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GUEST EDITORIAL

Emotional Engineering

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I arise in the morning torn between a desire to improve the world and a desire to enjoy the world. This makes it hard to plan the day.

E. B. White

One thing alone I charge you. As you live, believe in life! Always human beings will live and progress to greater, broader and fuller life. The only possible death is to lose belief in this truth simply because the great end comes slowly, because time is long.

W. E. B. Du Bois

I want to talk about emotions. Well, I don’t really want to. Frankly, not having to deal with emotions was one of the attributes of engineering that attracted me to this field of study. I liked keeping interactions on an intellectual level. Answers to Math and Physics homework sets were cut and dried and the odd numbered ones could be found in the back of the book. There was security in knowing the right answer. However, despite the promise of clarity, even as an engineer, I found questions finding their way in, or their way out, questions that were rooted in my emotional landscape. Is this all there is? What do I want my life to be about? How am I making the world a
better place by the work that I do? These weren’t academic questions for me; they were soul searching questions that challenged the core of my identity. Could I be an engineer and be whole, whatever that might mean? I’m proud of the work I have done to become an engineer, but there is something missing.

Adding to the difficulty, I felt alone. No one else seemed to be asking these types of questions. It looked more and more as if I were the bad data point. Others may have complained about aspects of the job, but few articulated asking what we were doing on a fundamental level. Thankfully, I found some fellow travelers who were also questioning our place as engineers in a larger context. This Engineering, Social Justice, and Peace community is a sanity-saving organization for me. While there are few of us, and we may all be bad data points, I know that I am not alone.

However, to my surprise, with this new connection, I still wasn’t able to abandon my emotions and center only on intellectual pursuits. The emotional tumult was still there, but now with different questions. How do I know if I am doing enough? What is enough? Everyone is doing so much more than I am. Is change even possible? Maybe nothing we do will actually make a difference. In my meandering relationship with my emotions, I have finally come to believe that emotions are not just a bug in the program that need to be controlled, but the unacknowledged feature that holds the critical key to our work towards social justice.

Instead of running from these questions, I am practicing sitting in the discomfort of them. Furthermore, I expect that if these questions lose energy for me, others will appear in their place. We need to embrace the emotional aspect of our engineering lives. A classic quote from Einstein asserts that a problem can’t be solved at the same level with which it was created. The level on which our profession of engineering operates is one which de facto denies emotions. This denial hurts. It hurts us because we aren’t acknowledging our whole selves. It hurts our quest for social justice and peace because we certainly can’t acknowledge the whole planet if we don’t even know ourselves.

Welcoming our emotional lives to the table is a step we have to take in pursuit of fundamental change. It will be easier for some of us than for others, and we need to be respectful of where everyone may be in their own journey. However, we have to stretch through our uneasiness, with the same effort and dedication that we had to use when faced with an academic challenge like thermodynamics. I see it as an inverse function where my goal is now to move from certainty to mystery.

For me, the ESJP conferences are where I feel most connected to the emotional dimensions of an engineering community, aligned to the pursuit of social justice. This is why I volunteered to host the ESJP conference on Whidbey Island in 2009. In the face-to-face interactions, in the space between the formal presentations, I found what was missing in “normal” engineering conferences. In the conferences that I attended in Binghamton, NY, we played theater games and constructed dioramas with modeling clay. We acknowledged that we were more than people who just think.

At the conference at Smith College, we found ourselves constantly behind schedule. We would have thought-provoking presentations, and then we would spill over into conversations that included our feelings of hope and despair. A theme for me is the importance of what happens in the space around the actual presentation or exercise. “Debriefing” sounds so cold, when that is often the richest part. At the conference in Bogota, we did a “privilege walk” where we took steps forwards or backwards depending on our lived experiences. After several questions were asked, we found ourselves spread out—a strong visual of how privilege plays different roles in our lives. The harder,
and more painful part, was the conversation back in the classroom. It illustrated for me that we can pretend all we want that information is just information, but we were clearly traversing an emotional terrain while on our privilege walk. I don’t think we have all the answers on how to do this work perfectly or with extreme grace, but I fully believe that the work we want to do won’t be accomplished without opening ourselves to the vulnerability of sharing our emotions—risky behavior with a huge potential reward.

The conference at RPI illustrated again that our community is willing to take the risk of connection. Our conversations went beyond facts and delved into the feelings of what we are dealing with. Those feelings weren’t necessarily comfortable. Maybe they are necessarily uncomfortable? We were asking if all of this is just a complete waste of time. What are we putting our students through? For me, I was thankful for the level of honesty. We experienced even more discomfort later by sitting in a circle with no guidance or rules of conversation and dealing with what emerged. Again, the willingness to pursue other ways to be with each other is inspiring.

Another example honoring emotional connection came from the conference held on Whidbey island. We participated in a lively, somewhat intellectual, exercise about “polarities”—the both/and aspects in our work such as the tension between working from within the system and working from outside the system. We then took a long walk on the beach, hanging out in small groups, collecting driftwood and shells. From that relaxed space and using our found objects, we started individual art projects of creating mobiles that represented our own personal polarities. Patience and activism. Individualism and community. Chaotic creativity and detailed precision. The art pieces were beautiful to behold. However, a profound part of the process, which I had completely underestimated, was when we gathered around each mobile, and its creator explained the meaning behind the art. Deep, real sharing happened. The world wasn’t quite so lonely.

I have certainly been inspired and grown from intellectually knowing what others are doing and researching, but the most powerful moments for me at the ESJP conferences have always included a large emotional content. Working on social justice within an engineering context is lonely. There aren’t enough of us and it can be hard to tell who is an ally in the work. When we honor and acknowledge our emotions in the space of other engineers, we are offering our trust in each other and a certain level of bonding. We are not going to create social justice within engineering as individuals, we have to be in community. These connections happen, even when the emotions leave the realm of love and joy and veer into the terrain of fear, pain, or anger. Social Justice and Peace work isn’t supposed to be comfortable. We have built an environment that gives us some moments to turn towards our emotions and towards each other. How rare for us engineers and how thankful I am for the space and for all of you. I am interested in diving in even more deeply to the emotional landscape we bring to this work.
ARTICLE

How Can Engineers Learn From The Past?
A Potential Role for History in Engineering Education

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ABSTRACT

At present, in many societies, engineers play a significant role in solving problems of energy, transport, accommodation and production; but similar problems have been solved through technical and non-technical means for thousands of years. Numerous historical examples therefore exist, in which the ends of different approaches to problem-solving are apparent: some producing socially just and/or ecologically sustainable outcomes, and some less positive.

Historians do not simply narrate the past, they explain and interpret changes and continuities by paying attention to larger issues of, for example, class, gender, polity and economy. Such historical narratives, we argue, may have a useful role to play in efforts to shift the perspective of engineering students away from a narrow focus on complex technical solutions, towards the broader context in which their problem-solving will take place. This ability to assess the relationships between engineering problem-solving and the broader social and environmental context is critical to the development of a more sustainable and socially-just engineering practice.

KEYWORDS: history, engineering education

INTRODUCTION

Engineers play a significant role in shaping important dimensions of contemporary societies and environments. However, the dominant engineering paradigm in industrialised nations has been one of technical problem-solving, in which engineers were rarely required to consider the way a problem is framed (is it really a technical problem?), nor to work with social justice and ecological sustainability as key design criteria (Riley, 2008, pp. 40–1).1 A growing number of voices are advocating a new paradigm for engineering, with goals of sustainability and social justice at its core (Beder, 1998; Conlon, 2008; Johnston, McGregor, & Taylor 2000). In this context we propose that the discipline of history could potentially be a valuable component of the education of “new engineers.” Humanity has been solving problems through technical and non-technical means for thousands of years, and in recent years an increasing number of historical narratives have emerged in which the ends of different approaches to problem-solving are apparent: some producing outcomes that are socially and ecologically sustainable; others leading to disaster. Historians are well-placed to bring such episodes to life, engaging the imagination of engineering students as well

1 The story of the development of this paradigm in the Soviet Union is evocatively sketched out by Loren Graham (1993, chap. 4).
as providing them with analyses that highlight the importance of engineers understanding the social and power relationships in which their work may intervene, as well as the ecological context.

**SUSTAINABILITY AND SOCIAL JUSTICE**

Before exploring this potential in greater detail, it is worthwhile reflecting in a general way on what we mean by sustainability and social justice, and the relationship between them. Social justice is a concept that resists a precise and stable definition, as our understanding of it always depends on our personal values and experiences. However, in a survey of how different organisations devoted to social justice conceive of it, Donna Riley (2008) has identified some common themes, namely “the struggle to end different kinds of oppression, to create economic equality, to uphold human rights or dignity, and to restore right relationships among all people and the environment” (p. 4). Here we see that the environment has a role to play in social justice, though the relationship between social justice and sustainability is contested, as is the concept of sustainability itself.

The idea of sustainable development, though far from novel, was popularised by the 1987 publication of Our Common Future, which summarised the work of the World Commission on Environment and Development (WCED). In it, sustainable development was defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987, p. 37). Much emphasis was subsequently placed on the notion of intergenerational equity, for example in the concepts of “strong” and “weak” sustainability. However, as Oluf Langhelle (2000) has pointed out, the fundamental goal of the WCED was to reconcile ecological sustainability with “need satisfaction, and equal opportunities within and between generations” (p. 297). Although the approach taken by the WCED has been criticised on a range of grounds (Irvine, 2003, p. 173), we argue that in principle, its effort to integrate issues of equity and environment was sound. Although some have proposed that there is no necessary connection between social justice and sustainability (Dobson, 2003), it seems clear to us that at a basic theoretical level, a just yet unsustainable society cannot survive, while an unjust yet sustainable society is not worth sustaining. Furthermore, there are often strong functional relationships between social equity and environment: for example, people living in poverty are likely to have fewer choices in relation to their environmental impacts, and often feel most acutely the effects of environmental degradation.

Therefore, we understand ecological sustainability and social justice as ideally integrated and identify them together throughout this paper in order to emphasise the way in which they are both critical to a more ethical engineering practice.

**THINKING HISTORICALLY/HISTORICAL THINKING**

What are the strengths of the discipline of history, and how may these be deployed to serve the transformation of engineering education? Historians do not simply construct lists of events or even just narrate the past, they explain and interpret changes and continuities by paying attention to broader contextual and structural elements, such as culture, political organisation, class, and gender.

How can we, living in the present, learn from historical studies? Despite a widespread popular belief in the need (and often failure) to “learn the lessons of the past,” the context in which events occur is ever-changing, so history never repeats itself exactly. Its predictive potential is therefore limited: although it can tell us about potential preconditions to a particular outcome, and draw our attention to the characteristics of actors or contexts that shaped unfolding events, it cannot provide
an infallible guide for contemporary behaviour. On the other hand, comparisons of the present and past can highlight which elements of our present circumstances are transient, and which are more enduring (Tosh, 2006, p. 34). This is one means by which it contributes to our store of knowledge about the present. History can also very usefully provide what John Tosh (2006) has called "an inventory of alternatives" (p. 32), and as cultural historian Natalie Zemon Davis (1984) has put it, "I show that things don't have to be the way they are now. . . . I want to show that it could be different, that it was different, and that there are alternatives" (p. 114-115). This is not to say that historical narratives will provide comprehensive or even extensive descriptions of possible socially-just or ecologically-sustainable solutions to a particular “engineering” problem, not least as outcomes are far too contingent on particular historical contexts for that. Rather, their principal utility for engineering education lies in their ability to vividly demonstrate why understanding of the social and ecological contexts, as well as social justice and ecological sustainability as key outcomes, must form an intrinsic part of engineering practice. The past is littered with examples of the ruin precipitated by engineering practice lacking these features.

