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Soil Science teaching principles

Damien J. Field [a,*], Anthony J. Koppi [a], Lorna E. Jarrett [a], Lynn K. Abbott [b], Stephen R. Cattle [a], Cameron D. Grant [c], Alex B. McBratney [a], Neal W. Menzies [d], Anthony J. Weatherley [e]

[a] Faculty of Agriculture, Food and Natural Resources, The University of Sydney, New South Wales 2006, Australia
[b] Faculty of Agriculture and Natural Sciences, The University of Western Australia, Western Australia 6009, Australia
[c] School of Agriculture, Food and Wine, The University of Adelaide, South Australia 5005, Australia
[d] School of Land, Crop and Food Sciences, The University of Queensland, Queensland 4072, Australia
[e] Melbourne School of Land and Environment, The University of Melbourne, Victoria 3010, Australia

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ABSTRACT

Soil Science is a unique discipline concerning a complex material that is part of many natural and utilitarian systems. As such, the teaching of Soil Science requires principles that reflect the nature of soil and the practices of soil scientists. Because no discipline-specific teaching principles could be found for Soil Science in the literature, an iterative approach was used to develop them, which involved input from students, academics, employers, graduates in the workplace, as well as published generic teaching principles. The synthesis of these perspectives was achieved via a series of cycles that first involved student feedback on Soil Science teaching from five Australian universities, combined with academic reflections on learning and teaching. The outcome of this activity was subject to perspectives provided by employers of soil scientists and practising soil scientists in the workplace. Quantitative and qualitative analyses of these sources and published generic teaching materials were blended into a set of 11 teaching principles of Soil Science that reflect the unique nature of soil and the outcomes required of graduates who have majored in Soil Science.

1. Introduction

Soil Science is a discipline concerned with a material that has unique features and behaviour (Churchman, 2010) and has been recognised as a natural science in its own right (Ruellan, 1997). Effective teachers of Soil Science must therefore be familiar with the unique qualities of soil as well as the practice of Soil Science through personal experience. Furthermore they must be able to relate these unique qualities and experience to other disciplines and in other contexts. It could be argued that a unique set of teaching principles applies to Soil Science (distinct from those of other disciplines), but even though Soil Science is taught worldwide, specific teaching principles have not yet been articulated and published. Countless books and other publications about soil and its properties and behaviour are used to teach Soil Science but these offer little, if any guidance about the principles on which its teaching should be based. Worldwide there are also undoubtedly many soil science curricula that include prerequisites, content descriptions and learning outcomes but the teaching principles upon which they are based are apparently implicit or assumed. There are many general and discipline-centred education conferences and publications, and many generic teaching principles but we have been unable to find any published teaching principles specific to any particular discipline. This is perhaps surprising because if separate disciplines exist because they are unique, they cannot all be taught in the same way.

Soil Science has a broad holistic role in society, so rather than simply treat it as an isolated discipline soil scientists have to be involved with scientists from other disciplines, with policy experts who make decisions affecting soil and its stakeholders, and also with other users of soil information (Bouma, 1997, 2001; Warkentin, 1994; Wessolek, 2006). Soil is integral to many ecological and social systems and it holds potential solutions for many of the world's economic and scientific problems, including scarcity of food, fuel, and water, as well as climate change (Flannery, 2010; Hartemink and McBratney, 2008). That Soil Science is understood to be so important reflects the maturity of this discipline. In recognising that soil scientists must engage with a variety of people to provide information and solutions to increasingly complex environmental problems, the context of their education must be broad or it will lack relevance. In a recent set of recommendations addressing trends in soil science education in the US the need to develop a relevant and broad curriculum is clearly identified (Havlin et al., 2010). These authors note that this curriculum needs to be: integrated with many of the related sciences;

* Corresponding author. Tel.: +61 2 8627 1138; fax: +61 2 8627 1099.

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prepare graduates for application in environmental, agricultural, land resources and related sciences; and be developed in cooperation with employers and industry partners to ensure practical relevance.

