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ORIGINAL ARTICLE

Developing integrative research for sustainability science through a complexity principles-based approach

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Abstract The importance of taking an integrative approach to research has long been integral to sustainability science, and has recently been highlighted as fundamental to the co-design of research and co-production of knowledge. Just what this means, however, and how to implement such a broad notion has escaped effective methodological development. In order to become more than a generic descriptor, integrative research needs to be conceptualized and presented in ways that offer guidance to researchers designing and conducting integrative research projects, whilst remaining broad enough to be relevant to the breadth and depth of sustainability-related problems. Drawing on complexity theory and fundamental aspects of integrative research, I present a methodological framing that seeks to achieve this balance. Using a definition of integrative research as "research in the context of complexity, with an action imperative", I draw from complexity theory that proposes minimal specifications, generative relationships, focusing on enablers and seeking diversity as core features of a complexity-based approach. On that basis I propose four principles that can be used by researchers to guide the design and implementation of their projects: embrace uncertainty; engage stakeholders; be transdisciplinary; and have a learning orientation. Each of these principles is explained, and their relationships to research design, methodological framing, choice of methods and project development are presented. Two integrative research project frameworks are presented as examples of how this principles-based approach can be implemented in research design. Using this approach offers a simple but powerful structure to guide integrative research for sustainability science at the project scale.

Keywords Integration · Complex systems · Sustainability science methodology · Research design · Transdisciplinarity · Systems thinking

Introduction

Integration forms a major part of the rationale of sustainability science and its distinctiveness from conventional research. This can be understood as a recognition of the limitations of increasingly fragmented science; that science for sustainability-related problems and challenges needs to devise ways of drawing on conventional science, whilst allowing for the complexity of those challenges and, crucially, maintaining a focus on innovation, action and implementation. In this article I present an approach to integrative research that can orientate researchers to the methodological task of designing and implementing research projects that seek to operate within the complexity of our socio-ecological domains, with a specific aim to contribute to action, implementation and practical change. This work arose from exploring integrative research from the perspective of teaching, rather than researching. It was the result of developing and implementing a syllabus for an innovative university course entitled "Integrative Research Methods", a capstone course for final year sustainability students in a research methods stream. While research projects are inevitably (and appropriately) bounded and contextualised by the problems, scales, and issues they are

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addressing, teaching integrative research required the development of a framing that extends beyond an individual project or program, or a cluster of methods. It needed to document and address the fundamental characteristics of integrative research, and identify ways for these to be implemented in sustainability research design and practice. This should be regarded as one step in a larger process of methodological development, that does not restrict the application of other methodologies or methods but rather places them in an integrative framework in which the complexity of the research is accommodated. The framework guides and shapes the integrative, synthetic aspects of the research project, within which more conventional research components may well be placed. It includes a definition of integrative research; an understanding and implementation of principles drawn from complexity studies that can be used by researchers to guide research project development and conduct; and principles that encourage the emergence of new outcomes from the basis of consideration of a small number of key processes.

While there have been attempts to formulate integrative research methodologies (Bammer 2005), these have typically sought to adapt and develop existing methodological approaches, such as transdisciplinary and participatory methods and frameworks (see for example, Wuelser et al. 2011; Jahn et al. 2012; Van De Fliert and Braun 2002). In the context of education, considerable efforts have been made to develop effective conceptual frameworks for guiding and developing research-led education, including identifying a range of key student competencies (Wiek et al. 2011), and developing and operationalising a framework of requirements for higher education for sustainability (Brundiers and Wiek 2011). The work presented here is consistent with much of this analysis, in particular highlighting the importance of involving students directly in research on complex sustainability problems, and fostering their own understandings of the role of research in transformational change through direct experience.

While all of these approaches are useful, I argue that an alternative research pathway may be constructed that is more fully cognisant of the complexity of the problems and challenges we are seeking to address in sustainability science. I draw on the field of complexity science to propose a principles-based framework approach to integrative research that places the researcher *within* the complexity we are engaging with, rather than viewing complexity as a characteristic *of* the issues we are studying. This opens up new ways of drawing together many existing principles and practices of integrative research, offering a wide range of options without being prescriptive, but still giving guidance as to how to design and conduct integrative research. The application of this approach is illustrated with reference to student research projects. This balance between openness, creativity and innovation with practical guidance and design criteria may help to create a productive space for critically and creatively engaging with the complex issues we confront through sustainability science practice.