History is rarely singular, and if it is, it is rarely that way for long. Historical interpretations proliferate, diverge, and compete for followers. Hayden White (1973) has argued that histories are essentially stories, in which the interpretation presented has as much to do with rhetorical style and literary genre as it does any “truth” about the past. To put it another way, the past is not a story, but a history is. Although most historians retain a commitment to historical truth, they also recognise that history is not chronicle, and that in assembling facts into a narrative, issues of form (or rhetorical practice), as well as politics and preferences, come into play. In relation to the latter, William Cronon (1992) has proposed that:

Because stories concern the consequences of actions that are potentially valued in quite different ways, whether by agent, narrator, or audience, we can achieve no neutral objectivity in writing them. Historians may strive to be as fair as they can, but . . . it remains possible to narrate the same evidence in radically different ways. (p. 1370)

Cronon (1992) then asks, how, in the face of divergent narratives, “are we to choose among the infinite stories that our different values seem capable of generating” (p. 1370). He proposes that the range of acceptable historical narratives is limited to those that “do not contradict known facts about the past,” and that are produced within a critical community that demands respect for sources. Beyond that, the best “historical storytelling helps keep us morally engaged with the world by showing us how to care about it and its origins in ways we had not done before” (p. 1375). What this means for engineering educators seeking to draw on historical narratives in their classes is that they should choose the narratives most likely to inspire their particular group of students to approach problems by giving serious consideration to the social and ecological context, as well as whether the solution will deliver sustainable and socially-just outcomes.

Given that many historical narratives would not be in a form suitable for presentation to engineering students, and also because engineering faculty may not be very familiar with the relevant body of historical scholarship, it is likely that successfully introducing histories into engineering education would require at least some minimal collaboration between engineering educators and historians. Of course, the use of history alone will be unlikely to achieve a thoroughgoing commitment among engineering students to a sustainable and socially-just engineering practice. Rather, we anticipate that it would appear in the curriculum alongside complementary critical approaches and interventions, including perspectives from science and technology studies (Jasanoff, Markle, Peterson, & Pinch, 2001; Jasanoff, 2004), appropriate design
(Nieusma, 2004), and contemporary literature and case studies in engineering and social justice (Riley, 2008; Nieusma & Riley, 2010).

One place within the curriculum with considerable potential for introducing historical narratives is the first engineering unit in an engineering degree program, which is often an introduction to the engineering profession that includes definitions of engineering and engineering processes, problem solving, communication skills, and issues of ethics, sustainability and social justice. This first unit may introduce engineering design and include a major design project, such as the Engineers Without Borders Challenge. For such projects, students need to identify social justice and sustainability issues as design objectives, as well as define metrics that measure whether these objectives have been achieved in the final design. Historical case studies might be used within this type of unit to encourage students to think broadly and critically about how to identify and work towards key community objectives, and to highlight—in a generic sense—the possible consequences of ignoring these objectives in their work process and final design. This might be accompanied by a discussion of some of the more specific issues involved in engineering and development projects. This first design project is typically a conceptual design task that is not discipline specific, and may in fact be multidisciplinary. In any case, historical examples that highlight the importance of addressing social issues in one engineering field should provide valuable lessons for any other engineering field. For example, with sufficient opportunity for discussion in which to tease out the relevant elements, the lessons learnt about the social and environmental impacts of gigantism in water management, which are directly relevant to civil and environmental engineers, could inform electrical engineers on the potential for similar long-term harm from gigantism in energy projects such as hydroelectric and geothermal energy generation.

In this article we outline, by way of example, two historical stories that might be used in an engineering education context to illustrate the divergent consequences of different approaches to the problem of irrigation, as engineered systems that divert, store and move water around a modified landscape for crop production purposes. Although employing similar engineering technology, in the form of canals, the two systems—in central Asia and the island of Bali—operated in different ecological settings, and perhaps even more importantly, in the context of different social and power relationships. As such, they led to very different social and ecological outcomes. These are of course only two of the many possible historical narratives that could be told of irrigation in the Aral basin and on Bali. The two we present both conform to historical facts and have been subject to critical scrutiny within an historical community, and were chosen with the aim of encouraging students to consider issues of scale, power, knowledge and proximity (as discussed below), as well as arriving at a general appreciation of the importance of context and the pursuit of just outcomes.

**EXAMPLE 1: THE ARAL SEA**

The Aral Sea is located in the deserts of central Asia, in the republics of Kazakhstan and Uzbekistan. It was once the world’s fourth largest lake, but following a dramatic expansion of irrigated cotton production in its catchment, it now occupies less than ten percent of its original area (see Figure 1). This dramatic hydrogeological change, precipitated by the engineering of canals for large-scale irrigation schemes, has left a host of social and environmental problems in its wake.

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3 As outlined for example in Nieusma & Riley (2010).
The Aral basin has a very long history of irrigation, with irrigated orchards supporting wealthy settlements such as Bukhara and Urgench from the 9th to 13th centuries, until they were destroyed by the Mongols (Weiner, 2003, p. 70). For example, by the 12th century the ancient city of Merv, in present-day Turkmenistan, had over 1 million inhabitants and a cultivated area of 700 km² (O’Hara & Hannan, 1999, p. 24). Despite using only a small part of the water of the Murgap river, the city was able to feed itself, and export food to adjacent areas. The writings of Arab historians and geographers reveal that at the heart of the system lay small plots that were intensively cultivated and watered regularly. The management of water was coordinated by a *mirab*, or water master, who was one of the most important people in the polity. Every canal was fitted with a water gauge and the level of the main canal was monitored hourly. The level of water flowing in spring guided decisions about how much land was to be cultivated each year, and in dry years only essential cultivation was undertaken. Around 12,000 people were employed in managing the system; water users contributed to the system through a water tax, and by assisting with annual maintenance activities, and construction of new works. This system operated effectively until the Mongol invasion, but was not re-established on the same scale thereafter, perhaps because of the level of centralised bureaucracy involved in its management.

In some areas, however, parts of the ancient systems of small-scale canals and irrigated farms survived through to the twentieth century. K. Sh. Sirozhidnikov has argued that in 1917, the year of the Russian Revolution, central Asia boasted a well-developed and environmentally-sustainable traditional irrigation system (Micklin, 1992, p. 270). Each farm was 2–3 hectares with irrigated fields of 0.3–0.8 hectares, sufficiently small to be carefully managed. The fields were bounded by permanent low earthen walls, which prevented secondary salinisation by acting as salt accumulators. These walls were also planted with trees which transpired sufficient water to prevent waterlogging and drainage runoff. Irrigation was often undertaken at night, to minimise evaporation losses (O’Hara & Hannan, 1999, p. 27). These systems were likely managed, as they were in neighbouring Afghanistan, by the villagers with the guidance of the village leaders or a nominated local *mirab* (Thomas & Ahmad, 2009, p. 20; Weiner, 2003, p. 70). The system used basic equipment to withdraw water and canals were unlined, leading to water losses in the order of 30%.

In spite of this, because of the small scale and intensive management, the traditional system on
average used less water per hectare than modern irrigation in the region, crop yields were higher, and fertility loss and soil salinisation were not serious problems, as they are today (Micklin, 1992, p. 270). In such systems, the landscape had been engineered to produce crops in a desert, but the engineering was small-scale, locally—and carefully—managed, and apparently sustainable.

However, such systems would soon be radically transformed. As Central Asia was annexed by the Russian Empire in the late 19th century, engineers and agricultural experts were sent to the region. After seeing the existing irrigation, and the remains of the larger systems not resurrected after the Mongol invasion, they reported that it had significant potential for irrigated cotton production, and drew up plans for large-scale schemes. These failed to find financial backers, so were not implemented under the Tsarist regime (O'Hara & Hannan, 1999, p. 25). In 1920, however, Lenin declared that irrigation in central Asia would be modernised; the destruction of traditional irrigation systems was accelerated with the creation of large collective and state farms under Joseph Stalin from the 1930s (Weiner, 2003, p. 70; Micklin, 1992, p. 270). The acreage under irrigated cotton increased, and that devoted to food production declined. By this time, the political climate in the Soviet Union was such that engineers had become justifiably afraid of speaking out about social and economic problems associated with engineering projects: at least one engineer critical of Soviet engineering practice was executed. Furthermore, the education of engineers in the Soviet Union had become increasingly narrow and technical, with an exclusive focus on increasing production (Graham, 1993, p. 68). Informed dissent from engineers was thereby extinguished.

In the 1950s, under Soviet Premier Khrushchev, there was a dramatic expansion in the area earmarked for the production of irrigated cotton in the region. At that time, most irrigation was drawn from the smaller rivers as the largest, the Amu Dar'ya and Syr Dar'ya, presented considerable challenges to irrigation engineers, being fast-flowing rivers with high banks, strong currents, fluctuating levels and changing courses (Lewis, 1962, p. 103). However, Soviet engineers rose to the challenge, designing more complex diversion and storage facilities, and larger and longer canals. By these means, it was anticipated the water from the two major rivers feeding the Aral Sea would make the desert bloom and the Soviets self-sufficient in cotton. Construction of the largest canal, the Karakum, commenced in 1954. By 1999 it diverted almost 13 km$^3$ of water along its length, and irrigated around 1 million hectares of land (O'Hara & Hannan, 1999, p. 25). Not only did the area of irrigated land increase, but also the use of water per hectare. Large-scale works like the Karakum canal created an illusion of an almost limitless water supply; furthermore, it was essentially free, and there was relatively little monitoring equipment. In combination, these factors led to endemic over-watering, leading to local problems of waterlogging and secondary salinisation (O'Hara & Hannan, 1999, p. 27). That measures to avoid this outcome were not made an integral part of the system is surprising given that even in 1953 it was known that soil salinity was a major problem in the area: at that time, for example, 88% of the irrigated land in the Turkmen S. S. R. was classified as saline (Lewis, 1962, p. 106).

In 1960 the total river run-off into the Aral Sea was 40 km$^3$; by 1975 this had fallen to just 11 km$^3$; in 1980 there was no significant runoff at all, and the sea level had fallen by 7 metres (Kotlyakov, 1991, p. 6). By that time, crop yields were also beginning to decline (Brookfield, 1999, p. 6). The increasing quantities of water extracted by the system were rapidly beginning to threaten the area's ecological and economic foundations. The threat to the Aral Sea from the irrigation expansion was not unforeseen. In 1968 Soviet scientist V. L. Shul'ts declared that “it is necessary to drain the Aral Sea in the future. . . . The time has come for the rational use of the water resources of the Aral basin for the benefit of the Soviet people building communism” (Glantz, Rubinstein, & Zonn, 1993, p. 187). It was often argued at the time that the monetary return from water used for irrigation would be greater than if the same water were allowed to run to the sea, even if that ultimately
meant the loss of the Aral Sea. Dissenting voices were ignored in the single-minded pursuit of the policy of rapid expansion of cotton production, in which Soviet engineers were apparently—and understandably—compliant participants (Glantz et al., 1993, p. 188).

In the 1960s and 70s, the consequences of the over-developed and under-managed irrigation system in the Aral basin began to be noted in the scientific literature. They included:

- wind erosion, salt-laden dust storms, destroyed spawning grounds, the collapse of the fisheries, secondary salinization, increased salinity of seawater, waterlogging, disruption of navigation, the likely division of the sea into separate parts, the need for extra-basin water resources to stabilize the sea level, the loss of wildlife in the littoral areas, the large reduction of streamflow from the two main tributaries, a change in the regional climate, the disappearance of pasturelands, and so on. (Glantz et al., 1993, p. 189)

By the 1970s, over 46,000 hectares of degraded land were being abandoned in Turkmenistan alone every year (O’Hara & Hannan, 1999, p. 27). The previously productive fishery ceased in 1985 (Brookfield, 1999, p. 6). The erosion of the resource base of much local economic activity has led to considerable unemployment and consequent poverty in the region. The cost in terms of human health has also been enormous, as the toxic pesticides used in cotton production have accumulated in areas that are now desiccated, and are blown on dusty winds into towns and homes. Pollution of air and water, lack of potable water, and lack of appropriate food has precipitated a public health crisis, with extremely high infant and maternal mortality rates, widespread illness, and reduced life expectancy (Glantz et al., 1993, p. 185; Kotlyakov, 1991, p. 8). Ecosystem effects have also been devastating. By 1991, just over half of the bird species previously found, and just under half of the mammal species, remained in the region (Kotlyakov, 1991, p. 7). As irrigation has continued, and the sea has continued to shrink, these problems have continued and in some cases increased.

