An ecology of science education

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This article reports on a 15 month study of attempted innovation in school science. The teachers in an Australian secondary school were attempting to introduce a constructivist approach to their teaching of science. The change attempt is interpreted through analogical transfer. In this method of analysis, the school science system is mapped against an ecosystem. That is, the science education system is conceptualized as an ecosystem; a self-sustaining, homeostatic, yet evolving, system of interacting influences. This ecological view of science education provides a way of interpreting the findings of this case study by using biological features of ecosystems, such as succession, evolution, selection and adaptation, to explain stagnation, degradation and change in school science. Implications of this interpretation of school science are considered including a proposed mechanism to promote innovation, such as a constructivist approach, through successive stages and the production and communication of knowledge.

Introduction

In this article, the findings of a study (Aubusson 1997) of attempted change in school science are reported and interpreted analogically. First, the context of the study is described including a brief outline of the situation, data collection, data analysis and findings. The findings of the study are then interpreted analogically as further insights into the school science system are sought. In the analogical analysis, the school science system is compared with an ecosystem. The features of an ecosystem are made manifest by considering a particular ecosystem, a heath. Key features of the ecosystem are identified and mapped against the school system. This mapping identifies consistencies between the heath ecosystem and school science including complexity, homeostasis, fragility and evolution, as well as contentious similarities such as knowledge production and selection. The systematic similarities (Gentner 1983) between the heath and school science justifies the application of established biological theory to explore the nature of change and stagnation in school science. Then, implications of this interpretation of innovation in school science are considered. This includes discussion of a mechanism to promote innovation (such as constructivist approaches) through successive stages and the production and communication of knowledge.

Context

This study was situated in an Australian secondary school. Two science teachers (Chris and Joan) in the school introduced a constructivist approach to the other
teachers of their science department (Brian, Dean, Fred, Gail, Hugh and Lance). The approach was based mainly on the ‘Generative Teaching Approach’ (Cosgrove et al. 1982, Osborne and Freyberg 1985). Led by Chris and Joan, all the teachers set out to implement this new teaching approach throughout junior secondary science at their school. As a researcher, I set out to understand this process of change in school science by identifying the influences that affected these teachers as they attempted their innovation.

I observed this attempted change in the school intensively over a period of 15 months. Over this period I collected data, primarily as a participant observer (Burns 1994). During the first six months of the study I visited the school at least one day per week when school was in session. This was followed by a period of 10 weeks when I visited the school for four days per week. I then visited at least one day per week for the remainder of the school year; and then I returned to the school about twice a month for another three months. This completed the intensive 15 month period of the study. However, I continued occasional visits to check on data and its interpretation for another two years.

A range of data sources and data gathering techniques were employed to investigate the attempted change. There were four informal interviews (Tuckman 1994), of about 50-60 minutes duration, with each of the eight teachers and two students from each of these teachers’ classes. The specific questions and content in each interview varied according to the views expressed by different teachers, students and observations of each teacher and class. This approach is based on the specific situations of each teacher, as recommended by Feiman-Nemser and Floden (1986). Discussions occurred with teachers and students before, during and after lessons. While unstructured, the discussion remained geared to the ‘interviewer’s research interests’ as recommended by Minichiello et al. (1990). They covered views about lessons, the change being attempted, or they sought clarification of previously expressed views or interpretations of data. Over 200 classes taught by the eight teachers were observed. Observations took place initially one day per week and then 4 days per week. Transcripts of discussions and conversations were returned to teachers for checking.

Data analysis
The data were analysed using the procedure for interpretive studies recommended by Erickson (1986). Written and oral reports, including both data and the researcher’s interpretations of the data, were provided to staff for member checking. Seven of the eight teachers involved in the study confirmed that the picture outlined in the final report to them accurately described their views and the environment in which they operate. (One of the teachers, Dean left the school to teach elsewhere before he could respond to the final report.)

All eight teachers in the science department, two reluctantly, agreed to the implementation of the constructivist approach in the teaching of science in their science classes. One of the main strategies employed to implement the approach was the development of new programmes for each year group, organized according to the phases of the generative teaching approach (i.e. preliminary, focus, challenge and application phases [Cosgrove et al. 1982]). New programme units were written for year seven science during the first 12 months of the study and plans were made to gradually write new units for the other junior secondary years (years 8 to 10).
Meanwhile, teachers agreed to introduce the new approach throughout years 7 to 10 whilst using the old 8 to 10 programme units. According to the teachers, these old units were based on a ‘process approach’ to science education, which emphasized the development of science process skills. The units, both old and new, listed learning as behavioural objectives and suggested activities and resources. At the end of each unit, students completed tests that were based on the behavioural objectives in each unit.

During the study, Chris and Joan were able to teach in ways consistent with the constructivist intentions from the beginning. Other teachers changed their teaching, sometimes, in unpredictable ways. Lance tried a problem-solving approach for one topic with his year 8 class, which he saw as consistent with the constructivist approach. Brian, Fred, Lance and Gail had ‘dabbled’ (Claxton and Carr 1991) with teaching in ways new to them. These new ways of teaching included a range of teaching strategies that were not inconsistent with but different from the intended innovation (e.g. employing some open-ended activities and individual work throughout a topic). Dean and Hugh, who had reluctantly agreed to implement the constructivist approach, tried to do what they thought the new constructivist programme required in year 7 and to implement the approach in other classes. Like all the other teachers, they interpreted the constructivist approach to mean that the students could not be told the correct science by the teacher but had to work out the science principles and concepts for themselves. Dean and Hugh became increasingly dissatisfied with their teaching and the poor learning they thought it engendered.