The purpose of identifying and applying a set of teaching principles specific to Soil Science (as opposed to a generic set of teaching principles) is to provide graduates with relevant knowledge, skills and abilities that will help them address complex problems that affect the earth and its biosphere.

This paper describes the process by which a community of university teachers in Soil Science developed a set of teaching principles unique and relevant to the discipline of Soil Science. The project team comprised academics from the universities of Adelaide, Melbourne, Queensland, Sydney and Western Australia and was funded by the Australian Learning and Teaching Council (ALTC). The authors are part of the Australian university teaching community and the principles developed and presented here are intended for consideration by the wider soil science community of practice.

2. Methods

The process used to develop the unique Soil Science teaching principles was cyclical and drew on the approach of Kelly et al. (2006) which improved public utilisation of research outcomes related to the quality of New Zealand soil. Their work recognised the cultural issues involved and the need for an iterative approach to change. Similarly, our project involved a community of Soil Science teachers who went through several cycles in a process informed by internal aspects (e.g. personal experiences in learning and teaching) and external aspects (e.g. feedback from students, employers of soil scientists and other stakeholders, as well as the published literature).

The cyclical nature of the community process to develop the Soil Science teaching principles is given in Fig. 1 and follows recognised procedures. The four elements of each action cycle include *Planning*, *Action*, *Observation* and *Conclusion* (Altrichter et al., 2002; Kemmis and McTaggart, 2000). Reflection on the conclusion of one cycle led to the planning of the subsequent cycle.

The first cycle (Figure 1) was concerned with the perspectives of teaching staff and the feedback provided by current undergraduate students of Soil Science at the five participating universities who responded to an online survey designed by the project team. Students were asked about the quality of teaching, their learning preferences, and their recommendations to improve teaching in the discipline. The 107 responses (approximately evenly distributed between the institutions) were analysed by members of the project team for a forum of teaching staff from each institution (Figure 1, Cycle 2). In preparation for the first Forum, teaching staff completed a *pro forma*