**Example 2: Bali**

Historical examples of more socially just and ecologically sustainable engineering are, unfortunately, few and far between. However, one such example may be found in another highly-engineered irrigation landscape, Bali. Much of the historical work on Bali comes to us from sociocultural anthropologists, intent on explaining a system of social organisation that Clifford Geertz referred to as “pluralistic collectivism” (Geertz & Geertz, 1975, p. 30). This is characterised by multiple power structures, with individuals involved in several different groups, each of which has a particular single purpose. For hundreds of years, the complex irrigation systems that produce much of the Balinese people’s food have been managed at a local level by one such set of groups, known as subaks. Subaks are irrigation societies, each consisting of between 50 and 400 farmers, who draw water for irrigation from a common source such as a dam, spring, or irrigation channel. Subak leaders are elected by members, who meet regularly to plan cropping and maintenance tasks, and allocate water on an equitable basis. A series of higher-order water temples link subaks using a common water source, such as a river or main canal; for at least half of the island, this hierarchy terminates at what is believed to be the ultimate source of the island’s fresh water, the Temple of the Crater Lake (Schoenfelder, 2000, p. 38). Today, a subak is “a semiautonomous sociopolitical and socioeconomic unit responsible for group decision-making about the irrigated landscape” (Scarborough, Schoenfelder, & Lansing, 2000, p. 81), and which coordinates the plethora of daily tasks required to maintain an active rice paddy. Decisions about the timing of water use are particularly critical: in order to maximise the availability of water, each irrigation area would plant their crops—and so draw on the water—at different times. However, this would enable a build-up

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4 Some of the historical reasons for this compliance are discussed by Graham (1993).
of pests, which would be able to move from a drying area to a newly-planted one. On the other hand, synchronising the watering and fallowing of paddies would deny pests a continuous food supply, but demand for water would be very uneven, as all farmers would need water at the same time, then none would need it. Through the temple system, subaks work together to strike a balance between water use and pest damage, and thus maximise the harvest (Schoenfelder, 2000, p. 38). This system has produced sustainable, high-yield and adaptive cropping over a long period of time.

Wet rice irrigation technology has been employed in Bali since at least the 9th century CE, when the island was ruled by Indianized kings. Hillsides were terraced to create wet rice fields, and tunnels were constructed through the steep and highly dissected ridges (Scarborough et al., 2000, p. 80). By the 11th century centralisation of power was increasing, but the island was invaded by the Javanese in the 13th and 14th centuries, and over the succeeding centuries, as Schoenfelder (2000) puts it, “the core region of southern Bali seems to have become increasingly ungovernable as a single entity” (p. 43). The large kingdoms were replaced by dozens of smaller independent and semi-independent principalities (Geertz, 1980, p. 19). These operated as largely non-instrumental “theatre states,” which had an important symbolic role, but little involvement with the construction or management of the irrigation systems that provided rice in abundance to support them. This is perplexing, as the irrigation systems presented an opportunity for the regents to exercise control and increase their power and wealth, but Scarborough et al. (2000) have argued that as the population increased and along with it the amount of food to be produced, control over the irrigation systems that were fundamental to the society was relinquished to the evolving subak (p. 82). Because the Balinese regents did not—or were not able to—exercise greater control, and establish greater centralisation of population and resources, the society developed along lines that better matched the dispersed resource base within a tropical ecosystem. Schoenfelder (2000) argues that it was the emergence of pest and water stresses, as population grew and irrigation systems became larger and more complex, that provided the impetus for the organisation of subaks as self-organising networks of social groups, that could micro-manage local systems in a coordinated way, for optimum yields (p. 41). As a result, “On Bali, culture and agriculture have long prospered because of a sophistication about the landscape derived from evaluating ecological and economic relationships within the evolving engineered environment” (Scarborough et al., 2000, p. 90). The engineering of the landscape occurred slowly and incrementally over time, and the groups that lived and worked in that landscape were able to adapt to changes in the environment, because of their intimate knowledge of the landscape and capacity to share knowledge with neighbours.5

The system has also proven resilient: when the “green revolution” came to Bali in the late 1960s, farmers were encouraged to plant the new high-yielding rice varieties as quickly as possible, and traditional irrigation patterns were abandoned. Yields did indeed rise, but so did problems of water shortage and pest outbreaks. A similar challenge occurred when a large irrigation development project, funded by the Asian Development Bank, was launched in 1979. Local irrigation systems were restructured by irrigation engineers, but the new systems often neglected to consider the context of social relationships within which irrigation was managed. As a result, arguments broke out within subaks that had been merged; in some cases, subaks refused to use the new systems, opting instead to recreate the old canals. Between 1982 and 1985, the island experienced declines in both crop yields and cropped areas, as a result of the bureaucratic and engineering interventions. However, the work of anthropologist J. Stephen Lansing, amongst others, convinced the Indonesian government to encourage the restoration of the subak system. The water temples subsequently

5 Lansing has proposed that the widespread use of a simple adaptive rule—“copy your neighbour’s crop timing if your neighbour’s rice yields are higher than yours”—created a system that was adaptive to change in the natural or built environment (Schoenfelder, 2000, p. 39).
regained informal control over wet rice cropping on most of the island and by 1991 the traditional systems were once again in place (Lansing, 2008, pp. 111–125). This marked not only the end of the immediate problems of decline in cropping and yields, but also a return to a system that was both more sustainable and more socially-just, based on equity, cooperation and democratic values.

**LEARNING FROM THE PAST**

What, then, can these historical narratives of the development of two highly-engineered irrigation landscapes offer to engineering students? Firstly, they begin to provide the “inventory of alternatives” that is one of the key social resources generated by historical scholarship. In a highly-cited article published in *Science* in 1993, three scientists claimed that “Although there is considerably variation in detail, there is remarkable consistency in the history of resource exploitation: resources are inevitably overexploited, often to the point of collapse or extinction” (Ludwig, Hilborn, & Walters, 1993, pp. 17, 36). The example of Balinese irrigation gives us a little more hope than this, showing that management of water resources can be sustained without overexploitation for a long period, if appropriate social structures, relationships and values are in place.

Secondly, both examples highlight the important problem of scale: the capacity for engineers to create systems—be they irrigation, communication, transport, power, or otherwise—on a massive scale has the potential for correspondingly far-reaching consequences. Thirdly, if these historical examples are extended, they demonstrate that engineering works that lead to undesirable social or ecological outcomes are not characteristic of any one time or place, or indeed political regime. For example, the ecological disasters precipitated by irrigation projects in California (Hundley, 2001; Reisner, 1986) occurred in a democratic, capitalist context very different to the command economy of Soviet Central Asia.

Contrasting the Balinese and Aral basin experiences, however, some important issues for socially-just and sustainable engineering begin to emerge. One relates to centralised power and decision-making. Where decisions about engineering interventions are made on the basis of abstract knowledge of local landscapes and relevant social structures, and make little provision for effective local involvement in management of engineered systems, they are unlikely to deliver sustainable and just solutions. If, on the other hand, local people with first-hand knowledge of the land and its social context are empowered to have meaningful input into decisions about the role of engineering in local problem-solving, the chances of a socially-just and sustainable engineering solution are surely greater. The issues here might be summarised as power, knowledge and proximity. They point to the inadequacy of traditional engineering practice in which a design brief is prepared in consultation with a client, but not necessarily those who will potentially use or live with the system or object to be produced. Another issue that students might be led to consider from comparison of these case studies is that of the potential advantages of incremental change to enable adaptation, or amelioration of emerging problems before they become major or irreversible.

Still, the key lesson to be learnt from historical interpretations of past engineering practices, such as those considered here, is that resource problems—which many engineering projects seek to address—are fundamentally “human problems that we have created at many times and in many places, under a variety of political, social and economic systems” (Ludwig et al., 1993, p. 36). The idea of engineering as delivery of technical solutions no longer stands up: engineers are working with complex “human-technology-environment systems” (Pahl-Wostl, 2002, p. 396), and as such, they must give as much consideration to the human elements of those systems as the technological and environmental components.
The problem of a narrow, technical approach to problem-solving by engineers has arisen as engineering has increasingly come to be understood as a set of universal, transferable knowledge and practices, rather than a discipline that foregrounds context. History, as a stubbornly contextual discipline, can perhaps help to re-inject the required sense of the critical importance of social and ecological contexts for engineering design: varied contexts call for diverse approaches to problem-solving, which may well involve knowledge and techniques outside the scope of current mainstream notions of “engineering.”

Of course there is an emerging technical literature on adaptive and participatory management, but in spite of these concepts now being decades old, they are still quite fluid, and may be insufficiently able to engage with multiple stakeholders (McLain & Lee, 1996). Moreover, as Claudia Pahl-Wostl (2002) has put it, “major conceptual gaps exist regarding how to include the human dimension into integrated assessment models and processes” (p. 395). Furthermore, rarely can such technical works match the ability of historical narratives—stories about people—to engage interest, and facilitate deep understanding. Historical stories can graphically illustrate what is at stake in engineering projects that succeed or fail in effectively negotiating their social and ecological contexts to achieve socially-just and sustainable outcomes.

The examples chosen here are perhaps less successful in demonstrating how and why the stakes of engineering projects are often concealed by a narrow focus on technical elements. This was not an issue in the contextually-embedded, socially-responsive engineering practice seen in Bali, and the regime under which Soviet engineers operated was so oppressive that even had their education been less narrowly technical, to challenge the dominant engineering paradigm was likely to have involved life-threatening risks. What is needed are more examples from the twentieth century global north which highlight the role of engineering culture in reducing engineering questions to technical ones, and thus provoke students to think about what it would take as an engineer to challenge this culture from within. Also useful would be historical analyses that interrogate the significance of capitalist control of engineering systems, and the ways in which engineering systems have been shaped by profit motives at the expense of social justice and sustainability.⁶

**CONCLUSION**

Historical studies appear to have considerable potential in the education of engineers, offering interesting case studies for students to consider and reach conclusions about the importance of an engineering practice that gives due attention to social and ecological contexts, and aims to achieve social justice and ecological sustainability among its core outcomes. The two case studies we have chosen explore issues of relevance to students in any area of engineering, though they might be most germane, and thus have greatest appeal, to students intending to work in the areas of civil or environmental engineering, or in a developing world context. As issues of sustainability and social justice are just as critical, if perhaps not always so obvious, in the industrialised west, one challenge for historians and engineering educators together would be to locate a broad range of case studies, involving diverse engineering projects in multiple historical contexts, for use in engineering classrooms.

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REFERENCES


ARTICLE

Indigenous Ways of Doing: Synthesizing Scholarly Literature on Ethno-Engineering

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This paper synthesizes the literature on indigenous ways of doing or what we call ethno-engineering. Western literature on indigenous knowledge is expansive, yet a deliberate focal point and explicit conceptualizations on ethno-engineering in indigenous literature are slim. In this paper, we have collected scholarly literature on indigenous knowledge and synthesized articles specifically on ethno-engineering. We have exemplified this literature with several published case studies in order to contrast indigenous-engineering with Western-engineering. Our literature review methods proceeded in two phases. During the first phase we accumulated relevant sources (N=89), compiled these in a database, and coded them with an eight-item framework. In the second phase, we sampled literature from the initial database (N =32) and coded these items more extensively using an inductively developed coding scheme. In addition, this paper includes four case studies highlighting indigenous engineering practices and associated principles. Our intent was to contribute to a starting conversation on indigenous engineering, bringing it to the forefront of social justice engineering discourse.