Background

The idea of integrative research has been a foundational aspect of sustainability science since 1999, when the National Research Council Board on Sustainability wrote:

> "Sustainability science will therefore have to be above all else integrative science—science committed to bridging barriers that separate traditional modes of inquiry. In particular, it will need to integrate across the discipline- based branches of relevant research described above—geophysical, biological, social, and technological. The same can be said for sectoral approaches that continue to treat such interconnected human activities as energy, agriculture, habitation, and transportation separately. In addition, sustainability science will need to integrate across geographic scales to eliminate the sometimes convenient but ultimately artificial distinctions between global and local perspectives. Finally, it will need to integrate across styles of knowledge creation, bridging the gulf that separates the detached practice of scholarship from the engaged practice of engineering and management." (National Research Council 1999, p 283).

This description highlights the multi-faceted nature of integration in sustainability science: across disciplines, sectors, scales and between knowledge and action. There has been a wide range of important approaches developed over the decade since, that present different conceptual frameworks for thinking about research in ways that are more cognisant of complexity (both explicitly and implicitly) and the challenges of integration. Resilience thinking, socio-ecological systems research, adaptive management, adaptive governance, adaptive capacity, integrative modelling and decision support and social learning are among the most prominent, but there are many more (the challenges characterised here are also found in other fields, notably public health, security studies, globalisation, development, and technology studies, but an examination of these is beyond the scope of this paper). These concepts have shaped more holistic and systematic ways of thinking about the relationships between social and ecological systems, and offer a range of conceptual models and frameworks. The importance of integration has been reaffirmed in related fields such as global environmental change. The major initiative Future Earth announced in

2012 emphasises the fundamental importance of integration: "Doing 'Future Earth' research means committing to processes of co-designing research agendas and co-producing knowledge that addresses issues of global sustainability. These processes lie at the heart of the concept of integration." (Anon 2012). Yet this begs the simple but important question of how researchers should set about (co-)designing and conducting integrative research projects and processes.

Despite this enthusiasm for the idea of integration, the development of integrative research practice has been somewhat more difficult. A recent bibliometric study, for example, suggests that relatively few publications in the vast field of sustainability and sustainable development actually demonstrate cross-disciplinary work (Schoolman et al. 2012, see also Evely et al. 2010). Literature regarding the integrative aspects of research has tended to focus on conceptual and practical ambiguity (van Kerkhoff 2005; Tress et al. 2005; National Office of Atmospheric Administration 2004; Stock and Burton 2011), or present insightful but largely isolated examples of integrative projects and approaches (Van De Fliert and Braun 2002; Kueffer 2006; Sherren et al. 2010). Some authors have sought to consolidate this disparate range of experience and learning under the single banner of 'transdisciplinarity' (Lang et al. 2012; Roux et al. 2010; Hadorn et al. 2008; Russell et al. 2008) but this has tended to be too broad and contested a term to gain much methodological traction (Lang et al. 2012). Other approaches that have sought to develop integration from the perspective of research design have tended to look at methods that perform particular integrative tasks rather than the overarching research design. McDonald et al. (2009) for example, document 14 dialogue-based methods for integrative research, such as Delphi technique for integrating expert judgements and Most Significant Change technique for evaluating complex interventions; Liu et al. (2008) describe integrative modelling as a tool for linking science and decision-making. Other researchers have focussed on the institutional aspects of operationalising sustainability science (e.g. Blackstock and Carter 2007) or created frameworks for conceptualising sustainability science and integrative research at multiple scales (e.g. Jerneck et al. 2011; van Kerkhoff and Lebel 2006).