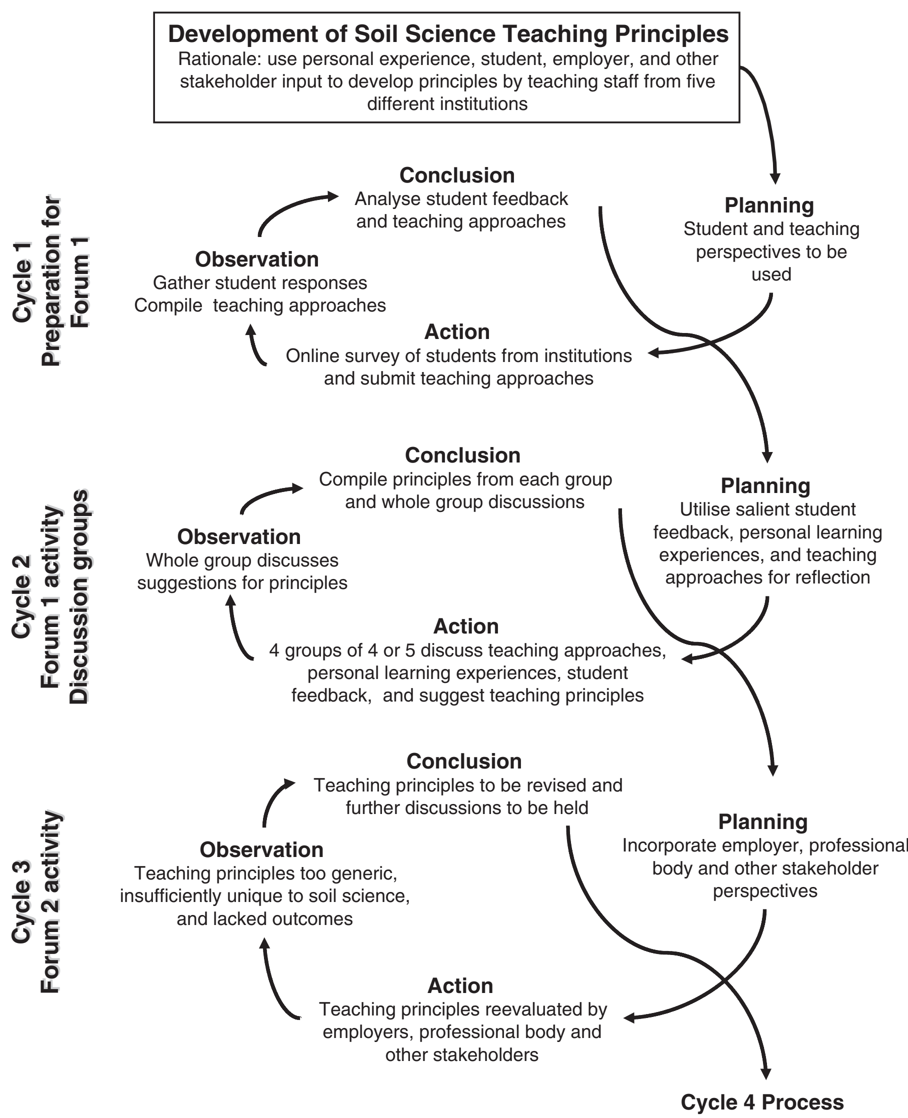

Fig. 1. Cyclical nature of the process used to develop unique Soil Science teaching principles.

concerning their teaching units and practices, which were compiled and summarised for discussion.

The second cycle (Figure 1, Forum 1) was concerned with academic reflections on teaching, individual learning experiences, and feedback from the students in a process mirroring that proposed by Brookfield (1990). Informed by the elements from these diverse sources, the teaching staff worked in small groups to derive a set of teaching principles that would optimise student learning of Soil Science. A plenary discussion followed the small group activities as a first step to formulate a unique set of teaching principles within the academic context. The Forum concluded by recognising that we needed critical external comment on this first iteration of the teaching principles.

The project team subsequently designed two surveys: one for employers of soil scientists and the other for graduates who had majored in Soil Science and nearly all of whom were currently employed as soil scientists. These groups were asked similar questions about university teaching and preparation of graduates for the workplace and to recommend improvements. Fifty-two employers (37% response rate) around Australia responded to a paper-based survey, and 205 graduates (unknown response rate) from six institutions (the University of New England also participated) responded to the online survey. The graduates were contacted by email by their university alumni office and asked to complete the online survey.

In preparation for Cycle 3, the numerous comments and suggestions made in Forum 1 were organised into common themes. Fig. 2 illustrates the process for deriving the first iteration of the teaching principles, which involved qualitative data analysis informed by the work of Boyatzis (1998) and Bogdan and Biklen (2002). The generic teaching principles of Chickering and Gamson (1987) and Boyer (1998) were used to help identify the themes and develop a framework. It was found that all comments and suggestions made at Forum 1 could be grouped into themes similar to principles already published in the education literature. Although the generic principles were useful as a scaffold they did not help to identify the uniqueness of the Soil Science discipline nor the unique teaching approaches required. This preliminary outcome from the second cycle was subject to further refinement during the third and fourth cycles.

Forum 2 comprised the third cycle shown in Fig. 1 which expanded the development of the teaching principles by including external perspectives from employers of soil scientists (7 attended and there were 52 written submissions), Soil Science graduates in the workplace (205 survey responses), board members of Australia's professional accreditation body (Certified Professional Soil Scientist, CPSS), and the project Reference Group (external project advisors). There was some overlap between these affiliations (e.g. employers were also on the Reference Group or CPSS board).