KEYWORDS: engineering, indigenous knowledge, ethno-engineering

Disclaimer: This paper was written by two authors† who grew up in the developed part of the Western world with experience in different countries and cultures within the developed Western world and to a limited extent in the southern hemisphere world. One of the authors brings with him an academic background in engineering. The other author brings a background in education and Religious Studies, a field of study concerned with the cultural phenomenon of religion, not the doctrine of a particular religion. Both received academic training in philosophy. The frame of reference for this paper is mixed as it draws from the literature of the social justice and engineering reform movement within the United States and from literature, which originated on an international level such as UNESCO and locally at different places around the world. We are cognizant that our backgrounds impact how we frame this paper and do not presume to have escaped them; we attempt to reflect at our personal and professional mindsets, along with our own cultures’ presumptions about indigenous cultures. Our focus on indigenous knowledge could be perceived as a secondary form of colonialism, this time robbing the cultures of their knowledge and innovative processes. For us, by looking at what we can learn from indigenous cultures we attempt to de facto reverse existing prescribed roles making us, as “Westerners,” the listeners and learners in this situation. While our approach and mindsets might be interpreted as naïve, we argue that they are respectful, as we are explicitly conscious that our own cultural norms, including our research approach, may not do justice to other cultures, and our findings are at best approximations.

1 The authors would also like to note that they shared equal authorship for this paper.
INTRODUCTION

In recent research and policy documents of the developed world, we see an increased appreciation that engineering as a practice can contribute to social justice (Leydens, Lucena, & Schneider, 2012; Riley, 2008) and responsible development (Roco, 2005). Organizations such as the U.S. National Academy of Engineering have asked for stronger integration of environmental sustainability into the engineering curricula (National Research Council, 2009) and as Deanna Richards from the National Academy of Engineering (1999) points out, the shift to more sustainable engineering not only requires a major rethinking of current practice but also “human creativity and technological innovation” (p. 16). This emerging trend in engineering is embedded in a larger trend within Western culture today, in which we see a resurgence of emerging grass-root practices such as urban farming, community gardening, engineering service projects, and recycling art—to name a few (Fuad-Luke, 2009)—which has coincided with a long term interest in indigenous knowledge (Hinkson, 2003). In order to infuse and enlighten emerging engineering practices and engineering education in the western world, we turn to a potentially rich source: indigenous knowledge/practice, or ethno-engineering. These terms are discussed more fully below.

Our primary objective in this review is to explore engineering methods that indigenous people employ for their subsistence. These engineering components have not been systematically and explicitly reported in existing literature. This study aims to synthesize literature, which implicitly discusses indigenous- and ethno-engineering and to answer the following questions:

1. What indigenous ways “of doing” or engineering practices are represented in contemporary scholarly literature?
2. What are the sustainable implications of these indigenous ways of doing?
3. How does “ethno-engineering” compare to more Western oriented modes of engineering?

Operational Definitions

Defining “indigenous” and “indigenous knowledge and practice”

In defining indigenous we enter a contentious, intellectual, emotional and social space due to the many existing, often competing dimensions and perspectives, which rest on different definitions of cultural identity, law, autochthony and colonial history. Following a cautionary approach by the World Bank (2006) to not “put forth a rule of what does or does not constitute indigenous” because “that would contribute little and only invite controversy over perceived errors of inclusion or omission” (p. 2), we are defining indigenous rather by (1) the way of knowing and (2) forms of practice and processes than by political and legal dimensions or historical definitions of identity. Unfortunately, indigenous systems of knowledge and practice are often labeled “not by what they are but what they are not” such as “pre-modern” or non-scientific (Prakash, 1999, p. 157). This negative definition leads to an unnecessary dichotomy between Western and non-Western societies, where Westerners “think of Western science as science” (Selin, 1992, p. 11) and other forms of knowing as inferior. In the Western realm, scientists and engineers tend to show a worldview that perceives the environment in a way that “enable(s) them to understand and control the outside world” (Semali & Kincheloe, 1999, p. 25) and so “science-based societies have tended to overuse and simplify such complex ecological systems, resulting in a whole series of problems of resource exhaustion and environmental degradation” (Gadgil, Berkes, & Folk, 1993, p. 151). Our work takes Herrmann’s (2005) stance that “western knowledge is not in essence superior to traditional knowledge; both are complementary and have to mutually enrich each other, rather than replace each other” (p. 132).
To describe in more detail indigenous know-how and practices, we rely on several definitions, which focus on practice. The United Nations Environment Program (ca. 2007) defines indigenous knowledge (IK) as follows:

. . . the knowledge that an indigenous (local) community accumulates over generations of living in a particular environment. This definition encompasses all forms of knowledge—technologies, know-how skills, practices and beliefs—that enable the community to achieve stable livelihoods in their environment. A number of terms are used interchangeably to refer to the concept of IK, including Traditional Knowledge (TK), Indigenous Technical Knowledge (ITK), Local Knowledge (LK) and Indigenous Knowledge System (IKS). (para. 1)

A closer look at “engineering”

In order to contextualize ethno-engineering, we need to further elaborate on the conventional framework of engineering practice. We argue that ethno-engineering faces a conundrum when situated within traditional and even contemporary definitions of engineering such as the following: “Engineering is the application of mathematics and science in service to humanity and as a bridge that connects the sciences to the humanities” (Grasso, Callahan, & Doucett, 2004, p. 413). This definition incorporates two aspects of popular notions of engineering: (1) the application of mathematics and science and (2) the social relevance and responsibility of engineering decisions. Exploring further, when Pawley (2009) assessed faculty members’ responses to the question, “What is engineering?” three “universalized narratives” emerged with one group defining engineering as “applied science and math . . . problem-solving . . . and making things” (p. 317). The first characterization presupposed that engineering is rooted in and dependent on mathematics and science and “helped society more than science”; the second that engineers solved “problems that mattered”—leaving the question, “Mattered to whom?” answered as, “Society”; and the last grouping “connected engineering to the physical construction of highly technical and mechanized products” (p. 317).

Both the definitions presented by Grasso et al. (2004) and Pawley (2009) seem to be aligned and necessary for the proper function of any society, indigenous or modern. However, even in these seemingly socially conscious and all-encompassing or “universalized” definitions, engineering is partially defined by what Oldenziel (2000) calls the “cultural authority of math and science” (p. 20). This hegemonically prescribed dominance of mathematics and science, by definition, excludes alternative or non-Western ways of knowing. Any definition of ethno-engineering must be inclusive to different forms and representations of knowledge. To articulate such a definition, in the next section, we introduce the term “ethno-engineering” to define alternative ways of knowing and doing to combine our understanding of indigenous and engineering.

Introducing “ethno-engineering”

According to Pacey (2008), when we apply “engineering” to a “non-Western” context “the word ‘engineering’ is best limited to construction works” such as “fortifications, monuments, and water management” (p. 748). Pacey continues: “the smallest of such works, as carried out by individual house builders or farmers practicing irrigation, may often be better considered in other contexts, such as ‘building’ or ‘agriculture’” (p. 748). Jodha (1990) introduced the term ethno-engineering, which he refers to as “local resource-centered diversification being interlinked activities” which are “supported by systems of self-provisioning, on-farm storage, and recycling” (p. 67). He continues to suggest that “this approach not only serves sustenance needs in a relatively closed system (due to

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2 Referring to the title of Pawley’s 2009 paper: “Universalized narratives: Patters in how faculty members define ‘engineering.’”
inaccessibility), but has potential to benefit from heterogeneity of the resource base without damaging the fragile and marginal resources” (p. 67). Mukerji (2009) is one of the first written documents introducing the term “indigenous engineers” when describing the role of mountain dwellers in building the Canal du Midi in the South of France (p. 14, 119, 153, 189). She describes particularly the conflicts between the existing class of engineers (French royal corps of engineers) and the localized and sophisticated knowledge of peasants.3

Jodha (1990, p. 67) and Reij's (1991, p. 4) definitions limit ethno-engineering to the very specific context that they were working in: “...such practices as terracing mountain slopes, harnessing the runoff and developing small drainage systems” (Reij, 1991, p.4). Although never systematically defining the term, Mukerji’s use of the term indicates that ethno-engineering is similarly highly contextual—in this case the context of mountain farming—yet boundaries of indigenous engineering are implicitly broader than Jodha’s (1990) or Pacey's (2008) describing a class of practices and attitudes to be observed at different places.

Ethno-engineering or indigenous practices may define “right” in a spiritual, cultural, or sustainable context that does not necessarily involve Western-style advanced mathematics, a formal degree, or the maximization of economic profit. Indigenous ways of doing are highly empirically evolved through observations of nature for hundreds to thousands of years. Due to its lack of advanced Western mathematical, scientific and technological knowledge it could easily be argued that an indigenous perspective could very well contribute to the “definition of the problem” yet might be less usable for the “solving of the problem.”4 We, however, argue that indigenous engineering could and is contributing to both the definition and the solution of the problem.

The question remains, why we chose to use the term “engineering” to label practices in an indigenous context, especially if the practices stand in contrast to existing definitions and practices of engineering? To put it simply, considering the “status-minded community of engineering educators” (Noble, 1977, p. 45) and engineers, defining indigenous practices anything short of engineering and hence not using the term explicitly would be contradictory to the premise of our paper that Western and indigenous knowledge and practices are equal in value and complementary to each other.

For the remainder of the paper, we use the term ethno-engineering to define a broader class of practices in the following working definition: a method of defining and solving complex issues with constantly evolving deep experiential knowledge of the environment, without utilization of modern mathematics, science and technology, relying on bottom-up management, practicing resourcefulness, and being contingent upon a holistic worldview.

**THEORY & BACKGROUND**

We perceive indigenous knowledge as a realistic source of inspiration for environmentally sustainable engineering practices. Mazzocchi (2006) suggests that indigenous societies are more interested “in preserving their own social, cultural and environmental stability and integrity than in maximizing production. Consequently, there is commonly no ‘exploitation’ of nature” (p. 463) within indigenous societies, although this is by no means the rule. Likewise, natural resource management is often based on shared meanings and knowledge and avoidance and reduction of waste (Berkes, Colding, & Folke, 2000). Indigenous societies do not see themselves separated from

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3 A more detailed account is presented in one of the case studies later presented in this article.

4 See Lucena and Downey (2006) for the distinction.
Indigenous people “(a) have a long history without apparently disrupting ecosystems, (b) have a rich inventory of traditional environmental knowledge, (c) have specific management practices based on such knowledge about nature, and (d) have religious beliefs about ritual uses of animals and plants that safeguard their sustainable use” (Selin & Kalland, 2003, p. 3). Compared to western sciences and epistemologies, indigenous knowledge relies strongly on intuition, directly perceivable evidence, and an accumulation of historical experiences (Farrington & Martin, 1998) acquired through learning-by-doing, or knowledge-building through experimentation (Berkes & Berkes, 2009). Often-times, existing indigenous engineering strategies have proven to be environmentally sustainable (Apffel-Marglin, 1998; Diemont et al., 2006; Herrmann, 2005) and although the explicit notion of sustainability may be absent, implicitly, sustainability concerns are commonly present in the broader holistic worldview of the indigenous people (Blaser, Feit, & McRae, 2004; Loomis, 2000).

It comes as no surprise to us that disciplines such as medicine, conservation biology and ecology—to name a few—have researched indigenous knowledge systems extensively. However, it is surprising that engineering has not done similarly (Ross, Sherman, Snodgrass, & Delcore, 2010). A cursory examination of existing literature about indigenous knowledge reveals an emphasis on indigenous science, medicine and ecological practices and only a small amount of studies conducted on indigenous technical knowledge and indigenous technologies. Although an explicit dialogue on indigenous engineering strategies is rare, much of the discussion on indigenous technical knowledge is akin to contemporary understandings of engineering practice.