Many influences in the school inhibited change. For example, all the teachers, except Chris and Joan, held personal views of teaching and learning that were different from the constructivist views that underpinned the innovation. The old programs, which emphasized process skills and behavioural objectives, were inconsistent with the new approach. The tests did not test the deep learning the teachers were seeking. The tests emphasized recall and favoured teaching by telling rather than the constructivist approach that the teachers sought to implement.

**Findings and problems**

The main findings of the study (Aubusson 1997) were that:

- this science education system maintained the *status quo* with many interactions acting against innovation;
- the attempted innovation resulted in a variety of unanticipated outcomes, including teachers employing teaching strategies different from their constructivist approach;
- this science education system functions as a complex interacting system which resists yet, paradoxically has undergone and is undergoing gradual evolution.

The principal finding was that the school science education system is characterized by unpredictability, complexity and homeostasis yet evolution.

The study had set out to identify the influences and effects within a science department as it attempted to introduce a new teaching approach. Noting the interactivity among the influences and effects detected, an interpretation was first sought through a simple mechanical system of four connected components:
learning takes place through the teaching of a curriculum situated in a culture. This model of science education, characterized by its linear cause and effect (a clockwork paradigm), was unable to explain the observed subtle, complex and dynamic interactions that inhibited the innovation and maintained homeostasis. Therefore, an alternative way to interpret the findings was sought that might yield richer insights into science education.

The purpose of this article is to interpret the principal finding of my study: that the school science system is characterized by unpredictability, complexity and homeostasis yet evolution. An ecological analogue provided a more sophisticated way of interpreting the findings. It suggested a ‘fresh conceptual framework(s) to “improve” science education by understanding and explaining its events and phenomena better, more deeply and more systematically’, meeting the demands Roberts (1996: 244) places on any case study.

**Developing an analogical interpretation of a school science system**

In science, analogical reasoning is well respected (Hesse 1966, Holyoak and Thagard 1989, Eisenberg 1992, Gentner et al. 1997). ‘Although it (analogy) may mislead, it is the least misleading thing we have’ when the way forward is not clear, according to Samuel Butler (in Eisenberg 1992: 95). Analogy has two main purposes in science (Dunbar 1997), to explain phenomena to others and to allow the scientist to understand phenomena more deeply. These purposes place different demands on the selection of an analogue. If the purpose is the former then the choice of the analogue depends only on its capacity to communicate ideas. If the analogue is sought as a way of explaining phenomena more deeply, then the choice of the analogue needs to be more rigorous. Analogical reasoning is a ‘strong method’ of reasoning because it makes use of specific or abstract represented knowledge but its effectiveness depends on an appropriate source of knowledge being present (Kurtz et al. 1999). Thus, the selection of an appropriate analogue, as a source of knowledge, is critical in analogical analysis. Some authors refer to the analogue as the ‘base’ (e.g. Gentner 1983).

**Selecting the analogy**

Analogy is made up of two analogues, the target analogue, which is the domain to be explained, and the base analogue, which is the domain that serves as a source of knowledge (Gentner 1983). Both domain and base are analogues, parallel things that are compared. If an analogy is to be useful in knowledge production, then the power of the analogy does not lie in the overall number of overlaps between target and base. Rather, the central criterion, according to structure mapping theory, is that ‘a relational structure that normally applies in one domain can be applied in another domain’ (Gentner 1983: 156). Relational structures are attributes of the base and target that illustrate a similar causal relationship. They reveal a similar process and allow similar interpretations of base and target. Analogies may also have literal attributes. Gentner (1983: 159) illustrates the difference between relational and literal similarities through examples. Specifically, consider that the atom is analogous of the solar system. One relationship we might infer from this is that ‘the nucleus attracts the electron (and) causes the electron to revolve around the
nucleus’ just as ‘the sun attracts the planets (and) causes the planets to revolve around the sun’. By contrast, a literal similarity might be that a sunflower looks like the sun. This literal analogy provides a match that only illustrates a similarity of appearance, for example, both appear yellow. By contrast, relational similarities provide a system of connected knowledge for comparison. The exploration of relational similarities allows the process of reasoning from parallel cases to infer causes and processes in a target analogue. Relational structures provide access to an existing knowledge system in the base. High order mappings (Gentner 1983) generate deeper understanding of the target. These are characterized by mapping relationships, reasoning and argument rather than the mere identification of attributes in similar objects.

In this study a variety of analogies were tried as a base source of knowledge and mapped against the target (school science). Each of these proved useful as communication devices and provided some insight into the school science system. For example, inertia was employed as a base in analogical mapping. This analogy is not new in the description and examination of a social system’s resistance to change (Ward et al. 1997). However, the simplicity of the fixed interactions of balanced forces in the physical system selected was only superficially similar to those of the school system and could not explain gradual change. A buffered chemical system was also tested as a base. The complexity of the chemical feedback systems highlighted the feedback systems of school science; and Le Chatelier’s principle (where chemical reactions shift direction resisting change in a system) was consistent with the dynamic stasis of school science. Yet, the predictability of buffered chemical equilibrium was in stark contrast to the unpredictibility of the school science system.

These initial mappings provided structural overlaps between the base and target domains but lacked the coherence suggested for analogy by Gentner (1983). What was important in this research was an interpretation that addressed the interconnected relationships among unpredictability, complexity and homeostasis associated with gradual change. The mappings against inertia, buffered chemical systems (and others) provided isolated similarities between the target and base but lacked the high order interconnected relationships recommended in analogical mapping by Gentner (1983, 1989). Thus, these bases proved useful in communicating ideas about the science system but were less fruitful in providing a deeper understanding of the nature of the school science system.

