Melbourne posed a challenge for a real-world, case study-based education, which was identified as a limitation by the students. The time frame of one academic semester allocated for this elective was also perceived as a restrictive factor in the simultaneous exploration of inter-industrial networks and the role of landscape design.

The insightful, intelligent questions and counter questions raised by participating students during the learner-centric portion of the course were extremely constructive for enhancing their overall understanding of the subject matter while simultaneously enriching the course itself. For example, in questioning the practice of using arrows on paper to trace and indicate material loops, students challenged their peers' general perceptions on closing the material loop. In addressing the problem through landscape design, their own response was primarily to recycle the material through designed landscapes. The design exercises also generated debate on the purpose and scope of contemporary and conventional landscape design. For instance, the feasibility of employing contemporary design strategies, such as the use of constructed vertical landscapes and green roofs against the conventional landscape design strategy of constructed wetlands, was debated. The students thus inquired into the fundamental concepts of industrial ecology and experimented with landscape design strategies towards the aim of sustainable development.

The administration's position on selecting electives or design studios as the most feasible avenue for delivering an experimental course remained unchanged for the following year. The content and structure of the course was revisited in the second year of teaching, based on critiques from the previous year. Learning objectives and outcomes for the design studio environment were more rigorous than for an elective, with a stronger emphasis on both the conceptualization and resolution of the landscape design, and final

representations through drawings and models. Considering these factors, the knowledge of industrial ecology was framed and pitched differently in the second year. Rather than laying out the mosaic of industrial ecology principles, and thus overwhelming students with a number of secondary decision-making responsibilities besides design decisions, only the essence of industrial ecology was offered as one broad principle. The concept of symbiosis, which first inspired the emergence of the field of industrial ecology, became the central focus of this course. The existence of industrial, residential and biophysical contexts in proximity to each other was used as a key criterion for site selection. Activating symbiosis through landscape design interventions on this site was the broader mandatory agenda of the studio; the specific area or network of intervention was the variable left open for students' personal interpretation and selection. The intention was to allow scope for intellectual and creative freedom, to enable the students to begin recognizing their own interests in landscape design.

A residential neighbourhood located in proximity to industry was used as the site for the design studio on "Networks" and a recreation park converted from a landfill constructed and re-constructed many times over, within a constrained urbanized setting, was used as the point of investigation for the design studio on "Urban Eco-constructs". The problems in both design studios was to activate, strengthen or alter the ecological networks within the site through landscape design interventions; the fact that symbiotic networks are not always visible and tangible, provided further challenge to the students. Based upon the understanding of symbiosis and equipped with an understanding of industrial ecological tools, such as designing for the environment and life cycle analysis, coupled with the freedom to investigate an area or network of individual interest, students were able to generate engaging design responses.

Despite the novelty of the subject, students' design responses were truly insightful if sometimes divergent. The creative freedom rendered to the students to interpret the network of intervention was liberally utilized. The focus on "symbiosis" as the underlying agenda, however, led to avoidance of conceptually problematic digressions. The design responses that were finally displayed were extremely diverse and included responses sympathetic to human as well as biophysical communities. For example, the human community-sympathetic responses included design proposals for safe pedestrian and bike networks, household waste management systems, and an industry-sympathetic exploration of the role of landscape design to enable an intermediate storage of materials during the transportation cycle of recycled material from one industry to another (see Figure 4).

The outcomes of design studios exploring the role of landscape in the realm of industrial ecology brought forth a range of innovative design solutions contributing to sustainable development, and this was accomplished through the combined delivery of industrial ecology and landscape architecture knowledge.