The body of literature pertaining to indigenous knowledge, or indigenous ways of knowing, has been and is still rapidly growing. In 1992 Helaine Selin published an annotated bibliography of “Non-Western” sciences titled Science Across Cultures with more than 800 references, and in 2008 published the Encyclopedia of the History of Science, Technology, and Medicine in Non-Western Cultures with thousands of entries. The Indigenous Peoples’ International Centre for Policy Research and Education, also known as Tebtebba, has developed a website to disseminate information aimed to aid the indigenous movement (http://www.tebtebba.org/). The World Bank Group has developed a website titled Key Resources for Indigenous Knowledge and Practices which presents methods of integrating indigenous knowledge into development projects (http://www.worldbank.org/afr/ik/key.htm). UNESCO has also developed a database titled Best Practices on Indigenous Knowledge (http://www.unesco.org/most/bpikreg.htm). In all of these resources the term “engineering” is rarely used, if at all.

Indigenous knowledge for technology creation was accumulated through generations and passed down to the next generations (Krugier, Berhanu, Yohannes, & Kefeni, 1996; Reij, Scoones, & Toulmin, 1996), principally through verbal transmission from elders’ experiences. This does not mean that these specifications are invalid or “inferior” simply because they are unwritten. The existing scholarly literature about indigenous knowledge focuses particularly on agricultural production and resource management. Indigenous authors tend to explicitly attribute the oppression their own indigenous societies have faced to colonization and globalization (Beijing Declaration of Indigenous Women, 1995, p. 2; Blaser et al., 2004, p. 28). Issues especially begin to arise as Westerners extract resources, pollute waters or expand monoculture on lands held sacred by indigenous societies, depleting the resources indigenous communities depend on or find spiritual value in.

Indigenous knowledge and ethno-engineering are “inseparable from larger worldviews” (Semali & Kincheloe, 1999, p. 40), including a spiritual component that seems elusive and might sound foreign to “enlightened” Western ears. Western dominant worldviews tend to be more individualistic than
collectivistic with a focus on personal well-being. Meyer (2008) calls this Western model “shackles of ignorance” that “could be snapped via ideas that (are) indigenous and authentic” (p. 217). What Meyer discusses is an “indigenous epistemology as viewed by Native Hawaiian mentors, friends, and family” with the underlying premises that “specificity leads to universality,” “knowledge that endures is spirit-driven” and knowledge is not simply learned “about land” but rather “best from land” (pp. 217–219). This does not suggest there is a division between mind, body, and spirit, but that, “Our mind is our body. Our body is our mind. And both connect to the spiritual act of knowledge acquisition” (p. 222). Therefore, in our search we are conscious that integrating indigenous worldviews into contemporary engineering practices will inevitably produce larger tensions and discourse on the role of religion, spirituality and worldviews in the work of engineers.

From the modern Inuit of Canada (Oliver, 2003) to one of the only indigenous societies to overthrow their government, the Kuna of Panama (Hoehn & Thapa, 2009, p. 430), the knowledge of indigenous cultures is being extensively studied, while the relationship between indigenous knowledge and engineering is sparsely found. It is hard to imagine that indigenous peoples that have thrived throughout millennia have done so without some sort of “engineering.”

**METHODOLOGY**

This research project follows guidelines set for literature review research (Hart, 1998), its own genre of analyzing and synthesizing large bodies of research. The research proceeded in two phases.

**Phase 1**

Figure 1 shows an overview of the Phase 1 procedure of collecting literature:

![Figure 1: Phase 1 Literature Collection](image)

The project started with an initial search for indigenous engineering and ethno-engineering related literature. The sources gathered during the literature collection stage helped gather more sources, a process known as Type 1 reading. Synonymous or similar terms for “indigenous” were recorded and used to obtain more sources (e.g. Native, First Nation, Local, Traditional, Aboriginal, Fourth World, and in some instances Non-Western, Rural, or Ethno-terms). Given the limited results from “indigenous engineering,” the search for material using synonymous terms was the most viable means of discovering relevant literature.
Next, during “Type 2 Reading” we inductively developed a coding scheme, as shown in Table 1. We added literature to a database and coded each article based on an eight-item framework.

The “Relevance Score” gauged the relative amount of technical discussion within an article that might be considered engineering-like. If engineering practices were only discussed briefly, the score would be recorded as a 1. If the focus of the article was on the engineering-like strategies employed by the indigenous communities, the score would be ranked 10. The “Technicality Score” gauged the level of emphasis an article put in explaining how the engineering strategy operated.

Codes 3 and 4 were matters of fact. Codes 5 and 6 were binary and Code 7 was tri-lateral, each being questions that required value judgments. We defined articles as credible (Code 5) if they included references which could be followed to other sound article (e.g. if articles lacked sources or only cited internet articles, we considered them un-credible). We defined articles as scholarly (Code 6) if they were published in scholarly journals and/or included novel results obtained from following a specified methodology. We determined the type of materials used (Code 7) by relying on the author’s word.

Lastly, we determined whether authors were indigenous, Western, or both (Code 8) by examining biographies included within the text when possible. If this was not possible, we conducted an Internet search. The purpose of this code is to determine whether the author conducted his or her research from the “outside looking in.” It was possible that an author defined his or herself as “both.” This is a unique tension, which involves balancing multiple identities, as Brayboy (2000) explains in detail. Note that it was also possible that an author defined his or herself as Western while disregarding a native or indigenous upbringing.

These attributed scores are subjective in nature. To enhance rigor of assigning codes and reliability of value judgments two students collaborated for each found article.

Phase 2

Phase 2 involved a redevelopment of the initial database, a more in depth coding system, and a second literature review analysis. We eliminated sources that had low “Relevance” scores, low “Technical” scores, or sources that did not present specific case studies. We also looked for “Specificity” in this round. We analyzed indigenous-society-specific ethno-engineering-related case studies which included technical aspects of the engineering practices. A maximum of two sections from a given book source were uploaded into this database in order to minimize categorical shifts. For example, including numerous sources from Howard (2003) would cause the category “Role of Women” to greatly shift.

The final Phase 2 database is set-up to include, Continent, Country, Locality, and Name of (indigenous) People as well as bibliographic information pertaining to the source. The coding schematic is discussed in Figure 2, with explanations of each category.

Table 1: Phase 1 Literature Review Criteria

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<td>1</td>
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<td>Are visuals provided?</td>
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<td>5</td>
<td>Is the text credible?</td>
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<td>6</td>
<td>Is the article scholarly?</td>
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<td>7</td>
<td>Are materials renewable, non-renewable, or both?</td>
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<tr>
<td>8</td>
<td>Is the author(s) Indigenous, Western, or both?</td>
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**Figure 2: Phase 2 Coding Schematic**

A. What was the **engineering discipline?**
   1. *Agricultural/Biological (ABE)* — farming practices, resource management systems, etc.
   2. *Civil* — structural systems, architectural considerations
   3. *Hydraulics* — irrigation systems, water management strategies
   4. *Materials* — items manufacturing
   5. *Industrial* — trading and systems optimization
   6. *Education* — A merger of ethno-engineering related material and education
   7. *Biomedical* — Knowledge of local resources used to cure particular diseases, the collection and upkeep of such resources

B. What was the specific **practice**? We subdivided practices to show what subset of engineering the literature represents. Although agricultural sources might have discussed irrigation or other civil engineering-related techniques, we considered such sources primarily agriculture.

C. How **specific** was an article? We labeled literature as “Single” when the author(s) discussed one community of Indigenous people or locality. We labeled literature as “Few” when the authors discussed and differentiated between two or three groups or localities. Anything broader in scope we scored as “Many,” such as literature that included numerous Indigenous groups within a region. Literature not specific at all was removed from the Phase 2 Database.

D. Was the literature **taxonomic**? Did the literature perform statistical analyses or develop classification schemes to obtain results? These may be folk taxonomies or scientific ones.

E. What type of **resources** did the community require for the practice? If resources were primarily available within the “local” community we labeled the source as “Local.” When communities depended on both imported and local resources we labeled these as “both.” For example, in agricultural literature, farmers may have used seedlings from a distribution center along with their own seeds, or industrial pesticides along with manure.

F. What was the primary **source of power** used by the people? In many cases Indigenous inhabitants had access to modern technology. Despite this, the use by the Indigenous inhabitants might have been minimal. Such cases we labeled as “Human Power.” We did not code resource management or entrepreneurial practices when energy use was not a focal point.

G. Was the influence or role of **worldview** on engineering decisions considered important and/or extensively discussed?

H. Was the practice **sustainable**? Does the author explicitly state if a practice was sustainable? Often this was not explicitly mentioned. We considered ethno-engineering sustainable when the author suggests external influences such as colonization led to the demise of the system after it was in place for long stretches of time. In cases where the author did not hint whether the system was sustainable or when the question was irrelevant we marked as “N/A.”

I. Did the populace participate in a **local** or **global** economy? We labeled literature as “Yes” where the authors discussed any form of trade between Indigenous communities.

J. Was the **author** Indigenous, Western, or both?

K. Was the role/engineering strategies of **women** in particular explicitly discussed?

L. What type of **management** is there overlying the practice? We labeled sources as “Bottom-Up” when people made their own decisions at the home level or control was decentralized. We scored “In-Between” when the literature was in between bottom-up and top-down (e.g. community management systems with specific representatives deciding what land is used for what, chief hierarchies). We labeled literature as “Top-Down” when a centralized government agency made all/most community decisions.

* Neither *Education* nor *Biomedical* were present in the Phase 2 database but were included in Phase 1
The same two students that developed the Phase 1 database worked on the Phase 2 database. Coder 1, a PhD student in Engineering Education, went through and coded all 32 sources remaining in the database. Coder 2, an undergraduate student in Mechanical Engineering, then went through 10/32 sources and coded independently. 96/120 codes were coded identically, generating an inter-rater reliability score of 80%.

RESULTS

Phase 1 Results
During Phase 1, 88 sources were uploaded with an average Relevance of 7.1/10 and an average technical score of 6.0/10. The literature was published from 1942–2010 with 86.3% of the articles being published between 1990 and 2010. The majority of data stemmed from agricultural related fields (47.7%) and were coded as agricultural and biological engineering sources. The next most common fields include civil engineering (20.5%; primarily articles related to structural components), industrial engineering (10.3%), and hydraulics engineering (8.0%). Other fields covered included materials, mechanical, biomedical, and engineering education. These articles ranged throughout the entire world, with a large amount coming from Asia (29.0%) and Africa (27.5%). When the materials used by ethno-engineers were discussed, renewable resources were dominantly utilized (78.3%). This is largely because indigenous persons tend to use locally available materials. The authors included in this literature generally defined themselves as Westerners (85.2%) which means literature is generally conducted from the “outside looking in.”

Phase 2 Results
The relatively low technical and relevance scores from Phase 1 stimulated the need for removal of sources not directly related to engineering. We included 32 sources in this database (see Appendix for complete list) and coded these based on the Phase 2 criteria given in Figure 2. Table 2, which provides a summation of our findings, shows the number of times each Phase 2 code was employed and a relative percentage for the given category. Only articles which specified the indigenous populace(s)—as opposed to simply mentioning numerous practices without reference to an indigenous people—were included in the Phase 2 database. As Figure 3 shows, the geographic distribution of the scholarly literature on indigenous engineering was not limited to any single continent, suggesting that exemplary ethno-engineering practices are not specific to any locality.