Consequently, researchers seeking to 'do integrative research' as a fundamental aspect of sustainability science confront a bewildering array of case studies, methods, conceptual frameworks, and diverse interpretations. In terms of teaching, there is little clear guidance for research design, methodology and practice at the project scale. This was examined recently where Wiek et al. (2012, p 1) argued that sustainability science "requires a very different type of research and education … that enables students to be visionary, creative, and rigorous in developing solutions and that leaves the protected space of the classroom to confront the dynamics and contradictions of the real world." The challenge of developing a methodology of integrative research is that it needs to be specific enough to offer genuine guidance in research design and implementation, yet broad enough to accommodate the wide range of problems, perspectives and contexts that characterise sustainability.

Implicit in much of this work is recognition of, and efforts to address, the inherent complexity of sustainability-related problems. Yet this issue extends well beyond sustainability-related fields. Despite much rhetoric about complexity in science, there remains surprisingly little active development of complexity as a methodological issue that demands serious reconceptualisation of research design or practice (Shackley et al. 1996, but see also Ison 2010). Even the field of interdisciplinary studies "has not yet adequately studied how systems thinking can facilitate interdisciplinary learning and problem solving." (Mathews and Jones 2008, p. 74). Somewhat ironically, we tend to retain simple, linear research processes for engaging with complex, non-linear subjects: identify a topic and research question, define a methodology and method, collect and analyse data and draw conclusions from that. Even circular models of research, such as those based on a 'learning cycle' can represent fairly minor modifications to the standard linear model, often simply restarting the linear process as the project progresses. Integrative research fundamentally rejects this linear process as a basis for research design and practice; we, as researchers, are embedded within the systems we are examining and seeking to understand and act within, and so must be prepared to react and respond to our emergent findings in non-linear ways. This incorporates a genuine commitment to reflexivity, "the capacity of an individual agent [the researcher] to act against influences of socialization and social structure [including, for example, disciplines], based on critical self assessment." (Spangenberg 2011, p 279). Spangenberg goes on to expand the implications of a reflexive position for sustainability science researchers that resonates strongly with the complexity-based approach presented here: "It questions assumptions such as the objectivity of the observer, the value neutrality of science, the kinds of values inherited and possible alternatives, and the ability to predict future events. It requires the acceptance of uncertainty, ignorance and the impossibility of knowing all relevant facts about evolving systems, and that the existence of emergent system properties makes micro-level explanations of macro-level system behaviour impossible…" (op cit.). The implications of a reflexive and critical approach is emerging as an important theme in sustainability science (Jerneck et al. 2011).

In sum then, here we are seeking to build a methodology for integrative research that takes complexity theory as its starting point. This inevitably draws from and overlaps with established and emerging themes in sustainability science literature, but seeks to reconfigure those in a way that can specifically address project scale research design. It is not, and should not be regarded as, a panacea for solving complex and often intractable problems (Cartledge et al. 2009); nor does it engage in the kind of "methodologizing" referred to by Shackley et al. (1996), who write that "The ever-present danger is that the methodologizing tendency will merely offer the prospect to existing institutional forms of adapting to/coping with complexity, without any serious questioning of their own practices, or of the changing world in which they are operating." (Shackley et al. 1996, p 217). Rather, it offers guidance that draws on complexity theory to create a dynamic and reflexive framework within which research practices *can* be questioned and reconstructed, and the wide range of conceptual and practical ideas relevant to integrative research can be implemented.

Defining integrative research for sustainability

There are many different interpretations and definitions for integration in research (Stock and Burton 2011), many of which are vague and descriptive, rather than specific definitions (van Kerkhoff 2005). For the purposes of advancing integrative research as a methodological concept, a degree of specificity is required—without a functional definition it is impossible to judge whether the research design or outcomes were successful as *integrative* research. The definition that I worked with in developing this integrative research approach attempted to capture those aspects that were absolutely fundamental to sustainability science, and that highlighted what was different about integrative research. For the purposes of this approach, integrative research for sustainability is:

> Research in the context of complexity, with an action imperative

The idea of the *context of complexity* acknowledges that not all sustainability-related research needs to directly be addressing complexity or complex systems as their subject matter (although many may); however, even the simplest research questions and projects take place *within* complex socio-ecological contexts. From this perspective, integrative research rejects the notion that complex problems can be addressed by artificially simplifying the research domain and examining its component parts, and instead retains a focus on "relevant and authentic problems" (Stark and Mandl 2007, p 251). The extent to which this complexity is brought into, or remains contextual to, the research project is a judgement of boundaries that are at once practical (in terms of resources available to conduct the research), strategic (in terms of whose interests can or must be met), and intellectual (in terms of which questions are feasible to address given what we know) (Leach et al. 2010). Regardless, complexity inevitably frames the integrative research design, a key distinction from conventional research approaches that seek to abstract the research from real-world complexity. Importantly, this positions the researcher as a participant *within* that complexity rather than a separate observer of it.