In retrospection

Convergence of intentions

This experiment was largely situated within the educational institute tier and experienced strong, pervading influences from the internal regulatory body – the programme management. The internal regulatory body, in turn, was highly influenced by the dynamic interrelationships between the state of practice and students' expectations. Students expect to be equipped with marketable skills; the lack of consensual and vocal acknowledgement of the value in enmeshing industrial ecological design principles with landscape

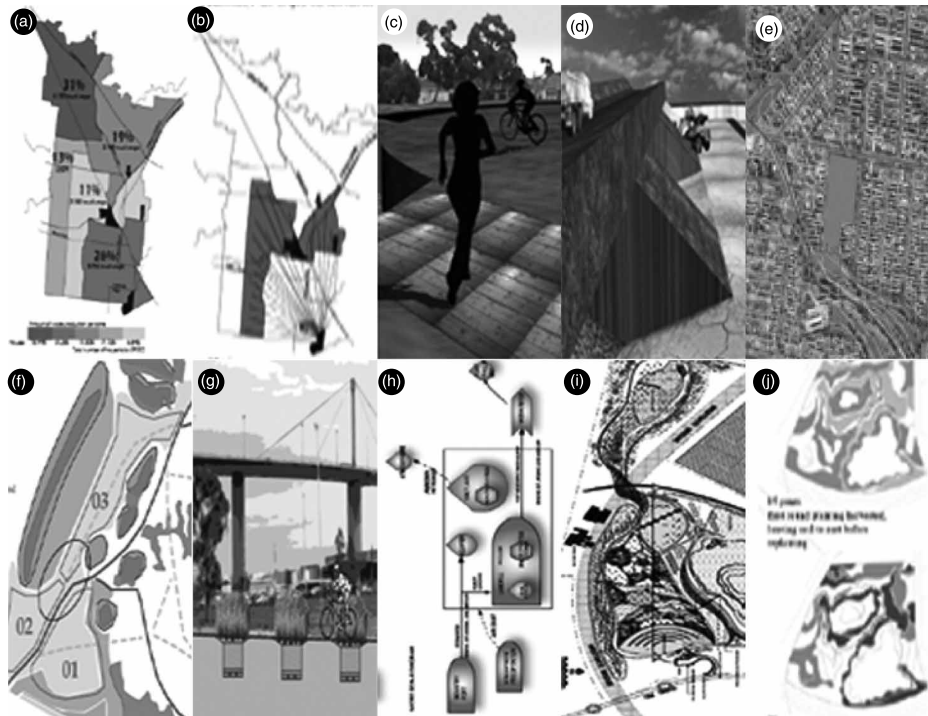


Figure 4. Design development and resolution drawings for industrial ecology education as part of the design studio on Networks and Urban Eco-constructs by landscape architecture students at RMIT University: Simon McHarg (a, b, c); Nicholas Owen Rose (d); Alexandra Malishev (e); Nicholas Beer (f); Monique Govers (g); Keith Farnsworth (h, i); and Bride Blake (j).

architecture practice inadvertently dampened students' enthusiasm for the course, which in turn influenced management's position on the delivery of this interdisciplinary knowledge. The need to integrate systems-based industrial ecology knowledge with landscape architecture, as well as other disciplines, needs to be acknowledged and agreed upon by administrators, students and practitioners; such integration would subsequently bridge the gap between the expectations of various key players, thus facilitating the avenue for teaching industrial ecology in an interdisciplinary context.

The above pedagogical experiment thus reasserts the significant role of the three-tiered model, consisting of regulatory body, educational institute and business practice. It also suggests the role of the student community as a strong and independent influence, which is in tandem with contemporary observations on the importance of practitioners and administrators' viewpoints (Ausubel, 1992; Ehrenfeld, 1994; Patel, 1992; Starr, 1992; Troxell, 1992). The essential role of the student community in the development of an interdisciplinary educational initiative is strongly acknowledged by Lidgren, Rodhe, and Huisingsh (2006) in their recommendation on using students' awareness, willingness and ability, in relation to the knowledge imparted, as a critical indicator of whether the new knowledge should be incorporated in the curricula. This experiment reaffirms the fact that teachers and students need to be considered as key players within the subset of an educational institute and that the convergence of intentions of all key players is crucial for a successful interdisciplinary educational initiative.