Note that a single publication may be coded across multiple categories, when the specific category does not include mutually exclusive items. The literature was primarily related to agricultural engineering, although other engineering practices were also present, including civil, hydraulics, materials, and industrial engineering. The specific practices emphasized in the article were highly variable, as shown in Table 2.
Table 2: Phase 2 Results

*The frequency counts for the given Phase 2 category, along with relative percentage.*

<table>
<thead>
<tr>
<th>A. Engineering Discipline</th>
<th>%</th>
<th>C. Specificity</th>
<th>%</th>
<th>H. Sustainable</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural and Biological</td>
<td>25</td>
<td>Single</td>
<td>19</td>
<td>Yes</td>
<td>18</td>
</tr>
<tr>
<td>Civil</td>
<td>3</td>
<td>Few</td>
<td>11</td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td>Hydraulics</td>
<td>2</td>
<td>Many</td>
<td>2</td>
<td>N/A</td>
<td>14</td>
</tr>
<tr>
<td>Materials</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Practice / Emphasis</td>
<td></td>
<td>D. Taxonomic</td>
<td>%</td>
<td>I. Economy</td>
<td>%</td>
</tr>
<tr>
<td>General Agriculture</td>
<td>8</td>
<td>Yes</td>
<td>13</td>
<td>Yes</td>
<td>21</td>
</tr>
<tr>
<td>Plant Cultivation/Cons.</td>
<td>3</td>
<td>No</td>
<td>19</td>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>Pest Control</td>
<td>1</td>
<td></td>
<td></td>
<td>N/A</td>
<td>9</td>
</tr>
<tr>
<td>General Resource Management</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation/Soil</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water/Wastewater</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coastal/Fisheries</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building Structures</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Harvesting and Conservation</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entrepreneurship</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G. Worldview</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discussed</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not discussed</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. Resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imported</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F. Power Source</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human Power</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human/Animal</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human/Machine</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K. Role of Women</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bot. Up</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-Between</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top-Down</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L. Management</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom-Up</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-Between</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top-Down</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

More than 80% of the practices discussed included the usage of local resources, and none of the articles discussed strictly the usage of imported materials. More than 65% of the articles suggested the populace participated in some sort of economy, trading goods for their engineered products. Most commonly, the source of power for the engineering practice was human power, although in a few cases animals or machines were also used. More than half of the articles suggested the practice was sustainable, and none of the articles suggested the practice was NOT sustainable (note that this does not mean that all articles included practices proven to be sustainable). The role of female engineers was discussed quite highly, explicitly appearing in nearly half of the articles. Similarly, the role of the indigenous people’s worldview was discussed in nearly half of the articles.
Case Studies

To provide depth to the results of the literature review, in the following sections we present four ethno-engineering case studies. The purpose of these case studies is to highlight the sustainable implications of the selected ethno-engineering strategies, how Western-oriented assimilating tendencies might negatively impact the thriving of ethno-engineering practices, and the diversity of ethno-engineering practice included within the Phase 2 database. The case studies present a variety of ethno-engineering be it (1) geographic diversity (North America, Asia and Europe), (2) the role of women (for example specifically as part of a female role), (3) the engineering practice involved such as resource management, manufacturing or construction work. Similarly, the case studies differ in the lessons they include about ethno-engineering (see summary in Table 3).

Table 3: Summary of Case Studies

<table>
<thead>
<tr>
<th>Attributes/Cases</th>
<th>Tidal Pulse Fishing</th>
<th>Citrus Ants</th>
<th>Coconut Kerala</th>
<th>Canal du Midi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discipline</td>
<td>Agric./Bio</td>
<td>Agric./Bio</td>
<td>Materials/Industrial</td>
<td>Civil/Hydraulics</td>
</tr>
<tr>
<td>Resources</td>
<td>Fish; Water; Stone</td>
<td>Insects; Lumber</td>
<td>Plants; Machines</td>
<td>Water; Stone</td>
</tr>
<tr>
<td>Geographical location</td>
<td>Alaska, USA</td>
<td>China</td>
<td>Kerala, India</td>
<td>France, Europe</td>
</tr>
<tr>
<td>Context</td>
<td>Non-western</td>
<td>Non-western</td>
<td>Non-western</td>
<td>Western</td>
</tr>
<tr>
<td>Gender focus</td>
<td>Not specified</td>
<td>Not specified</td>
<td>Specifically female</td>
<td>Specifically female</td>
</tr>
<tr>
<td>Practice</td>
<td>Resource management</td>
<td>Ecosystem management</td>
<td>Manufacturing</td>
<td>Construction</td>
</tr>
<tr>
<td>Synthesis / Lessons</td>
<td>Transformation of the natural environment for subsistence, with concern for sustainability</td>
<td>Replacement of indigenous solutions by Western agricultural practices and its ramifications</td>
<td>Indigenous technology co-developed with Western counterpart</td>
<td>Local knowledge proved superior to contemporary engineering practices</td>
</tr>
</tbody>
</table>

1. Tidal Pulse Fishing at Prince of Wales Archipelago in North America

This case study deals with a coastal Alaskan indigenous community, the Tlingit, and their techniques of catching salmon and is a shortened summary of Langdon (2006). The first recorded European observation of the Tlingit techniques, by French explorer Jean Philippe La Perouse, notes that with these Tlingit techniques "healthy runs of fish were returning to the streams in conjunction with these sophisticated technologies" (Langdon, 2006, p. 22). These techniques were therefore sustainable as the Tlingit used selective harvesting methods and did not overexploit the salmon populations. As is the case for most indigenous resource management strategies, "this approach to harvesting salmon relies upon a local cultural explanatory framework that combines detailed ecological knowledge of specific fishing sites with a cosmological explanation of fish behavior in which the fish turn downstream and 'give themselves' to the fishers" (Menzies, 2006, p. 15).

One of these technologies, intertidal salmon fishing, depended on the alterations between high and low tide. Oral tradition credits the brown bear for teaching the Tlingit this method of fishing, as they watched the "bears fish at natural intertidal pools holding salmon" (Langdon, 2006, p. 28). Two different types of materials used by the Tlingit led to two types of intertidal fishing structures.
some all of stone, some all of wooden stakes, and often-times a combination of these two local resources (p. 29). Here we discuss only the stone structures.

One stone structure used by the Tlingit was the weir. These weirs were essentially stone walls spanning a cross-section of a stream in the “intertidal zone of small streams on the outer islands of the archipelago” (Langdon, 2006, p. 29). Weirs constructed by the Tlingit were roughly 30 meters in length. But the Tlingit used two types of stone traps more often than stone weirs. The first kind, simple traps, were those of a “single-arched stone wall” made from “two or three layers of irregular stone cobbles” with no gaps and a circumference ranging from 28 to 70 meters. Most of these traps were located “slightly above high tide” (p. 32). This type of trap was used by roughly “two-thirds of the sites in the central reason of the archipelago” (p. 31).

The second type of trap, the joined trap, had a larger circumference and encompassed a larger fishing area than the simple trap. The basic construction of these traps was the same as simple traps, but “two, or conceivably more, traps are linked together by a shared section termed the stem” (Langdon, 2006, p. 32). Trap and weir systems may be combined to create what is termed a “composite.” Figure 4 shows an example of two simple traps joined together, as well as a composite of a simple trap and weir system.

Traps include a depression in each wall (1–2 meters in diameter and 20–30 centimeters deep) where, as the tide begins to sink, salt water will be held and fish will be held. These fish would remain alive until ready for harvest keeping them fresh. The depression also slightly protected the salmon from predators (Langdon, 2006, p. 33).

While these systems of harvesting salmon allowed “sufficient escapement to maintain healthy runs” (Langdon, 2006, p. 43) of salmon, Russians and Euro-Americans “ignored the logic of the Tlingit systems” and developed their own systems that obstructed salmon routes while seeking to maximize salmon harvests, a short-term venture. Such traps eventually were regulated to open their traps “one or two days a week for escapement purposes” (p. 45). This modern logic eventually completely eroded salmon stocks, whereas Tlingit technology “ensured the continuous replenishment of the runs on which they depended” (p. 45).
2. The "Ancient Cultured" Citrus Ant in rural China

This case study deals with the management of the citrus ant (Oecophylla smaragdin) in traditional rural farms of China. The use of the citrus ant was “discovered” by the Western world in 1915 when Walter T. Swingle, a plant physiologist for the US Department of Agriculture at the time, traveled to China in search of a new variety of orange, one that was impervious to citrus canker. What he found was “a small village where the inhabitants said their principal business was ‘growing ants’” (Huang & Yang, 1987, p. 665). The purpose of these ant colonizers was to use the ant to protect their trees and crops. The citrus ant:

... has been in use in the orange groves of southern China for almost 1700 years ... the value of the citrus ant lies not just in its ability to attack the large insect pests of the citrus plant. Equally important, it does not interfere with the activities of the natural enemies of the smaller pests, such as soft scale insects, aphids, and mites. (Huang & Yang, 1987, p. 670)

In order to be effective, a large amount of ants were needed each spring so they would be active during the new growing season. Every winter the ants would “die out.” Solutions were developed by the farmers to overcome this issue. In the province of Huaan each grove “contained not just orange trees, but also pomelo trees in which ant nests are able to survive the winter” (Huang & Yang, 1987, p. 670) and ant colonies did not have to be recreated each Spring. To colonize the groves, bamboo bridges were set up from tree to tree which allowed ants to migrate (p. 667).

Despite its long-term use, during the 1950s and 1960s farmers began to transition from ants to organic insecticides. The last users of the ant technology were from Sihui, but eventually even they “succumbed to the lure of modern technology and began to rely on chemicals for pest control” (Huang & Yang, 1987, p. 669). After traditional farmers completely transitioned to their use, the costs of organic pesticides rose and as prices increased “pests were becoming more and more common in all parts of the province” (p. 668). Sihui farmers tried to reestablish their ant technology, but flooding occurred frequently and their trees became infected. Pesticides were no longer effective, and the reintegration of the citrus ant as a local pesticide was impossible.

This specific case study portrays the ingenuity of local indigenous resource management strategies. It also presents an instance where the substitution of Western practices for indigenous ones eventually lead to failure of a system that had been effective for generations. In the short term the ant farms were likely inferior to organic pesticides primarily in terms of production potential. In the long term, however, the citrus ant was the better alternative.

3. Coconut Fiber Industry in Kerala, India

This case study, brought by Bhatia and Smith (2008), presents the use of natural plant fibers (pp. 7–12), their uses in engineering (pp. 12–14), and the different activities of indigenous individuals who are part of the engineering production process of products coming from coconut (coir) fiber. The final product may be coir mattresses, coir yarn, and coir door mats, among other products (p. 23).

Women in Kerala, India, manufacture products from coir (coconut) fibers through a process of separating fibers, extracting fibers by beating with wooden mallets, transforming fibers into yarn, and weaving the yarn into goods (Bhatia and Smith, 2008, pp. 17–23). Some parts of the coir industry do this entirely by hand, while others use mechanized sewing equipment. Overall, these women have “meager wages, have no health care benefits, have no bank accounts or savings, and work long hours, both at their jobs and for their families, such as preparing meals and washing clothes” (p. 36).
Coir fiber is extracted “from the husk of coconuts, which grow extensively in tropical areas of the world, such as in the Philippines, Indonesia, and India” (Bhatia and Smith, 2008, p. 17). The engineering production process of coir fiber involves four principal manufacturing activities: “retting of husks, extracting of fiber, formation of yarn, and weaving” (p. 17). This engineering production process involves unique cultural factors: typical storytelling and singing to diminish the tedium of hard work, good team relationship, gender and class roles (p. 24). Following are four engineering manufacturing activities of coir fiber production:

1. **Retting (fiber separation)** — this activity is important to help loose the fiber from the coconuts. Green coconuts will yield a white fiber and mature coconuts will yield a brown fiber. In Kerala, the kind of fiber typically produced is the white one. For white coir fiber, “green coconuts are soaked in brackish water for 8 to 10 months to remove natural tannins, which encourage bacterial action to decompose fiber-binding pectin” (Bhatia & Smith, p. 19). Brackish water is the result of mixing freshwater with seawater (p. 19). There is a traditional method “done by driving a pole into the sediment of the backwater, arranging the husks on top of one another in a circle around the pole, covering the husks with mud and palm leaves, and weighing down the bundle under the water with rocks” (p. 19). Brackish ponds are also used to place husks for separating the fiber.