During this third cycle, the principles developed internally by teaching staff (with survey input from current students), and structured with reference to published generic principles were reconsidered with input from the external groups (employers, graduates, professional body members). The principles were found to be too generic and it was thought that their application would not result in outcomes specific to Soil Science. In the fourth cycle the project team redesigned the teaching principles to make them specific to Soil Science. The set of Soil Science teaching principles presented below was therefore derived from broad community consultation and reflects the uniqueness of teaching Soil Science that generic teaching principles could not.

3. Results

The quantitative and qualitative survey data and findings from all the discussion forums are too numerous to present here in detail. However, a pertinent example of results is given in Table 1, which shows a qualitative analysis of the text responses from current Australian undergraduate students on the most effective learning activities. Field and laboratory activities are considered by far to be the most effective learning environments.

The eleven Soil Science teaching principles (Table 2) evolved through four cycles of consultation including that of students, teaching staff, employers and graduates employed as soil scientists, and are also informed by generic teaching principles.

4. Discussion

The eleven teaching principles for soil science are a combination of those that are discipline-specific (1, 2, 3, 6 and 11) and those that are more generic. The application of all the principles in a soil science context is considered to be the most effective strategy for students to learn soil science and become members of the community of practice.

The first teaching principle expresses the emphasis of forum attendees with the uniqueness of Soil Science (Churchman, 2010) and that the teaching of the discipline requires people who are cognisant of this and have the appropriate experience to make the connections between the various sub-disciplines (soil physics, soil chemistry, soil biology and pedology) and relationships to other disciplines. This principle also emphasises the higher-order thinking required, such as making comparisons and synthesis (Bloom, 1956) that the teacher has to help the students attain.

The second teaching principle involves fieldwork in the natural environment, which is valued by soil science staff as well as students (Table 1) as a learning context where abstract theories and concepts from lectures and readings can be made real. Field and laboratory work are particularly beneficial for kinaesthetic learners who have a learning style that involves doing a physical activity rather than passively attending lectures or watching demonstrations. Employers also noted that simple visual and tactile observations in the field could be used to predict soil behaviour and that these direct observations are best made in the field. The macroscopic scale of expression of the soil in the field allows the effects of abstract notions at a microscopic

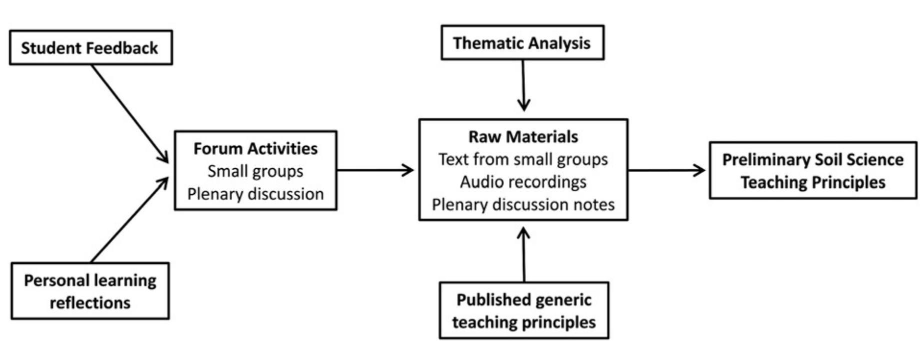

Fig. 2. Process for deriving the first iteration of the Soil Science teaching principles.

Table 1
The seven most effective learning activities based on the analysis of student survey text responses.

Activity	% of responses	Reasons given
Field work	43	Relating learning to real-life problems; learning by doing is more memorable; "non-stop learning"
Laboratories	36	Complement lecture material / relate to theory; first-hand experience; group discussions
Tutorials/ group discussions	11	"Being passive and just listening to lectures is boring. If you discuss and interact with the professor, your mind becomes more receptive and learning this way has a long-term impact."; Time to process new material; promote deep thinking
Lectures	8	"Well-structured and flowing, topics were relevant and discussed as individual blocks rather than rushed through"; Class-involvement in lectures
Presentations	7	Group work
Assessments	7	"Authentic, educative assessment tasks with prompt feedback".
Writing reports	5	Putting ideas into own words enhances understanding; gives students the opportunity to study the literature; drawing conclusions from data requires students to understand the theory

scale such as cation exchange and sodicity to be seen and felt in the greater landscape. While many disciplines can be learned without fieldwork, it would seem that fieldwork in the natural environment is an essential component of soil science teaching without which it would be incomplete.