To understand science education as an interactive system, an interpretation is required which penetrates the interactivity to conceptualize unpredictability, complexity, homeostasis and evolution. Kelly recommends biology as a source of models for complex systems, commenting:

Clockwork logic - the logic of machines - will only build simple contraptions. Truly complex systems such as a cell, a meadow, an economy, or a brain (natural or artificial) require a rigorous, nontechnological logic. We see now that no logic except biologic can assemble a thinking device, or even a workable system of any magnitude (Kelly 1994: 2).

This view paraphrases Donmoyer’s (1992) and White and Klapper’s (1994) criticism of science education research for its location in a mechanical paradigm, attempting to explain phenomena in terms of linear causes and their effects as its principal features. By contrast, biology has had to deal with causal complexity
both proximate and ultimate. That is, proximate cause and effect, such as a change in DNA affecting the structure of a protein and hence a related characteristic of an organism, as well as ultimate unpredictable consequences, such as in evolution. In biology, to deal with only a single cause results in ‘conclusions which are at best incomplete and more likely wrong’ (Mayr 1988: 18). Hence, biology provides models of complex interactions.

Living systems are characterised by a remarkably complex organisation...biological systems have the further remarkable property that they are open systems, which maintain a steady-state balance in spite of much input and output. This homeostasis is made possible by elaborate feedback mechanisms, unknown in their precision in any inanimate system (Mayr 1988: 14).

This complexity of living things exists at a hierarchical level and at each level the complexity is compounded by the combining of complex systems (Mayr 1988). Biological systems include details at the levels of cells, tissues, organs, organism, species and ecosystem. Thus, there is both micro and macro homeostasis. These homeostases are built upon the connectedness within and across the hierarchical levels. The ultimate level of biological homeostasis is the ecosystem where ecological homeostasis has been clearly described in terms of connectedness:

(In an ecosystem) everything is connected to everything; everything feeds back through the ecosystem on itself. The interconnectedness preserves the overall system. The natural tendency of any complex...ecosystem is to maintain a dynamic steady state despite environmental stresses, changes and shocks. Even where stresses are too great...a biotic community can evolve a new steady state in balance with changed environmental conditions (Miller 1975: 77).

Miller identifies in ecosystems a base, source of knowledge, with potential relational structures including homeostasis, complexity, variation and the seemingly paradoxical change of a system in equilibrium. There is a prima facie case to explore the ecosystem as an analogy for interpreting the school research findings. Specifically, the analogy between ecosystem and school science provides a potential for the systematicity of better analogies demanded by Gentner (1983, 1989). That is, it provides a link in high order relations or functions (e.g. gradual change - evolution and maintenance of the status quo - homeostasis) and not merely a matching of isolated attributes (e.g. ecosystems and schools both experience night and day), which are analogous but not relations with explanatory power.

Having identified ecosystem as analogy for school science with potential to contribute to a deeper understanding of this episode of science education, the next step is to describe the features of an ecosystem in some detail. This is done to provide a basis for interpreting the phenomenon under study-the science education system. Each analogue, according to Gick and Holyoak (1983: 4), is divided into different stages: the initial basis for mapping and the conclusion. The initial basis for mapping in this case study is the complexity and homeostasis of the eco- and science education systems. In moving towards a conclusion, Gick and Holyoak (1983: 8) recommend maximizing the extensiveness (of the analogy) 'by moving to more detailed representational levels'. Taking this advice, the analogical interpretation of this case study will be extended by mapping relations in an extensive ecosystem, a heath ecosystem, against the school science system.
A detailed representation of the base domain

The general features of ecosystems can be recognized by considering a heath ecosystem. On the Great Dividing Range in New South Wales lies a small heath ecosystem. Nearby a variety of ecosystems flourish in the same broad climatic conditions, including rainforest, woodland, and sclerophyll forests. The heath thrives on a west-facing sandstone plateau which is exposed to strong, cold, prevailing winds; the soils are impoverished and poorly drained; and fires occur (usually every 10 to 15 years but sometimes more frequently). It is an environment to which the heath is well adapted.

The heath is a complex ecosystem. Within 100 square metres it is not uncommon to find over 30 different species of plants. Throughout the heath, patches can be observed in different stages of succession, showing how the heath has developed. There is bare rock stained by cyanobacteria, rock encrusted with lichen and moss, regions of native grasses and sedges, as well as the heath dominated by small shrubs dotted with the occasional stunted eucalypt. Each of these communities has modified its environment slowly, making it less suited to itself but more suited to a succeeding community. Soil, for example, accumulates around the moss. Grass seeds colonize this soil and themselves create a deeper humus and soil suited to the shrubs. Conditions for plant growth remain poor but the shrubs are well adapted to the conditions. Carnivorous plants, such as sundews and bladderworts, capture insects and aquatic arthropods to supplement their nitrogen intake. There are three *Banksias* on the heath (the swamp [*B. paludosa*], heath [*B. ericifolia*] and old man, [*B. serrata*]) which flower at different times of the year providing nectar to a variety of animals. The heath *Banksia* is important because it flowers in winter, producing copious amounts of nectar, just when other sources of food for birds, mammals and insects are scarce. Yet the relationship between the *Banksia* and these animals is not one-sided as they, particularly ring tail possums, pollinate the *Banksia*.