2. **Extraction of fiber** — this activity involves the traditional process, performed by women, of beating the retted husks with wooden mallets. Typically men perform the extraction of fiber with fiber-extraction machines.

3. **Transformation of coir fiber into yarn** — the transformation of coir fiber into yarn involves the spinning of yarn. It is traditionally done using only hand-work, by hand-rotating spinning wheel—known as ratt, or by motorized ratt. This spinning wheel “was introduced in Kerala by the Portuguese, Dutch, and English during the 15th and 16th centuries” (Bhatia and Smith, 2008, p. 21). This activity is mostly performed by women and the mechanical ratts have the drawback of requiring a continuous back and forward walk movement. Later, the yarn is twisted to form a stronger yarn.

4. **Weaving** — this activity involves the hand or mechanical weaving of coir yarn to produce value-added products, such as mattresses and geotextiles, and final products such as material for fences, scaffolding vines, fishing ropes, and house construction (Bhatia & Smith, 2008, p. 25).

4. **Constructing the Canal du Midi in France**

This case study comes from Mukerji and was published first as a book chapter in 2007 and later as its own book in 2009. Our case study was informed by the later publication.

The Canal du Midi, running through southwestern France, is a shortcut from the Atlantic Ocean to the Mediterranean Sea. It was designed and built during the 17th century and was intended to provide France strategic military advantages. As Mukerji (2009) explains, “Cutting a navigational canal across southwestern France seemed feasible, but actually taking it over uneven terrain with multiple locks was not an enterprise that was obvious to achieve with the engineering expertise of the times” (p. 3). Due to the limited hydraulics engineering knowledge of the 17th century, the project relied on knowledge and engineering skills of locals to build its one hundred locks (p. 1). Particularly in areas of land measurement, construction, and hydraulics, indigenous knowledge was more suited to meet the engineering challenge than the dominant Western expertise. “It was precisely this kind of local knowledge—the intelligence of bandits, fishermen, washwerwomen, masons, charcoal makers, and women indigenous engineers—that made it possible to build a canal in Languedoc” (p. 14). Locals living in the area where the canal was being constructed had developed intricate knowledge of techniques used in building waterways in mountain villages,
knowledge directly applicable to the Canal du Midi. Mukerji explains; "Work in these areas was clearly facilitated by the indigenous knowledge of the laborers. The canal's water supply system was essentially an extended version of the systems used in the Pyrenees to serve large towns" (p. 141).

One particularly challenging problem for engineers was the eight-step Fonserannes Lock with a total elevation change of 21 meters over a distance of 280 meters. Engineers had repeatedly failed at computing necessary water volumes for double and triple locks (Mukerji, 2009, p. 151). Thus, France awarded the Medailhes brothers, illiterate peasants, the contract to build the Fonserannes Lock, who realized Pyrenees women "knew methods for controlling wild rivers, working with rocky soil, and keeping debris out of a water supply" (p. 126). With this knowledge the women also possessed "indigenous engineering skills specifically designed to move water through complex topography and put it to multiple uses" (p. 119). Pyrenees women had already worked on other parts of the canal, designing and constructing terraces (p. 137), silt barriers (p. 144) settling ponds (p. 145), and more. On the Fonserannes Lock, these indigenous women were able to test water volumes through indigenous methods, first digging the locks and then filling the cavities with water before finishing the interiors (p. 153).

To summarize, the role of indigenous women was essential to the engineering success of the Canal du Midi:

\[\ldots\text{allowing us to see more clearly the importance of their indigenous traditions to the design of the canal. The staircase lock at Fonserannes was a vivid demonstration of how powerful and useful peasant expertise could be; it was a testimony to the women who maintained the volumes and the illiterate men who hired them, knowing what they could do together. (Mukerji, 2009, p. 153)}\]

**DISCUSSION**

Many academics and practitioners in the development field are extensively documenting the ingenuity of indigenous knowledge and exploring ways in which this could benefit local livelihoods. Despite this, ethno-engineering or indigenous ways of constructing a built environment seldom is a focal point in this area. The 32 articles in the Phase 2 database compiled here (see Appendix) are all instances of ethno-engineering, although these articles rarely explicitly label themselves as so, with a few exceptions (Jodha, 1990, 1991; Mukerji, 2009; Reij, 1991).

Most ethno-engineering strategies included in the database, such as the Andean peasants (Apffel-Marglin, 1998) and the Hopi Indians (Wall & Masayesva, 2004), are part and parcel of one's indigenous worldview. Thirteen of the thirty-two sources explicitly stress this point, whereas eighteen sources neglect to mention this component whatsoever. In the dominant Western worldview spiritual beliefs and religion are portrayed as diametrically opposite from and in competition with principles and practices of science and engineering (Roy, 2002), yet, in order to understand indigenous design strategies we must realize spiritual beliefs and engineering practices are inseparable.

When Western methods are adopted by indigenous communities the result is often the demise of indigenous knowledge systems, such as with the citrus ant colonizers (Huang & Yang, 1987), where global resources become too expensive and ethno-engineering systems become impossible to sustain or re-introduce. In other cases, such as the Tlingit salmon fishermen (Menzies, 2006), the indigenous population finds their resources becoming depleted by a colonizing system of fast-paced mass exploitation. When this happens, the exploiters cannot say “let the tribesmen reclaim and
redeploy their indigenous agricultural and social practices and solve their problems in their own way" (Semali & Kincheloe, 1999, p. 18) as the landscape has drastically changed making it inoperable with their now unsuitable indigenous techniques.

Therefore, it is not surprising that indigenous people are often cautious when Western development organizations reach out to their societies. “Development” may be viewed as a tool to further oppress the indigenous, where indigenous knowledge “is required to fit into the existing framework designed to fulfill the needs of Western ideals” (McGregor, 2004, p. 74). Indigenous societies “remain rather impervious to extension messages that stress high external input agriculture” (Tanubil, Dittoh, & Kranjac-Berisavljevic, 2004, p. 98). As modern technologies are integrated into indigenous societies, they are adopted by few, perhaps only the richest, and the development goals at which modernists strive are never achieved. This may explain why 83.9% of the articles in the Phase 2 database discuss ethno-engineering strategies dominantly dependent on local resources and none only relied on imported resources. Only 2/32 sources revealed that the indigenous did not participate in some sort of economy, be it local or global.

Integrating indigenous engineering strategies into Western engineering thinking is a delicate venture, especially when considering that, globally, “indigenous knowledge exists in immeasurable forms among immeasurable groups of people in immeasurable environments” (Buabeng, 2004, p. 15). Not only are the engineering components largely absent from scholarly literature, but it is also constructed from the outside looking in (90.6% of authors in Phase 2 are Western and commonly “using anthropological jargon” (Buabeng, 2004, p. 15). The approach used by Western authors to understand indigenous ways of doing is often taxonomic (45.2% from Phase 2 database) where “it is the categorizer who decides whether a teaching, technology, or practice is indigenous and unique to a given heritage or society, adopted from Eurocentric knowledge, or a blend of local and introduced components” (Battiste, 2000, p. 6). The databases compiled here are no exception. The goal of these databases has been to find firm ground where we, non-indigenous authors, recognize indigenous persons for their ingenuity. The 32 case studies included in the Phase 2 database are a testament to the fact that engineering is not exclusively located in Western developed societies, yet, “the stories of the engineers involved in small-scale projects are rarely told, and almost never from a critical perspective that encourages self-reflection and analysis” (Lucena, Schneider, & Leydens, 2010, p. 157).

Although it has been argued that indigenous persons may not always be acting sustainably (Diamond, 2005), none (0/32) of the articles from Phase 2 suggested that the indigenous strategies are or were unsustainable. More than half (56.3%) of the Phase 2 sources included practices that the authors themselves considered sustainable, although 43.8% of authors did not solicit any sort of opinion on the topic. Orr (1992) points out that indigenous livelihoods have subsisted in such a way that the modern world would be wise to take heed of, indicating that:

\[ \ldots \text{the only people who have lived sustainably on the earth without damaging it could not read. This does not mean they were ignorant. To the contrary, they had enormous amounts of knowledge. Indigenous peoples' knowledge of their ecosystems is extensive. We will never be able to match it. (p. 3)} \]

As Arquette and Cole (2004) put it, “we have a great opportunity to learn from the past, reorient our relations, and build a relationship based on mutual respect and partnership in the sharing of responsibility in this land and natural world” (p. 349). But it should be noted that what Menzies (2006) calls “a central strength and weakness” of indigenous knowledge is its limited applicability to only the site at which it has been developed. The “strength” is that it “can provide highly specific
and detailed information crucial for the management of local ecosystems” (p. 2). The “weakness” is that it is non-transferrable, and suitable for a relatively small-scale. Ethno-engineering strategies do not presuppose, as do scientific paradigms of a given time (Kuhn, 1962), that practices used locally may be implementable globally. Rather, if transferred—and we make no claim whether or not they should be, they must be adapted and modified.

Indigenous people’s worldviews are highly salient in the analyzed scholarly literature, generally being discussed alongside indigenous engineering practices. Existing, secular, Western worldviews cannot be understood without their roots in Judeo-Christian monotheistic beliefs, which provide the underlying basis of dominant worldviews even in secular societies. At the core of the Judeo-Christian worldview is an hierarchical order, in which God, who is deemed omnipotent and omniscient, has complete “dominion over his creation” (Salmón, 2000, p. 188). One tier beneath God are human beings who are believed to have “dominion over the creatures of the world” (p. 188), a notion generally absent from indigenous worldviews where instead there are “several aspects of a domain on an equal plane” (p. 188f). The result from the Western model is that societies aim for “personal well-being through material consumption” thereby creating “growing problems with household waste and disposal of slow-moving consumer goods” (Matutinovic, 2007, p. 98). In contrast, indigenous engineering practices are inseparable from the people’s holistic worldviews. The primary difference, and perhaps the most fundamental, between indigenous and Western modes of engineering is that Westerners tend to see themselves as controlling nature and its resources in the name of progress, whereas indigenous people tend to consider themselves part of nature and stewards of the land.

LIMITATIONS

As a technical limitation, this paper is not based on primary data collection through observations or conversations. Taking what we know, and with the developed framework of this paper in mind, further fieldwork is necessary to collect primary data on the topic of ethno-engineering directly from the field.

As non-indigenous authors, we want to emphasize again and explicitly note that we are on the outside looking in. Sandy Marie Anglás Grande (2000) suggests, “Whitestream America has never really understood what it means to be Indian and even less about what it means to be tribal” (p. 474). Notice that less than 10 percent of our literature review sources are authored by indigenous persons. How are we sure even those authors are credible, when they too are on the outside looking in? Nonetheless, these drawbacks do not suggest that “Whitestream America” or Western society should not strive for understanding. We must find the key to our “shackles of ignorance” (Meyer, 2008, p. 217). For us, the key is in the discourse we employ.

CONCLUSION

In this paper we have synthesized indigenous ways of doing that are akin to engineering, what we have called ethno-engineering. We offered a working definition of ethno-engineering as a method of defining and solving complex issues with constantly evolving deep experiential knowledge of the environment, without utilization of modern mathematics, science and technology, relying on bottom-up management, practicing resourcefulness, and being contingent upon a holistic worldview.