The third principle is concerned with the use of jargon (the specific specialised technical language of disciplines) in communicating the language of Soil Science. Forum attendees noted that excessive use of Soil Science jargon confused students and encouraged rote learning. For effective dialogue, especially with people new to the discipline of Soil Science, the use of jargon can be exclusive and should be avoided (Burns et al., 2003). Furthermore, students develop improved understanding of new concepts in science when they start by understanding key phenomena in everyday terms (Brown and Ryoo, 2008). Relating to everyday terms and contemporary issues highlights the relevance of Soil Science. Jargon can be introduced gradually as students become more inducted into the community of practice. Employers also noted the importance of jargon-free communication with clients who may not be soil specialists, and that students need to learn to tailor their communication style to suit the context.

There was considerable discussion about making Soil Science relevant and about engaging and using practical scenarios to draw out theory. These considerations led to the fourth principle concerned with active learning, which is essentially the prevailing paradigm in education as advocated by Dewey (1910). It involves students doing, discovering and experiencing things rather than passively being told about them or rote learning (Chickering and Gamson, 1987). Active learning is defined well by Grabinger and Dunlap (1995) and strongly supported by the Boyer Commission on Educating Undergraduates in the Research University (Boyer, 1998). The use of laboratory classes combined with field exercises and problem-based learning in Soil Science are some examples of active learning environments reported in the literature. Student feedback indicates that the level of their engagement and learning increases and in some cases teachers have reported an improvement in assessment results with the implementation of these activities (Amador and Görres, 2004; Grossman et al., 2010; Mikhailova et al., 2009). The students surveyed in this project also favour active learning as shown in Table 1.

Because soil is such a complex material – perhaps the most complex material in the world – the numerous conceptual connections within and between disciplines cannot possibly be made by the students without repetition and practice in different contexts. This realisation led to the fifth principle concerned with allowing students to revisit concepts in different situations to facilitate making the connections between the Soil Science sub-disciplines and with related disciplines. Cognitive load theory supports the notion that to develop expertise, repeated practice is required, especially in the construction of mental schema able to deal with complex problems (van Merriënboer and Sweller, 2005).

Employers of graduates emphasised repeatedly in survey responses and forum discussions that students need to appreciate soil holistically and as part of larger systems. The sixth principle is therefore concerned with helping students appreciate that soil is part of larger systems from local to global scales. These systems include not only scientific knowledge but also social, political and economic aspects (Bouma, 2001; Hartemink and McBratney, 2008; Wessolek, 2006). While undergraduates might not be expected to develop the complex schema required to effectively operate at a systems level, they should be aware that 'big picture' thinking is part of their ongoing development as soil scientists.

The seventh principle includes communication, the lack of which ability in Soil Science graduates concerns employers and is also a common complaint in many other disciplines (e.g. AC Nielsen Research Services, 2000). While writing and presentation skills were noted as being very important by employers and graduates in the surveys carried out for this project, the communication teaching principle suggests that these skills can be embedded in assessment tasks that help students develop conceptual understanding of Soil Science. Because learning involves a process of reinterpreting knowledge, and is essentially transformative (Mezirow, 1997), providing multiple opportunities and formats for students to communicate ideas, information and data can help them refine their understanding of concepts in Soil Science as well as enhance their ability to communicate effectively.