The second part of the definition, *with an action imperative*, emphasises that integrative research needs to be actively concerned with processes of change towards sustainability. This corresponds to Wiek et al.'s (2012) differentiation between "transformational" sustainability research and "descriptive/analytical"—the definition of integrative research here deliberately excludes research that is concerned primarily with the descriptive/analytical task of increasing our *understanding* of sustainability-related issues or problems, but is not seeking to see that understanding implemented. Rather it aims to support the development of research projects that seek to contribute to transformation in identified ecological, social, political, institutional or economic arenas, and hence draw together biophysical and social, economic, political or organisational concerns. This reflects the idea of sustainability science as being committed to action and change noted earlier, and corresponds to the "need for action" starting point identified by Stark and Mandl (2007, p 251) in the context of integrating basic and applied research for education.

Other elements could have been included in the definition of integrative research for sustainability. Other authors emphasise, for example, issues of uncertainty, scale, and dynamics as fundamental to sustainability research (Leach et al. 2010). It could be argued that complexity implies each of these other dimensions, in that complex problems inevitably invoke uncertainty, are dynamic and need to be considered across scales. However, the value of defining integrative research in terms of complexity in general is that it allows for various aspects of complexity to be explored or emphasised depending on the ways in which researchers and collaborators seek to frame their research questions and problems.

Similarly, others may prefer more politically charged terms such as 'empowerment' or 'justice' over the more neutral *action imperative* (see, for example, Agyeman and Evans 2004). Again, however, the aim here was to specify a broad mandate, that could include empowerment but did not exclude the many sustainability-related problems that may not adopt an empowerment mandate or stance. This clearly poses some questions in terms of where integrative research, as conceptualised here, stands in relation to the

fundamental concept of social justice, which will be touched on in relation to the principles presented below.

Incorporating complexity

Complexity is central to sustainability science, and we need to take care to specify the way that we are incorporating complexity in this approach. Complexity has a long and illustrative history in understanding natural and social sciences, and socio-ecological systems were among the first to be described in the language of complexity theory. Our approach here, however, is not concerned with the description of complex systems as subject matter; rather, it is to place research (and researchers) *inside* those complex systems, and draw on relevant complexity theories to actively engage with system dynamics and change (for similar work in the context of interdisciplinary research, see Robinson 2008). We seek to use the ideas of complexity to shape our actions as researchers, not as a theoretical lens through which to gather and interpret data.

There are few research fields that have explored how complexity theory might apply to research practice, beyond rather vague notions of inter- or transdisciplinary faculty arrangements through which new ideas may emerge serendipitously. Other areas interested in applications of integrative research have drawn on complexity as a methodological context. In the context of education research, Stark and Mandl (2007) argue that choice of research methods and tools, for example, need to be guided by a complexity-based "meta-theoretical orientation [that] corresponds more with the complex goal structure of integrative research than more unified theoretical and methodical positions."

Organisational management theory offers useful guidance to developing integrative research frameworks that incorporate complexity theory into their design and practice, in order to place researchers *within* that complexity. Cutting edge organisations and organisational studies have sought to identify how best to structure work practices in order to foster innovative solutions to complex tasks and dynamic contexts; as this is essentially the same goal that we are seeking in integrative research, the ideas promulgated in this context shape the "meta-theoretical orientation" taken here. While there is a wide-ranging literature in this area (for a recent overview, see Allen et al. 2011), this approach draws particularly on the work of Plsek and Wilson (2001) writing from the domain of health. Plsek and Wilson usefully distil from the broad range of organisational complexity concepts and models five key strategies that can be implemented in a research context: minimal specifications; whole system performance; generative relationships; working with attractors for change; and fostering diversity. These do not draw specific reference to other complex systems concepts, such as emergence, self-organisation and self-similarity across scales that are listed in other writings (for example, Merali and Allen 2011) as relevant metaphors for organisational change, but can instead be understood as the strategies that can deliberately foster key change trajectories such as emergence and adaptation. This is in recognition of the limitations of drawing analogies too strongly between complex biophysical systems and complex social systems. Although writing from the domain of health research, the issues and context are broadly congruent with the socio-ecological dynamics we confront in sustainability science.