Through evolution the organisms have adapted to the environment and know (genetically) how to respond to it. After fire, the *Banksias*, like most of the heath plants, drop their seed, and soon after, the blackened soil (rich in nutrients for a short time) is covered by seedlings. The swamp *Banksia*’s thickened roots (lignotubers) lie protected beneath the soils and shoot after fire. The old man *Banksia*’s buds (epicormic buds) are buried beneath a thick, corky bark where they are protected from fire and burst forth within days of its passing. When fire occurs in frequencies of less than five years, the heath *Banksia* is unable to reach reproductive maturity and is wiped out, unable to drop seed in response to fire. When this critical species is lost many animals struggle to survive winter. However, fires rarely recur within this five-year span except when lit by humans in neighbouring farmland from where they spread into the heath.

After a fire the soil is littered with seeds, which provide abundant food for many small animals, thus allowing populations of these mammals to regenerate. But the changes after fire also allow different species, less well adapted to the heath ecosystem, to thrive for a time. The house mouse population increases rapidly after fire, due to the abundant food, as does the marsupial mouse that feeds on the house mouse. Yet as the ecosystem recreates itself the house mouse population diminishes and the plants become re-established. The animals come again into balanced populations and the heath in five to ten years looks much as it always
has - a self sustaining ecosystem - regenerated and only slightly altered. The distribution and abundance of species may vary but the variety of species and their interactions are unchanged.

Hence the heath undergoes slow and gradual change through succession where the ecosystem slowly modifies itself from within and, organisms well adapted to the conditions succeed each other to create and recreate ecosystems.

*Features of the heath analogue*

This description of the heath ecosystem identifies 11 features:

1. **Complexity** - there are many interactions among plants, animals and their surroundings.
2. **Buffered homeostasis** such as the heath’s self-maintenance in spite of stresses like fire.
3. **Succession** over time such that different stages of succession are present in different parts of the ecosystem at the same time.
4. **Fitness** such as the sundew’s carnivorous adaptation to impoverished soil.
5. **Generation - regeneration**, in that the heath ecosystem generates itself from within through succession and response to fire.
6. **Opportunism** when the house mouse exploits the short-term, altered environment after fire.
7. **Reproductive maturity** in that species, if they are to survive, have to pass on information present in their genetic code to successive generations.
8. **Fragility** when changes in fire frequency can eliminate a species, subtly modifying the ecosystem.
9. **Variational evolution** as organisms have evolved through natural selection.
10. **Purpose** in that the organisms function as if there is an unconscious purpose, the survival of the species [after Plotkin 1994] through such adaptations as the Banksia’s production of nectar to attract animals to pollinate its followers.
11. **Knowledge present in the gene pool** [after Plotkin 1994] which enables it to respond to its environment.

These 11 interdependent features indicate that a deep understanding of the heath ecosystem requires an appreciation of the adaptation of organisms within it; of the capacity of populations to evolve and communities to change; and of the interactions among organisms and their environment. These characteristics, paradoxically, maintain robust stasis but allow unpredictable change.

*Selecting elements to be mapped*

Before mapping these characteristics to the school setting, consideration will be given to the nature of the information derived from the heath ecosystem. Many of characteristics identified from the ecosystem are themselves metaphors (e.g. fitness, opportunism, knowledge). The metaphors serve primarily as communication devices but the metaphors influence knowledge generated in the mapping. The metaphors of the heath ecosystem not only convey ideas about the ecosystems but
are part of a mental representation of ecosystem. They bring broad relational structures (Glucksberg et al. 1997) to the analysis. Fitness for example is in itself a complex notion including both adaptation and reproduction. Hence, the analogical mapping relies on the explication of the relations not just of the school science-ecosystem analogy but on the relational overlap between these metaphors and the phenomena they represent. A detailed mapping of each metaphor against the original phenomena is too great an undertaking for this article. Where these metaphors are well known (e.g. fitness, succession, buffered), the metaphors are used in the analysis with limited elaboration of their meaning in biology. Where the metaphor is being used with a particular meaning (e.g. knowledge, reproductive maturity) the metaphor is explained.

**Mapping ecological features onto this case study of science education**

The essence of analogical reasoning, according to Gick and Holyoak (1983) is the transfer of knowledge from one situation to another by a process of mapping - finding a set of one-to-one correspondences (often incomplete) between aspects of one body of knowledge and another. Analogical transfer results in the recognition of:

- positive elements, where there are structural parallels;
- negative elements, where features of the analogy are inconsistent with phenomena; and
- neutral elements, where the degree of agreement between the analogy and phenomena is inconclusive (Hesse 1966).

To identify the correspondence between the heath ecosystem, and school science structural parallels, inconsistencies and inconclusive areas have been mapped, as first recommended by Hesse (1966). Some of the overlaps between the base and target domains are more important than others. The correspondences reported here have been selected because they are likely to be interesting. That is, their correspondence is not only mandated by local similarity but also by the degree to which the features play the same roles in the relational structure of the base domain and target (Gentner et al. 1997). Furthermore, a more detailed treatment is given to selected areas of the structural alignment that are inconclusive as these should be highlighted and explored (Hesse 1966, Holyoak and Thagard 1995, Markman and Gentner 1996). In the mapping outlined below, assertions in the base (heath ecosystem) are aligned with the target domain (school science) and further assertions evident in the base domain are then inferred as potentially true of the target, as recommended by Gentner et al. (1997). (For a discussion of the mapping of all 11 features from the heath onto school science, see Aubusson 1997.)

**Homeostasis**

The school science education system maintained the conditions such that it changed little. The constructivist teaching innovation was counteracted by interacting features of the complex system including:

- an assessment process emphasizing the measurement of accurate recall;
the organization of learning in fixed blocks of time;

- remnants of behaviourism such as learning described in advance by behavioural objectives and managed by reinforcement.

The interconnectedness of these features rendered the system stable. Homeostasis is a parallel between the analogue and the case study.