Binary model

The hypothetical assumption that industrial ecology education is a binary model of dual order – the first order imparting industrial ecology as core knowledge and the second imparting it as supplemental knowledge in other disciplines – provided a clear structure around which this experimental interdisciplinary course was developed. A binary structure facilitates the delivery of industrial ecology knowledge to be delivered as supplemental content, allowing for sufficient adaptation to suit the desired learning outcomes of the predominant host discipline. Identification of the desired learning outcomes and capability development by educators in the field of industrial ecology and the predominant host discipline could be the first step in developing the course for interdisciplinary education. The course content can then be developed around these desired learning outcomes. In this particular experiment, the learning outcomes were sympathetic to the outcomes of the host discipline of landscape architecture.

The measures used to evaluate the performance of the course also need to be clearly established. Determination of educational goals for industrial ecology, clarifying the interdisciplinary, multidisciplinary or transdisciplinary intentions will also significantly influence the curriculum design and teaching pedagogy.

Collaborative learning

This paper recommends a thorough assessment of student capabilities, including critical thinking abilities, at the onset of the course, and strongly emphasizes on practising teaching as collaborative learning. The author presumed an adequate knowledge by participating students of landscape design intervention for sustainable development, at the onset of the course. Such a presumption could be misguided. Based on the experiment, the author realized that, despite first order administrative checks, student knowledge needs to be carefully assessed so as to devise appropriate learning activities and teaching strategies based on different levels of knowledge and the diversity of learning styles.

The attitude of some students of passive participation in the course, to remain at the receiving end of knowledge, rather than actively engage in the process in an exploratory fashion, proved to be inequitable with their actively engaged and contributory peers. Select student's lack of engagement at times forces the course content and delivery to stagnate at the descriptive and prescriptive level, rather than progress to a more thematically innovative and rigorously investigative level. This proves restrictive to knowledge-building intentions of experimental, interdisciplinary design studios.

It should be noted that the industrial ecology knowledge base, when interfaced with other design disciplines such as landscape architecture, is still in a relatively nascent stage and, therefore, needs to be strengthened and nurtured through wide-ranging teaching and learning initiatives and through the student community's proactive participation. In the opinion of the author, the overall engagement of students within this course of study could be more intense, if students' accountability in the educational process was strongly impressed upon them at the onset.

Conclusion

This paper describes and critiques a pedagogical experiment that took a largely unprecedented position on the interdisciplinary delivery of industrial ecology education. The commonality of the goal of sustainable development in the fields of industrial ecology and landscape architecture offered the experimental ground for this initiative. This case

study acknowledges the vital role of administrators in determining the introduction of a new course, while simultaneously highlighting the significant influence of four key players in such an endeavour: teachers, students, administrators, and practitioners. This case study further supports the potential usefulness of the hypothetical binary model of industrial ecology education, since it provides an advantageous launching ground for both participating disciplines. For instance, this particular study contributes towards the development of the industrial ecology discipline as an integrated knowledge base, on one hand, while concurrently introducing a diverse knowledge base to the discipline of landscape architecture. The binary model could be a useful integrative tool for inter-disciplinary education in general. In terms of teaching pedagogy, this paper advocates the practice of teaching as collaborative learning, especially to strengthen students' involvement and perspective in the further development of a new interdisciplinary knowledge base.

Acknowledgements

I am grateful to Judy Rogers and the anonymous reviewers for their feedback in improving the clarity of this paper. I would also like to thank my students for their enthusiasm, support and contribution. Thanks are also due to Michael Howard, Jane Shepherd and Fiona Harrison for facilitating these exploratory educational initiatives.

The views expressed in this article are those of the author alone and do not represent the views of the Landscape Architecture Programme or the School of Architecture and Design at RMIT University.

This paper was developed by Archana Sharma in 2007 while she was teaching as a Lecturer at the School of Architecture and Design, RMIT University, Australia.