Minimal specifications

Complexity theorists have observed that innovation arises from actors having a large range of choice in actions, circumscribed by a small number of rules or specifications. This runs counter to most research approaches today, which require as much of a project as possible to be agreed and laid out in detail before the project is started, typically before it is even funded. Logframe-based project design and management with detailed plans, specified goals, subgoals, activities and milestones is the mainstay of research practice, and is a far cry from an approach that offers minimal specifications, and then allows participants to range freely. Minimal specifications does not mean carte blanche however—such specifications need to set boundaries, allow actors to allocate resources, give direction as to the overarching goals in place, and give participants permission to step beyond their usual roles or practices. Some suggestions for relevant minimal specifications will be presented below.

Whole system performance and boundary setting

As a systems-based approach, complexity theory emphasises the importance of considering performance in terms of the whole system, rather than its component parts. A key task is to define the system under investigation, and carefully consider the gains and losses, inclusions and exclusions that are made in this boundary-setting work. Ulrich and Reynolds (2010) extensively discuss the importance of being aware of power relations that are exerted in this decision-making process, and offer a suite of heuristics, or key questions that can guide a critical approach to deciding where the boundaries of our systems lie, and the implications of such choices. Cartledge et al. (2009) caution that although negotiating clear boundary conditions and monitoring them are helpful for integrative research, they cannot guarantee innovation and change due to political and social lock-downs. Other aspects of whole system performance

may be conceptual rather than political, for example an integrative research project to conserve biodiversity that focusses on ecosystem health rather than the protection of a small number of identified species, represents a shift to a more complex, integrative goal.

Generative relationships

Generative relationships emphasise the interactive nature of complexity-based research, where new ideas, processes and practices emerge (are generated from) relationships amongst key actors. This casts the role of the research as creating the spaces in which these generative relationships can take place and flourish, convening key actors and structuring interactions in such a way that participants are able to interact in positive and productive ways. Participatory research approaches have a long history of supporting the development of generative relationships, but are not the only option. More broadly, Allenby and Sarewitz (2011) describe the value of "productive conflict" as crucial to developing an anticipatory, rather than reactive, stance towards knowledge creation. This implies researchers deliberately opening up thinking and planning for research to non-researchers, creating spaces for (bounded) conflict to take place. Many participatory research methods have been developed for this purpose, including the use of models (Jones et al. 2009) and game simulations (Cleland et al. 2012) to foster discussions about the allocation of resources or environmental stresses that may generate new ideas and possibilities that creatively capitalise on this new opportunity. Done well, under favourable circumstances, this allows new relationships and pathways to emerge that could not be predicted from the individuals alone.

Generative relationships can be harnessed early in integrative research design through processes of collaborative problem framing. For example, Lang et al. (2012), Leach et al. (2010), and Bardwell (1991) emphasise the importance of problem framing. Different affected or involved groups will often frame a problem differently, reflecting their interests, context and experience. Working with stakeholders to collaboratively define the boundaries of the system is itself an important starting point for developing generative relationships.

Working with attractors for change rather than battling resistance

In many instances, when confronted with complexity, we spend considerable intellectual and practical resources aiming to understand why things do not work out the way we hoped. Barriers, gaps, roadblocks, shortcomings of all kinds are targeted, and solutions to 'fix' those problems are devised. Almost inevitably, however, when one barrier is removed, another springs up in its place, and one person's 'solution' creates another's 'problem'. Under complexity theory, however, resources are directed towards understanding why people may choose to act differently; what may attract them towards a particular goal or desired change, rather than what is preventing them. This aspect of complexity theory implies the need for integrative research to define goals that focus on the positive aspects of change.