Succession

Remnant stages of broad trends in science education can be seen in this case study. Some teachers (e.g. Fred and Gail) held a Brunerian view that science subject matter is to be transmitted according to the logical order of the discipline. A science process skills approach is specified and emphasized in programme units and supported in discussions among staff. Others (e.g. Dean and Hugh) hold that everyone is not capable of success in science and that physics is for the elite. By contrast, others insist that science is for all and have attempted to develop a programme that caters for all students (e.g. Chris, Joan and Lance). There are remnants of behavioural psychology in assessment, rewards and programmes. A transmissive approach is evident in the didactic presentation of information in lessons by some teachers (e.g. Fred, Dean and Hugh). Remnants of past ecosystems, which have been supplanted by the climax ecosystem, remain in the heath. So too, in school science, remnants of past science education systems remain. What is less clear is how these past science education systems contribute to their own replacement. Also, there is a possibility that there is some science education climax community; that is, a climax (for any given environmental features) to which science education gradually reverts, as would be predicted by this ecosystem analogy.

In the heath succession, each ecosystem alters the environment making its own survival more difficult and favouring the next ecosystem. For example, the moss and lichen on rocks contribute to soil production bringing about their own demise and their replacement by grasses. The heath ecosystem, in the absence of fire, becomes woodland. In the school science system all the teachers attempted to employ a constructivist approach but only two were successful. These two teachers, Chris and Joan, had believed that science process skills were worth learning but regarded their students' learning of science subject matter knowledge to be of little consequence. They had so devalued science subject matter knowledge that a process approach to science had dominated their thinking about teaching and learning in science. In Chris and Joan's classes, the shift towards the constructivist approach was facilitated by their belief in the value of a process approach, which had previously dominated their teaching. These teachers did not teach by telling but were inclined to teach by allowing students to 'work things out for themselves'. If the students did not learn the 'correct' science when they employed the constructivist approach these teachers were tolerant of this. The preceding science education paradigm (process science) had created the conditions promoting its own demise and for the constructivist approach to develop in these teachers' classes. Nevertheless, it is not clear whether the change towards a whole school science education system, dominated by constructivism is made easier by succession through other stages (e.g. a process approach).
The existence of a climax community is less equivocal. The two advocates of the innovation (Chris and Joan) generated constructivist views and attempted to disperse them throughout their science department. To do this, they produced new programme units (which contained the same science subject matter as in the previous year 7 programme) but built around a generative change approach to teaching (Cosgrove et al. 1982). In their testing, they attempted to assess student learning but developed tests similar to those they had used in the past. These were matched to behavioural objectives testing recall and application of science process skills. Once the innovation had stalled, there appeared to be little difference between the day-to-day teaching at the advent of constructivism and the end of the attempted innovation. The school science system appeared essentially the same, though there were subtle changes. Factors, such as testing in the school, had established conditions that favoured a transmissive or process-based science education ‘climax’ system rather than a constructivist science education system. The system, in response to an environmental stress (the innovation), was able to regenerate itself. There was equilibrium yet subtle evolution.

If this view of succession in science education is valid then it suggests two avenues of further research. Firstly, the exploration and identification of a sequence or sequences that might promote desired change in school science; secondly, the identification of ‘environmental factors’ that may allow desired teaching in science to slowly evolve towards a climax that features a constructivist approach to teaching (if that is desired). Different environmental factors in a school, such as a reduced emphasis on external exams, would be expected to allow the development of a different and perhaps more desirable school science education.

Fitness

These teachers are adapted to the system - they have all survived. Teachers occupy a niche they have selected for themselves. Some, such as Dean, accept that they are in ‘no position to argue’ against the constructivist approach to which they are opposed. They attempt to employ their version of the mandated constructivist approach with their class but manage to teach in a way that is satisfactory to them. They survive despite innovation. All these teachers survive and had survived for at least five years in schools. If Lortie’s (1975) thesis that teachers reproduce themselves is correct, then the two key features of fitness in an evolutionary sense hold for school science: survival and reproduction. There is no requirement that a teacher or organism be best or even good but merely able to survive. Thus, in a biological sense, they are fit and this fitness is another correspondence.

Reproductive maturity and fragility

The attempted constructivist innovation has neither matured nor been passed on to other members of staff. About 12 months after the innovation began it stalled. One of the main advocates (Joan) departed at this time and without her support it was difficult for the innovation to continue in year 7, let alone spread throughout years 8-10. Although working well with each other, in this learning through their own innovation, the advocates were not well equipped and had little time to
support others or promote the innovation among staff. This notion of reproductive maturity is linked to fragility. In this case study the innovation was not sufficiently robust at the time of a new external pressure (which came in the form of the imposition of new senior syllabuses) to continue into years 8-10. Initially the demands of new syllabi and the departure of one of constructivism’s advocates stopped the innovation proceeding. These critical events combined with the resistance to change inherent in the system to prevent the advocates working together to develop their innovation themselves and dispersing their innovation to others. Three years after it began, though the senior syllabi had been programmed and implemented, the constructivist approach had only colonized years 7-10 in classes taught by the remaining principal advocate, Chris. Thus, in ecological reproductive maturity and fragility, a structural parallel is detected. This overlap between the ecosystem and the science education system is most striking as it demonstrates that both systems are robust. It seems both the heath and the school science system can survive extreme pressures. Yet, the opportunity for change is short lived and the variants, be they a characteristic of a plant or a new teaching approach, are fragile not because they are intrinsically fragile but because the new characteristic is initially possessed by few individuals in the population. This renders it susceptible to extinction and making change difficult to sustain. As a consequence, many ‘good’ teaching practices may be introduced but only a few are likely to survive and spread. Those that do survive and are reproduced by successive teachers, are, by definition, the ‘fittest’.