It was particularly noted at the forums that the employers attended that graduates had to be good at solving problems (often in teams) and designing solutions to meet the needs of clients in different contexts. Development of the eighth principle was therefore concerned with providing teams of students the opportunity to engage with authentic, challenging problems in Soil Science. Authentic problem-solving activities require students to define a problem and discover how to find solutions (Biggs, 2003). They involve students in various forms of inquiry in which they must take responsibility for their learning, assess and synthesise information, and to communicate their findings (Justice et al., 2007) to people with limited (if any) knowledge about Soil Science.

It was acknowledged that providing plenty of constructive feedback helps students to learn. The ninth principle emphasises the importance providing students with timely feedback because the learning process can be greatly focused when students appreciate what they know and what they don't know (Chickering and Gamson, 1987).

Forum discussions included the importance of aligning assessment with the desired learning outcomes and with the activities students undertake, hence the tenth principle (Biggs, 1996; Biggs, 2003). In group work, assessment should reflect the performance of individual students as well as that of the group so that shirking is avoided and students are rewarded for contributions (Marin-Garcia and Lloret, 2008). It was recognised that giving credit where it is due in teamwork is problematic and an on-going challenge in all contexts of professional life.

It was noted in forum discussions that students attend university for a relatively short time during their professional lives and that apart from the acquisition of transient knowledge and skills, a graduate requires independent learning abilities to manage on-going personal development. The development of lifelong learning skills can occur through the application of the Soil Science teaching principles, especially by engaging with authentic problems and through autonomous, active learning. The final principle therefore concerns the

Table 2
Teaching principles for soil science.

Principle	Rationale
1. Uniqueness Soil Science is a scientific discipline that should be taught by people experienced in Soil Science who appreciate the uniqueness and functions of horizons (which define profiles), aggregates and colloids and are able to make connections within the discipline and with other disciplines. (See Churchman (2010) for unique aspects of Soil Science.)	This principle recognises both the uniqueness and connectedness of Soil Science and encapsulates the challenge of the teaching and learning methods of the discipline.
2. Fieldwork To demonstrate relevance and real-world connections and engage hands-on learners, use field and practical learning activities wherever possible and appropriate. Field activities are an important component of Soil Science as they help students to comprehend soil as part of the landscape and functioning ecosystem.	This principle is concerned with students making sense of the soil, particularly through fieldwork where the interaction of soil horizons, aggregates and colloids are expressed. Students will appreciate the practical relevance of theory, data, and abstract concepts, and have more time and opportunity to think and interact with staff. Experiencing soil *in situ* demonstrates that they are part of the landscape system, emphasises the links between Soil Science and related disciplines and makes explicit the context within which principles are applied.
3. Jargon With students new to Soil Science, use every-day language, relate to familiar or current issues, and introduce Soil Science jargon gradually	This principle is concerned with keeping students engaged and not alienating or overwhelming them with unfamiliar expressions; and making Soil Science relevant.
4. Active learning Assist students to derive Soil Science theory by using current real problems, scenarios and case studies.	This principle is concerned with giving students responsibility, enabling learning by doing and engaging students in a particular situation and guiding them in deriving the lessons learned from the context, e.g., the students work out why the soil eroded from a particular site through literature searches and practical activities in the field and/or laboratory.
5. Connections To encourage the creation of connections, synthesis and integration, allow students to revisit concepts in different situations.	This principle is concerned with students making connections across the sub-disciplines of Soil Science (soil physics, soil chemistry, soil biology and pedology) and other disciplines by building on familiar concepts in different parts of the course. Applying principles in multiple contexts helps students learn how context shapes the application of theory and gives students more opportunity to process information, resulting in improved learning outcomes.
6. Systems To assist students develop systems thinking and transfer knowledge laterally and vertically and to appreciate that soil is part of larger systems, emphasise the nature and role of soil in various natural, managed, social and economic systems at local, regional, national and global scales.	This principle is concerned with students appreciating that soil is part of a system in different contexts (production, environment) and at different scales and that humans are part of any system.
7. Communication Allow students to interpret and present information and ideas in a variety of formats that resemble real-life scenarios where possible.	This principle is concerned with helping concept development by students processing and reinterpreting information and data and presenting it in their own words; by contextualising knowledge in applying it to realistic situations; and by choosing data and text suitable for the context and intended audience.
8. Authentic problems Allow students to solve contemporary, authentic, challenging problems in groups to enable them to apply their abilities and experience, learn from the multiple perspectives in the cohort, reinforce concepts, and develop personal skills.	This principle is concerned with recognising the breadth of abilities and experiences of the student cohort, and helping them develop concepts, employ different learning styles, learn from each other and develop interpersonal and communication skills.
9. Feedback Provide students with timely, constructive and plentiful feedback to aid their learning.	This principle is concerned with improving the quality of student learning so that they develop better understanding and appreciate the standards expected. Feedback should be specific about the changes students need to make to their work in order to improve.
10. Assessment The assessment regimes are aligned with the desired learning outcomes and group assessments are fair to all group members.	This principle is concerned with assessing the demonstration of the desired learning outcomes, e.g., if a learning outcome is concerned with the development of problem solving abilities, then an appropriate problem-solving task must be part of the assessment. Where group work is assessed, marks should reflect the abilities and efforts of individual members.
11. Outcomes The outcomes resulting from the application of these principles are that graduates are proficient in 5 areas: 1. Identification, understanding and application of the unique features of Soil Science 2. The role, context and relationships of Soil Science to other disciplines and society as part of interrelated systems 3. Identifying problems and designing relevant contextual solutions 4. The ability to coordinate and function within and between relevant groups and effectively communicate results 5. Manage self for personal development and lifelong learning	This principle is concerned with the outcomes of graduates that have majored in Soil Science and are able to effectively relate and apply the discipline to a variety of contexts and design and communicate relevant solutions in language appropriate to the people concerned.