The field of appreciative inquiry offers some guidance to this aspect of integrative research (Reed 2007; Cooperrider and Whitney 2005). As Watkins and Mohr (2001) write: "…Appreciative Inquiry focuses on the generative and life-giving forces in the system, the things we want to increase." (p 14). This harnesses the creative ability of people in their own contexts to find innovative ways of making those changes, once the change becomes attractive and sought after.

Fostering variation and difference

Science, historically, has tended to favour homogeneity over heterogeneity, the single 'silver bullet' solution to a problem rather than many solutions. Complexity theory counteracts this view, regarding variation and difference as positive and desirable. In complex systems, predictability is limited, so there will always be unexpected outcomes from any intervention or change. Having multiple strategies or plans or responses in place allows for more flexibility in the system to react and adapt to emerging or unpredicted outcomes.

As indicated, these features of complexity are apparent across a range of research fields and approaches. The references presented both above and in the next sections should be regarded as indicative, not exhaustive. The point of this approach is to bring them together into a single framework that can be used to determine appropriate strategies and methods for designing and embarking on an integrative research project.

Minimal specifications: a principles-based approach

As noted earlier, the approach presented here seeks to develop a productive space between dominant, detailed plan research designs and open approaches that resist any prescription. In keeping with the implications of complexity in management theory, the first task, then, is to develop the "minimal specifications". The specifications in this approach draw from a range of key literatures. These include participatory research, resilience thinking and adaptive management, transdisciplinarity and social learning, but more broadly reflect common themes that are

widely referred to throughout the range of literatures that engage with the complexity and integrated nature of sustainability-related challenges. They are presented here as four principles of integrative research:

1. Embrace uncertainty
2. Engage stakeholders
3. Be transdisciplinary
4. Have a learning orientation

The purpose of these principles is not to act as a formula to be followed, but rather to pose a series of questions that research designers can ask in developing an integrative research project. These are each discussed below.

How does my project embrace uncertainty?

Uncertainty is an inherent aspect of research into complex systems; these systems are, by definition, dynamic and changing and continually capable of surprise (see, for example, Kasperson 2008; Kasperson and Kasperson 2005). The uncertainty and unpredictability of change in complex environments is not regarded here as something to be reduced or minimised; it is a dimension of research to be prepared for—expect the unexpected. In terms of research design, this means building in regular points of review and reflection, not simply at the end of the study (for 'next time') but at defined points along the way. It also requires active surveillance; structures that can monitor relevant processes on a more continual basis. These can be regarded as "scheduled stops" along the research project, for evaluating progress, direction, change and response in relation to specified indicators; or be a more fluid and continuous approach to monitoring. What these relevant processes will be project-dependent, and themselves subject to review, but are important to negotiate and begin from the start.

How does my project engage stakeholders? Who? Are these processes or strategies sufficient?

Working with stakeholders as active participants in research projects is commonplace (Talwar et al. 2011), and is clearly supported by considerations of complexity. Allenby and Sarewitz (2011) state this clearly: "Pluralism is smarter than expertise" (p 163). Blackstock et al. (2007) propose that stakeholders are typically involved in sustainability science for normative (facilitating social learning, democratising processes), substantive (understanding multiple perspectives) and instrumental (improving buy-in and defusing conflict) reasons. We are not, however, advocating for "participatory" research in the sense that is so often given lip service in projects of all kinds, but for a commitment to building relationships with people beyond the research project team who have a stake in the project and its outcomes. From a complexity perspective, in the absence of certainty and predictability, relationships give an integrative research approach strength and flexibility and create opportunities for generative relationships to form. Given the "action imperative" aspect of our definition of integrative research, it makes sense for the stakeholders to be those who can take action in relation to the research project; although we also need to consider those not empowered to act who are also affected by the processes under consideration. This principle addresses the second aspect of complex systems noted above, that of whole system performance. One of the key drivers for engaging stakeholders is to develop a robust understanding of what the 'whole system' actually is, to collaboratively determine what may constitute 'performance', and to set functional boundaries around the area of study and the research questions and action concerns.