Variational evolution

The school science system in this case study has changed subtly and gradually despite its intricate and tightly buffered nature. One teacher, Hugh, having tried his version of constructivism, is more certain than before that it does not work. Another teacher had valued a problem solving approach but rarely practised it to his satisfaction. Having had the opportunity to try problem solving over an extended period, he now employs it throughout his year 7-10 teaching. The innovation, seen by some teachers as requiring uniformity in their teaching of science, had the unanticipated effect of generating variety. The constructivist variant has been introduced and survived (just) and the amount of variation, available for selection within the system, has been increased. As a consequence the system has evolved, though in an unpredictable way, and its potential to evolve has increased. Like an ecosystem it has evolved but established a new balance with the paradoxical capacities for both homeostasis and evolution. Thus, in evolution, an overarching relational structure is discerned.

Knowledge

The teachers possess knowledge that allows them to respond to, and influence, their environment. For example, the teachers have views about purposes, teaching and learning. They know about their school’s and government’s reporting and assessing policies and how to meet, at least, their minimum requirements. They know how to deal with new syllabuses. They respond in some way or other to an innovation. Thus, a knowledge system underpins the nature of both the heath and this school science system, yet the knowledge systems are different.
The differences between the heath and this school science system makes the correspondence of the knowledge parallel contentious; specifically the relative roles of genetic, brain and cultural knowledge. Populations in the heath develop primarily through changes in genetic knowledge. In contrast, humans have available an extensive cultural knowledge, which they continuously seek to validate. This enables them to respond very quickly to their environment (Plotkin 1994). In Plotkin’s analysis there are three, nested knowledge systems, genetic, brain and cultural knowledge. Underlying the ecosystem is a genetic knowledge system, which Plotkin refers to as the primary heuristic. Variation in genetic knowledge enables slow sustainable evolution. Variation in brain knowledge and cultural knowledge enable much more rapid adaptation. Brain and cultural knowledge are adaptations. Being the adaptations of humans, brain and cultural knowledge are subject to the same principles of biology as the adaptations of all organisms. Hence, knowledge is subject to selection and de-selection.

The conceptualization of knowledge in this school science education system is consistent with Edelman’s (1992) thesis that the brain is a ‘Darwin machine’, which learns by selecting pathways under the influence of a deep-seated values system; Reber’s contention that ‘psychology cannot be understood without a deep appreciation of evolutionary theory (because) we are a species whose form, structure, and behavioural repertoire are, like all others, the product of a selectionist process’ (Reber 1993: 74); and Plotkin’s thesis that all knowledge is Darwinian.

We are clever animals, and that cleverness needs to be understood, indeed must be understood, indeed only can be understood, using the same analytical tools and principles that we use to understand our size, shape, gait and metabolism, (specifically), accepted evolutionary principles of selection and descent (Plotkin 1994: xv).

Thus brain and cultural knowledge can be regarded not merely as a psychological feature of humans but also an ecological feature of a school science ecosystem. Hence, knowledge may be regarded as a contentious field in this mapping but the process of selection, operating on knowledge, appears to be a correspondence in the mapping.

**Analogy conclusion**

Mapping the heath ecosystem analogy onto the school science system identifies many structural overlaps and some contentious features (e.g. knowledge). The success of this mapping suggests that the science education system is like an ecosystem. The science education ecosystem is a self-sustaining group of organisms interacting with each other and their environment. It undergoes slow change, through a series of shifts in response to alterations in its environment, e.g. changing learning theory, purposes and curriculum. Further, it responds to change by maintaining conditions such that teachers can continue to function normally, just as they have in the past. These features result in slow evolution similar to the gradual change of biological evolution, science, history and technology as, respectively, species, ideas and practices develop.
Extending the analogy

The thesis theoretically argues that this case study can be interpreted as an ecosystem. This theory, like any theory, should be tested. Thus, there are two remaining tasks. The first task is to examine the theory to see if the conditions under which radical change might occur can be predicted. Secondly, meta-analysis of other cases should be conducted to see if its use has explanatory power in other cases. Should these two explorations prove fruitful and insightful, then the notion that school science education can be interpreted as an ecosystem can be more confidently embraced. The first of these tasks will now be reported. The interpretation of other case studies is too large an undertaking in this report (for an ecological analysis of three other case studies see Aubusson 1997).

Ecosystems and radical change

One of the four key features of this school science system (and its analogue the heath) is its homeostasis. The very low level of change, found in this case study, brought the ideas of homeostasis and slow evolution to the fore. Yet, radical change is also a feature of biological evolution and also of science (Kuhn 1962), of history (Atkinson 1978) and technology (Jarvis and Cosgrove 1994). In another ecosystem, or at a different time under different conditions, the homeostasis found in this science education ecosystem might be radically disturbed, and if the analogy is to stand up then it ought to be able to provide an interpretation of radical change.

The primary role played by genetic knowledge in the heath suggests that the heath is incapable of responding to cataclysmic change. Yet, this is not so. Ecosystems have, in their varied gene pools, the capacity to cope with change that surpasses their homeostatic plateaux. An ecosystem can change, and while some populations are lost, other populations evolve as better-adapted variants are selected. Thus, an ecosystem may occasionally undergo radical change, establishing a new homeostasis. One could imagine a science education system being similarly radically transformed. In short, just because this school science education system did not undergo radical change during the time span of this project it does not mean that it cannot or will not, any more than an ecosystem not changing during the period of a field study would demonstrate that it is incapable of radical change.