broader outcomes of a graduate who has studied Soil Science, and it reflects the unique nature of Soil Science. It also reflects the attributes that enable students to think about soil as part of complex systems, about problem-solving, about relating to and communicating with different people in different contexts, and about on-going personal development and lifelong learning.

5. Conclusion

A group of Australian universities developed teaching principles for Soil Science by synthesising input from students, academics, employers, graduates in the workplace, and generic teaching principles from the literature. Havlin et al. (2010) in the US also advocated a broad stakeholder input to the development of soil science education, and this sentiment had also been noted in Europe (Bouma, 1997; Ruellan, 1997). The proposed teaching principles transcend political boundaries and it remains to be seen if Australian developments have broader international currency and are also applicable where few major soil science courses still exist, such as in the UK.

It was recognised that Soil Science is a unique discipline, the teaching of which requires a unique approach. Therefore, Soil Science cannot be taught effectively simply by following generic teaching principles because the unique nature of soil requires special approaches and ways of thinking. Teachers of Soil Science thus need to be experienced with Soil Science practices and must appreciate the complexities and relationships inherent within the discipline.

Application of the Soil Science teaching principles will enable students to acquire knowledge, develop skills and become socialised into the discipline. Moreover, the desired outcomes of a graduate who has specialised in Soil Science will include the appreciation of soil as part of complex systems at a range of scales, the ability to communicate contextual solutions to relevant stakeholders, and to engage in continuous learning.

These teaching principles should be adopted and applied by university soil science teachers everywhere. However, the publication of these principles does not imply that the action learning process illustrated in Fig. 1 should cease. On the contrary, as we learn from the utilisation of these teaching principles on an international scale, further cycles of development may need to be initiated among the broader Soil Science community and managed by a representative body, such as the International Union of Soil Sciences. Should issues arise with the application of these principles, the inclusiveness of this proposed cycle would result in a more generally accepted and representative set of teaching principles with a wide currency. Once these principles are adopted by the broader international Soil Science community and ratified by the institutions charged with the teaching of Soil Science, a regular and continued review of the principles in line with the continued evolution of the Soil Science community would be warranted.

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