Building relationships and sharing power across stakeholders, however, is often not easy although fundamental to both the functionality of any actions that may emerge from the research as well as opportunities to incorporate issues of social justice. In relation to integrative research design, in simpler cases a small number of key stakeholders may be involved in establishing the initial research questions, and consulted as the study progresses. In more complex cases, resources may need to be shared more fully, with the research becoming a less-prominent (but still important) adjunct to a program of action and social justice. In either case and at any point along the spectrum between them, the research needs to be designed to incorporate qualitative and substantive input from stakeholders as an integral part of the research process.

Is my project transdisciplinary? In what way(s)?

"Transdisciplinarity" covers a wide-ranging academic discourse that cannot be covered here (for a recent overview and perspective see Jahn et al. 2012). Here I draw on Wickson et al. (2006), who highlight three defining characteristics of transdisciplinarity as problem focus, evolving methodology and collaboration. While collaboration overlaps substantially with stakeholder engagement, the problem focus and evolving methodology dimensions relate to other aspects of research practice. Sustainability science starts with a problem focus that eschews disciplinary perspectives. It demands taking an emergent approach to drawing in the research-based inputs and concepts that are needed as a project unfolds and combining them with experiences, insights and knowledge of stakeholders. This requires an academic perspective that transcends disciplinary pre-conceptions, but is capable of understanding and synthesising across a range of disciplinary and non-disciplinary ideas and theories. These kinds of research

processes have been developed under the concept of transdisciplinarity.

A key element of the principle to 'be transdisciplinary' also relates to the important point of maintaining a connection to "scientific practice" within any integrative project, as highlighted by Lang et al. (2012). It can be easy for theoretical development and other important aspects of academic work, such as rigour, transparency, peer review and dissemination to academic audiences to slip from view in projects that are embedded in action-oriented contexts. The transdisciplinarity principle serves as a reminder to ensure that research continues to develop an academic body of work and thought that abstracts from the day-to-day project and contributes to our theoretical and methodological understandings of integrative research and its application to important socio-ecological challenges.

Does my project demonstrate a learning orientation? Are we (researchers) engaging in structured learning processes? How?

The final principle reflects and reinforces the previous three, to reiterate that the objective of integrative research is to engage in ongoing learning and action, rather than to identify a prescriptive solution (tool, method, action) to a complex problem—or at least be alert to any solutions being inevitably partial, provisional, and likely to generate new problems. It draws particularly upon the concept of social learning in the context of sustainability "the collective action and reflection that occurs amongst different individuals and groups as they work to improve the management of human and environment interrelations" (Keen et al. 2005, p 4; see also Loorbach 2010). While learning-based approaches often imply a circular or spiral research design, reminiscent of an adult learning cycle (Kolb 1984) or action research processes (Reason and Bradbury 2008), they may also be embodied as much in the language and conduct of the research (critical, reflexive) as in the structural design, as indicated by the second question. The key here is to address another aspect of complex systems, that of developing generative relationships. Generative relationships that create innovation and new approaches need not take place within the confines of a particular order of events laid out in a research plan, and are as likely to emerge through spontaneous or serendipitous contact as through planned interactions. In other words, the principle of learning orientation falls short of prescribing an action research structure, taking a more flexible stance of learning being a way of thinking about and articulating the role of research.

This opens up the possibilities for engaging with stakeholders and embracing uncertainty, and while circularities in process that enable action research and social learning to take place will be a highly appropriate strategy in many cases, it is not proposed here as the only way in which learning can be framed or manifested in integrative research.

The integrative research framework

Taken together, the integrative research principles, whole system performance and boundary setting, and collaborative problem framing create a framework for complexity-based integrative research, as shown in Fig. 1. These four principles form the mainstay of the 'minimal specifications' indicated by complexity theory. While there are overlaps among them, each has its own distinctive characteristics as well; for example, while engaging stakeholders and having a learning orientation overlap in the sense that part of the point of engaging stakeholders is to facilitate mutual learning, learning is also drawn from the emerging research findings (not implied by stakeholder engagement), and stakeholder engagement is also for the purposes of empowerment, action and implementation (not implied by the learning orientation). Similarly, I do not argue that these principles are new in terms of research practice; indeed, each of the elements in the framework have long and established histories in sustainability research, as briefly indicated here. Taken separately, they incorporate insights from diverse fields, theories and practices. Yet as a set, they allow for any of these to be used, but are not wedded to them. The role of the principles is to allow researchers to develop an integrative research design, or framework, for their project that reflects these ideas in the ways that are best suited to the questions at hand, and can be developed collaboratively and revised flexibly as the project progresses.