An ecosystem may undergo radical change as a result of catastrophic events. (Biologically, such catastrophes are only disadvantageous to the ecosystem organisms that are lost. They are advantageous for those that remain and thrive. The extinction of dinosaurs may have been catastrophic for the dinosaurs but a boon to mammals.) Examples of radical change in ecosystems include the origin of bread wheat grasses, the extinction of dinosaurs, land clearing by humans and glacial and interglacial periods. Such change results from:

- the origin of variants within the population (generating new knowledge);
- invasion by exotic species (bringing new knowledge);
- environmental change (selecting knowledge).

Each of these types of events will now be considered in this science education ecosystem.
**Variants**

Consider the origin of variants. Within a population, the arrival of new genetic knowledge can precipitate change, and mechanisms operate to bring this about. This new knowledge may be selected and disseminated throughout the population. Yet, this new knowledge is often lost; that which survives may be fragile until change in the environment provides opportunity for it to flourish. Similarly, in school science, variants as a product of spontaneous knowledge generation *in situ* may not survive; if they do, their existence may be fragile.

Like biological environments, the school science environment selects those variants that are advantageous and de-selects those that are disadvantageous. Yet advantage is determined, as in all ecosystems, by the variants’ capacities to survive and regenerate in the existing environment. Innovative features, such as constructivist teaching, are less likely to survive than existing variants because existing variants have evolved in harmony with the particular system that they shape, and are hence better adapted to survival in that system.

**Invasion**

Consider invasion by new knowledge. In ecosystems, new organisms bring new knowledge. Marsupials, for example, were once widespread throughout South America but as placental mammals invaded almost all the marsupials died out under the onslaught of the ecologically more advantaged placentals, thus radically changing the ecosystem. Similar invasions have occurred more frequently over the last 2000 years as humans have facilitated the rapid transport of species across the Earth, e.g. the introduction of rabbits to Australia.

Humans have highly developed knowledge systems, which are capable of changing ecosystems rapidly. A human may set out to establish a pasture by introducing European agricultural ‘knowledge’ into a different type of environment: introducing English farming practice into ecosystems in Australia has resulted in radical but unpredictable change. The resulting fragile, degraded ecosystems, whose survival and maintenance is fraught with difficulties, are heavily dependent on persistent human intervention to manage and sustain them (Flannery 1994). The pasture is not self-sustaining; large (often extreme) resources are needed to maintain this alien system.

Just as European agricultural knowledge transforms Australian ecosystems, so too in science education a new knowledge system can precipitate radical change. However, in the teacher-driven case study interpreted here, the imported constructivist knowledge did not generate radical change. In ecological terms, there are two ways of looking at this. Either there were insufficient resources to sustain the invasion or the new knowledge system did not manifest itself as teaching variants that were better adapted to the environment than existing variants. For an invasion to succeed the new knowledge system must modify the environment; for the change to be radical this modification must be rapid. In this case, the knowledge system did not modify this environment sufficiently quickly for the innovation to flourish. Alternatively, the resources applied were too small to sustain change. The teachers in this school, for example, had to continue their normal work while attempting large change with far-reaching implications. The lack of
time to deal with innovation is one way in which these teachers were resource poor. If better resourced, innovation may have been more successful.

Environmental change (selecting knowledge)

Consider the influence of environmental change. Environments change. As Australia drifted north over millions of years the continent became drier. Rainforest was gradually replaced by dry adapted species. When fires became common in the Australian landscape over the last 100,000 years, fire adapted ecosystems, such as eucalypt forests, rapidly dominated becoming the new climax community. These eucalypts already existed, in small numbers, within the rainforest and other fire prone ecosystems. In ecosystems, the climax community is dependent upon the available species and the environmental conditions. Sometimes a small change in the environmental conditions can radically alter the climax community. There may be key elements in the school science system that, if altered, make new ways of teaching and learning science more likely to flourish. In this study, elements in the environment that inhibit the constructivist approach have been identified.

In this school science system, different approaches to teaching and learning coexist but the approaches that dominate are those best adapted to the prevailing conditions. Within the school, a constructivist variant survives with Chris and Joan. Traditional approaches to science teaching, dominate as they are favoured by conditions including, assessment policy and the prescribed syllabus. When these conditions change, they may favour another approach, such as constructivism, rather than the existing traditional approaches. While changing the syllabus, for example, may not quickly give rise to new ways of teaching it may promote teaching variants that hitherto survive in isolated pockets.

Coincidence of new knowledge and environmental change

The ecological analogy suggests a prediction: innovation is likely to arise from time to time as new knowledge is generated within the teaching population. If something perturbs the system it may contribute to minor, unpredictable evolution. And, if innovation is to succeed in a biological sense, then it is more likely to succeed if

- invading people bring cultural knowledge to modify the existing knowledge pool; and
- this change to the knowledge pool coincides with, or is followed by, a change in the environment, e.g. a change in assessment. That is, it is given opportunity to extend past fragile stages.

Such coincidence sometimes occurs by chance and, given enough time, radical and unpredictable change might occur by chance in the science education system, as it does in ecosystems.