References

- Aboelela, S.W., Larsen, E., Bakken, S., Carrasquillo, O., Formicola, A., Glied, S.A., et al. (2007). Defining interdisciplinary research: Conclusions from a critical review of the literature. *Health Services Research*, 42, Part 1, 329–346.
- Allenby, B., & Cooper, W. (1994, Spring). Understanding industrial ecology from a biological systems perspective. *Total Quality Environmental Management*, 343–354.
- Alvarez, A., & Rogers, J. (2006). Going “out there”: Learning about sustainability in place. *International Journal of Sustainability in Higher Education*, 7, 176–188.
- Ausubel, J.H. (1992). Industrial ecology: Reflections on a colloquium. *Proceedings of the National Academy of Sciences, USA*, 89, 879–884.
- Cohen-Rosenthal, E. (2004). Making sense out of industrial ecology: A framework for analysis and action. *Journal of Cleaner Production*, 12, 1111–1123.
- Cote, R.P., & Plunkett, T. (1996). Industrial ecology: Efficient and excellent production. In A. Dale & J.B. Robinson (Eds.), *Achieving sustainable development: A project of the sustainable research institute* (pp. 119–145). Vancouver, Canada: University of British Columbia Press.
- Dale, A., & Newman, L. (2005). Sustainable development, education and literacy. *International Journal of Sustainability in Higher Education*, 6, 351–362.
- Ehrenfeld, J.R. (1994). Industrial ecology and design for environment: The role of universities. In D.J. Richards, B.R. Allenby, & R.A. Frosch (Eds.), *The greening of industrial ecosystems: Overview and perspective* (pp. 228–240). Washington, DC: National Academy Press.
- Graedel, T.E., Allenby, B.R., & Linhart, P.B. (1993). Implementing industrial ecology. *IEEE Technology and Society Magazine*, 12(1), 18–26.
- Grant, J. (1997). Planning and designing industrial landscapes for eco-efficiency. *Journal of Cleaner Production*, 5, 75–77.
- Grant, J. (2000). Industrial ecology: Planning a new type of industrial park. *Journal of Architectural and Planning Research*, 17(1), 64–81.
- Jelinski, L.W., Graedel, T.E., Laudise, R.A., McCall, D.W., & Patel, C.K.N. (1992). Industrial ecology: Concepts and approaches. *Proceedings of the National Academy of Sciences, USA*, 89, 793–797.

- Lidgren, A., Rodhe, H., & Huisinsh, D. (2006). A systemic approach to incorporate sustainability into university courses and curricula. *Journal of Cleaner Production, 14*, 797–809.
- Lowe, E. (2001). *Greening existing industrial parks*. North Carolina: Research Triangle Institute.
- Lowe, E., Moran, S., & Holmes, D. (1998). *A fieldbook for the development of eco-industrial parks*. North Carolina: Research Triangle Institute.
- Patel, C.K. (1992). Industrial ecology. *Proceedings of the National Academy of Sciences, USA, 89*, 798–799.
- Piasecki, B. (1992). Industrial ecology: An emerging management science. *Proceedings of the National Academy of Sciences, USA, 89*, 873–875.
- RMIT University (2006). *Greening RMIT: The universities of Australia ecological development charter*. Retrieved December 16, 2006, from <http://www.rmit.edu.au>
- Socolow, R.C., Andrews, C., Berkhout, F., & Thomas, V. (Eds.). (1994). *Industrial ecology and global change*. New York: Cambridge University Press.
- Starr, C. (1992). Education for industrial ecology. *Proceedings of the National Academy of Sciences, USA, 89*, 868–869.
- Steiner, G., & Posch, A. (2006). Higher education for sustainability by means of transdisciplinary case studies: An innovative approach for solving complex, real-world problems. *Journal of Cleaner Production, 14*, 877–890.
- Troxell, D.E. (1992). Educating and training industrial ecologists for the 1990s. *Proceedings of the National Academy of Sciences, USA, 89*, 862–863.