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5 See Max Weber (1998) as an example of how Christian, and in this case Protestant, traditions secularized into cultural norms of capitalism.
This definition is dynamic, fluid-like, as is indigenous knowledge and indigenous forms of engineering. Indigenous communities have not lived in a vacuum. Western society has exposed itself to indigenous societies and changed their livelihoods, often assimilating these communities against their own will, sometimes exterminating these societies, or even destroying their indigenous modes of subsistence. Beginning the discourse on indigenous modes of engineering is essential to any social justice conversation of indigenous communities. It is undeniable that indigenous communities have subsisted for generations with modes of engineering. As Rolt (1973) explained, “The moral is that engineering talent is no monopoly enjoyed by any particular nation, but that such talent cannot flower unless the particular social, political and economic climate is congenial” (p. 4). Change at any level of engineering first requires “change in the dominant worldview, while its dynamics resembles that of a paradigm change in political and scientific arenas” (Matutinovic, 2007, p. 92).

ACKNOWLEDGEMENTS
We acknowledge the contributions by Nigel Lee who helped construct the Phase 1 literature review database along with inter-rating of the Phase 2 coding. Research on this paper started as a Summer Undergraduate Research Fellowship (SURF) project at Purdue University.

REFERENCES

References marked with an asterisk(*) indicate studies included in the meta-analysis.


case studies from Australasia, Melanesia, and Southeast Asia (pp. 66–87). New York, NY: Oxford University Press.


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## APPENDIX: STUDIES INCLUDED IN THE META-ANALYSIS

<table>
<thead>
<tr>
<th>Author (Last, First)</th>
<th>Book: Title or Journal: Source, Volume (Issue)</th>
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<th>Year</th>
<th>Pg. #s</th>
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<td>Anschuetz, Kurt F.</td>
<td>Book: Native People of the Southwest: Negotiating Land, Water, and Ethnicities</td>
<td>Soaking it in: Northern Rio Grande pueblo lessons of water management and landscape ecology</td>
<td>2001</td>
<td>48–78</td>
<td>United States</td>
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<td>Barrios, E. &amp; Trejo, M. T.</td>
<td>Journal: Geoderma, 111 (3)</td>
<td>Implications of local soil knowledge for integrated soil management in Latin America</td>
<td>2003</td>
<td>217–231</td>
<td>Venezuela, Colombia, Honduras</td>
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<td>Devarapalli, Jesurathnam</td>
<td>Book: Indigenous Science &amp; Technology for Sustainable Development</td>
<td>Hidden wisdom behind the primitive huts</td>
<td>2008</td>
<td>68–73</td>
<td>India</td>
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<td>Greenberg, Laurie S. Z.</td>
<td>Book: Women &amp; Plants: Gender Relations in Biodiversity Management &amp; Conservation</td>
<td>Women in the garden and kitchen: The role of cuisine in the conservation of traditional house lot crops among Yucatec Mayan immigrants</td>
<td>2003</td>
<td>51–65</td>
<td>Mexico</td>
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<td>Herrmann, Thora Martina</td>
<td>Journal: National Resources Forum, 29 (2)</td>
<td>Knowledge, values, uses and management of the Araucaria araucana forest by the indigenous Mapuche Pewenche people: A basis for collaborative natural resource management in southern Chile</td>
<td>2005</td>
<td>120–134</td>
<td>Chile</td>
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<td>Holter, Uta</td>
<td>Book: African Nomadic Architecture: Space, Place, and Gender</td>
<td>Mahria tents: The woman's domain</td>
<td>1995</td>
<td>124–149</td>
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<td>Hviding, Edvard &amp; Baines, Graham</td>
<td>Book: Resources, Nations, and Indigenous Peoples: Case Studies from Australasia, Melanesia, and Southeast Asia</td>
<td>Marine tenure, fisheries management and conservation in Marovo Lagoon, Solomon Islands</td>
<td>1996</td>
<td>66–87</td>
<td>Solomon Islands</td>
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<td>Langdon, Steve J.</td>
<td>Book: Traditional Ecological Knowledge and Natural Resource Management</td>
<td>Tidal pulse fishing: Selective traditional Tlingit salmon fishing techniques on the west coast of the Prince of Wales Archipelago</td>
<td>2006</td>
<td>21–46</td>
<td>Alaska</td>
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<td>Mukerji, C.</td>
<td>Book: <em>Impossible Engineering: Technology and Territoriality on the Canal du Midi</em></td>
<td>-</td>
<td>2009</td>
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<td>Nowak, Barbara S.</td>
<td>Journal: <em>Development</em>, 51 (2)</td>
<td>Environmental degradation and its gendered impact on coastal livelihoods options among Btsisi’ households of peninsular Malaysia</td>
<td>2008</td>
<td>186–192</td>
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<td>Turner, Nancy J. &amp; Clifton, Helen</td>
<td>Book: <em>Traditional Ecological Knowledge and Natural Resource Management</em></td>
<td>The Forest and the seaweed: Gitga’at seaweed, traditional ecological knowledge, and community survival</td>
<td>2006</td>
<td>65–86</td>
<td>British Columbia</td>
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BOOK REVIEW

Gilbert Simondon: Being and Technology
Edited by Arne De Boever, Alex Murray, Jon Roffe & Ashley Woodward,
Edinburgh University Press, 2012

Reviewed by Dr. John Reader, William Temple Foundation, University of Chester,
drjohnreader@hotmail.co.uk

How does one contribute to a process of transformation towards great social justice and what are the barriers that stand in the way? Some of the ideas presented in the book Gilbert Simondon: Being and Technology help us to address two issues vital to the above: first, that of why it is that humans are sometimes so loathe to oppose the forces and factors that prevent them striving for greater social justice, and second, how one can envision alternative forms of leadership—ones that rest less upon the power or influence of specific individuals, but do take into account human (and non-human) interdependencies. The publication of this text is a step in the direction of making Simondon’s work more readily available, and helps us to see how a different understanding of how human individuality is formed offers new insights into both these issues.

Gilbert Simondon: Being and Technology claims to be the first book in English dedicated entirely to the work of this French philosopher. Born in 1924, Simondon was a doctoral student of both the philosopher and physician Canguilhem and the phenomenologist Merleau-Ponty. His work has been foundational for Deleuze, but also has links to Latour, Massumi and Stengers, amongst others. His major writings are only now becoming available in English, so it has taken a long time to acknowledge his role in influencing these other thinkers. As the introduction comments, two main themes emerge, ontology and technology, but our main interest is his ideas on human formation, and therefore their implications for change, development and education more generally.

Chapter One is a translation of a previously unpublished text of Simondon on “Technical Mentality” and is helpfully followed by a commentary consisting of a questioning of Brian Massumi by the editors. This highlights the key themes of individuation, metastability—the fragile, provisional equilibrium that is subject to constant perturbation (p. 30), and the idea of the pre-individual—that which is always in advance of the actual process of individuation and which enables the constant possibility of change and transformation (p. 32).

Chapter Three by Elizabeth Grosz offers an exploration of feminist reflections on Simondon’s work and takes us further into the discussion of his concept of individuation which is so relevant to our wider debate. Simondon is interested in how pre-individual forces, not yet individuated, produce individuals of various kinds (p. 38). Such forces not only pre-date the individual, but constitute the potentialities each individual contains and that both sustain and transform it. So the individual is always more than itself, and has the potential to undergo further changes after it is constituted as such. What one is at any particular moment is only one manifestation of what one might be or become. “Being is at once pre-individual, individuating and individuated; it becomes something, something emerges or erupts, but it leaves in its context or milieu a residue or excess that is the future for further becomings” (p. 38).
This quote offers a critical insight into how Simondon's work coheres with the concern for threshold concepts which are essential to the search for growth and development through educational process. In our recent book, *Heterotopia: Alternative Pathways to Social Justice* (Caroline Baillie, Jens Kabo & John Reader, Zero Books, 2013) we employed the notion of threshold concepts to suggest that it is only when one is prepared to step out into the unknown, to enter "zones of entanglement" by "hanging out in the fog," that growth is likely to occur. Yet this itself presupposes the capacity of humans to change and be changed through such encounters with what is unfamiliar, hence the potential importance of Simondon's ideas on individuation and metastability. One needs to take these ideas further of course, but the notion of metastability, the potential of individuals to subvert and transcend their individuality at any particular moment, rather than to achieve or remain in a position of comfortable equilibrium, is surely vital to the process of transformation required by new pathways towards social justice.

*Transduction* is another term that Simondon uses to describe this dynamic, being “the process by which the various pre-individual forces move out of step with each other, generate a disparation, a problem, which individuation addresses through the creation or discovery of a process, event, dimension or object that enables a new order to emerge at another level” (p. 42). Although the conceptual language here is difficult, I believe it is also rich in meaning and possibility, and Grosz herself concludes that there is much here for feminism to draw upon as it struggles with the ideas of how identity is formed and re-formed.

Chapter Four engages in greater detail with Simondon’s employment of the growth of crystals as a key exemplar of his notion of individuation. This is his main picture for an ontology of becoming, of metastability in action, and the simplest image of transduction. It begins with a very small seed, grows out in every direction within its pre-individual milieu, each already formed layer serving as the structural basis of the next molecular stratum (p. 59). There is a pluralism of phases brought about by the changes and out-of-phasesness that is the individuation process, but what emerges is always still in the process of developing and does not result in a stable or completed identity. At the heart of this are ideas of the fold (taken up by Deleuze1), internal and external resonances, tensions and excess, each of which suggests that it is relation with that which is other that instigates and stimulates the process of change. As we described it in *Heterotopia* these are the liminal spaces that are entered when we venture into the cloud of unknowing or zones of indeterminacy. By entering into relation, one takes the chance of both being changed and changing the other.

Further chapters go on to talk about the concept of anxiety in Simondon’s work (Chapter 5); his concept of aesthetics (Chapter 8); the links with Deleuze (Chapter 9); and the book concludes with a glossary of 50 key terms in his work that itself offers a comprehensive means of accessing his ideas (pp 203–231). It is in Chapter 5 that one encounters Simondon’s understanding of the *transindividual* which brings into question how it is that individuals are part of a wider process of relationships, and this, in turn, allows us to see questions of politics and leadership in a different perspective. He does not hold to a notion of the psychological world as being autonomous, but rather proposes that there is a dialectical character to the process of psychological individuation, and indeed a mediation between the physical and the biological, between the world and the self, and this means a dialectic between exterior and interior that enables us to recognize the interconnected and collaborative character of human action (p. 80). It is through our relationships with others that we have most impact upon social and political life and these are mediated by emotion and affect which take place at the pre-individual level. Whilst one can recognize the importance of acknowledging this dimension of human activity, and the possibilities for change that

1 See especially Deleuze's *Cinema 2*, Athlone Press, 1989, Chapter 4 on "the Crystals of Time."
it brings into the picture, it does perhaps run the risk of underestimating the role of reason in the process of entering the required zones of entanglement.

The dimension of this work that I find most perplexing is that of how one interprets the process of pre-individuation in terms of time. If it is the case, as Simondon appears to argue, that the pre-individual is always present and thus is subject to change because of its inherent metastability, then it would seem to presuppose that there is not a linear understanding of time where one moves smoothly from one state of being to another. That which apparently is has to continue to contain that which is not, but which might be at some point . . . almost as if some backtracking can occur which brings the past into the present in a new way. If humans are so like crystals, then is there really enough continuity of identity or personality to prevent constant disintegration of the individual? Does there not have to be enough stability to counter or contain the metastability, in order for there to be coherent or consistent activity? If all is change and becoming, could one even begin to conceptualize alternative pathways towards social justice? Perhaps this is where the model begins to reach its limits, and where later developments from biology and technology might add different dimensions to this conceptual framework.

However, this does not alter the fact that the journey throughout the book is one of discovery and no little challenge, so I would commend the book as a whole as a vital and valuable way into the thought of this recently recognised philosopher, and a source of ideas that complement and develop other explorations into the fields of education and transformation.

FURTHER READING