This ecological interpretation of the place of knowledge in the school science system is consistent with the principal finding (homeostasis yet evolution) as it explains both the slight change, which did occur and why major change did not occur. So with this ecological interpretation, while radical change was predicted, its failure to occur is also rendered understandable.
Ecologically sustainable innovation in school science

The science education ecosystem is conservative but this does not, of itself, recommend conservative action by those who would develop science education. On the contrary, taking no action has consequences, specifically, the continued succession to an unpredictable and possibly undesirable science education system. Rather, this ecosystem theory suggests that importing and implementing externally generated knowledge into science education could lead to radical developments if these external pressures are sustained and sufficiently powerful to change the environment of science education. However, such radical outcomes may have unforeseen consequences and require the imposition of huge resources to sustain the new ecosystem. Hence, it might degrade rather than enrich the system and thus decrease the ecosystem’s capacity to cope with stresses in future. Gunstone (1996) for example has commented that when attempting significant change in school science, things usually get worse before they get better. This short-term degradation, which is characteristic of change projects, is also explained by this ecological model. It further suggests that research projects of short duration (which are common in science education research) are unlikely to probe the genuine consequences of innovation as reports may either reflect short-term Hawthorn effects, periods of degradation or momentary perturbations that are rarely sustained.

The ecosystem model explains and adds strength to Fullan’s (1993) belief that the implementation of planned innovation is an inappropriate way to attempt change, since the consequences of implementation are unpredictable. Change through implementation of externally developed innovation may unintentionally degrade rather than develop the knowledge base of the school science education system, just as the implementation of externally developed curricula has resulted in (unintentionally) deskilling teachers, according to Goodson (1993). Aspects of the system, for example practices and competing views, operate to inhibit change. These aspects are artefacts of the knowledge created by teachers, parents, students, administrators, curriculum designers and politicians (to name but a few of the stakeholders). Hence, the circumstances that prevent innovation are not addressed by seeking better methods to promote faithful implementation (after Fullan and Stiegelbauer 1991). Rather, on the basis of this ecological model of science education and the consequences of intervention in ecosystems, the problem of innovation and its promotion hinges on the production and communication of knowledge, particularly the production of knowledge in situ. The ecosystem view does not imply a likelihood of radical widespread change. Rather it suggests science education might progress through succession resulting in a mosaic of different forms of science education in the different locations to which they are adapted.

If the ecological model is fruitful, then as a consequence of being the subject of externally initiated change the school science ecosystem would be expected to be characterized by resistance, perturbation and stagnation or degradation. By contrast, if ecologically sustainable innovation is to be achieved then some knowledge needs to be generated within the ecosystem both to develop the innovation and to manage change to the ecosystem. Thus, in any science education system radical change could be promoted by accelerating succession if the interconnections among influences and effects can be managed through ongoing adaptation of change. And, to be managed they must be understood, not in advance, but through their investigation during attempted innovation. However, the teachers in this
study found it difficult to achieve this on their own. Trans-disciplinary knowledge (Gibbons et al. 1994) produced *in situ* and communicated among participants and researchers through extended periods of interaction, suggests a way to deal with this difficulty. In this approach teachers as practitioners and researchers collaborate. This collaboration enables the introduction of knowledge to the system through researchers, as well as the sharing of practitioner knowledge. This trans-disciplinary group contributes to knowledge by developing and sustaining innovation in the school context, solving problems that arise, generating and communicating ideas (after Gibbons et al. 1994). Thus, the implication is that if such accelerated succession is to be self-sustaining then, at least initially, it is likely to occur in different places at different times rather than be widespread, because it requires the prolonged persistent interaction of teachers and researchers in many locations. Having survived and evolved both modifying and being modified by the school system in which they are introduced or generated, new ways of teaching, knowledge and ideas have the potential to invade other schools as teachers and researchers move disseminating knowledge and thereby practice.

**Conclusion**

Attempted innovation, such as a leap from transmission to constructivism in a school, places stresses on the system that are so great that it may degrade or be perturbed and then gradually revert to its original state. Radical variations in teaching may not develop directly from a traditional approach. In a recent study, for example, Aubusson et al. (1998) found that teachers attempting to change from a traditional transmission approach to a constructivist approach seemed to progress through three stages, initially a shift to group work, then cooperative learning and only then to constructivism. The recognition of development pathways may facilitate sequential, systematic change.

Teacher knowledge drives change. This knowledge *in situ* can be produced through the interaction of researchers and teachers in school environments. This contributes to knowledge by developing and sustaining innovation in the school context, solving problems that arise, generating and communicating ideas. Once established in one site, innovation may disperse. People possessing knowledge about new ways of teaching and learning move to other schools and teachers move into schools where the new practices have become established. Teachers also need to participate as professionals to communicate their knowledge to others both within and beyond their school, if innovation is to become widespread. New teaching variants are likely initially to become established in individual classes and schools, where they may be nurtured, become robust and radically change many features of the class or school science system. Yet, innovative ideas that remain in individual classes or schools, because of their isolation, risk extinction. Thus, good practice needs to be identified, rewarded, promoted and shared.

When new ideas from outside the school enter school science they rarely flourish. As new ideas about teaching become practice, these practices struggle in a hostile environment. Constructivism seems doomed in an environment of recall tests, behavioural objectives and traditional expectations. A change in teachers views or beliefs about teaching and learning may give rise to new practice in schools but is unlikely to survive unless other inhibiting factors in the school system are identified and removed to produce an environment conducive to desired
practice. Hence, teachers and administrators need to identify factors that inhibit innovation and eliminate these. Some, such as simplistic testing and prescriptive programmes may be considered beneficial yet prove inimical to innovation.

Widespread, radical change may be initiated and sustained with the application of huge resources. Where huge resources are not available, widespread change in school science may still be initiated and sustained through a succession of stages. A process in which a new climax is approached through successive approximations; by generating and communicating knowledge among teachers and by identifying and eliminating environmental factors in the school system that inhibit change. Under these conditions, the knowledge dispersed and produced may cause sufficient perturbation to promote radical change evolving a new climax system, with a new equilibrium, characterized by ‘better’ teaching/learning.

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References

AN ECOLOGY OF SCIENCE EDUCATION