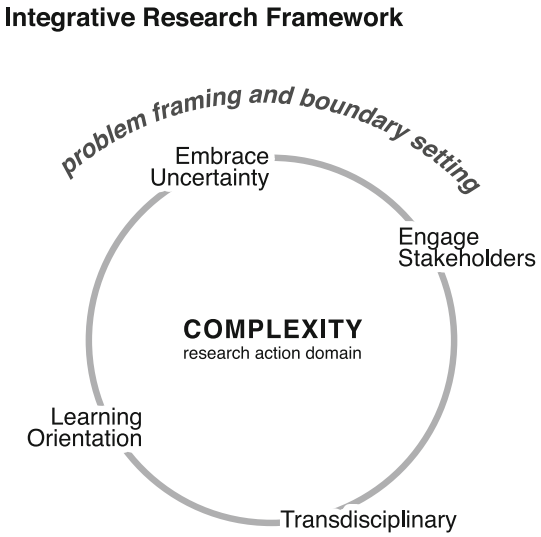

Fig. 1 Structure of the integrative research framework

As a result the researchers and their collaborators can choose how best to incorporate the principles, which concepts, methods, processes and structures will best facilitate their implementation in their research project, and to find the most appropriate balance between them for the action task at hand.

Similarly, the principles allow for a wide range of methods to be employed in the course of a research project. These may be quite conventional (e.g. qualitative interviews, ecological data collection and analysis) or be designed to be 'integrative' (e.g. multi-objective decision support systems). However, the specific research methods need to be complemented by other structures and processes, such as stakeholder committees, working groups, outreach to affected communities and ongoing revision and reflection that do not traditionally fall under the category of 'research methods', but are nonetheless crucial for an integrative approach to successfully meet its principles. Formally incorporating these *into* the research design and framework integrates the research *into* the social and political processes that an integrative study sits within.

Examples

The following examples are drawn from students' work in their final semester projects. The intention here is not to provide a full and complete analysis of these projects, which is beyond the scope of this paper (see Wiek et al. 2012 for a more comprehensive treatment of this issue), but to illustrate the application of the integrative research framework in real-world applications. The students were tasked with identifying an issue and defining research questions, designing a research project using the integrative principles, and working in teams to conduct the research over the course of the semester (for similar approaches see Brundiers and Wiek 2011; Rowe 2007; Stauffacher et al. 2006). I have drawn two examples of the frameworks developed by students to highlight the variety and the strength of applying this approach to integrative research, and have indicated in the cases where the different principles were applied. Students were encouraged to draw their integrative research frameworks in a visual format, an adaptation of which is included in the diagrams.

Urban wetlands study

In this project, a team of four students developed and undertook a project to examine the impacts of a recently completed urban wetland construction project in a local suburb. This was part of an ongoing program of urban wetland construction—the 'action imperative' being the government's existing commitment to continuing to build urban wetlands, with opportunities for the students' research to contribute to that program. They identified and contacted relevant government staff involved in the creation of these wetlands, and through conversation with them developed a provisional research question (*stakeholder engagement*, *embracing uncertainty*) to focus on the social benefits of such projects, given that the ecological benefits were reasonably well-established but the social impacts were not (*learning orientation*). This interaction and openness to collaborative problem-framing with stakeholders led to a research question that was relevant to the future program of work, reflecting the generative dimensions of this approach. The students then sought and gained permission from a local community group involved with the wetland to participate with the community in an upcoming planting day (*stakeholder engagement*), in order to observe the community dynamics, and conduct a small number of semi-structured interviews. In the course of these interviews they invited several participants to a second interview, where participants were asked to take photos in the meantime of the things that were meaningful to them about the wetlands (*being transdisciplinary*). In the interim they discussed their preliminary findings with their government stakeholder, and revised their research question to better reflect the emerging themes and concepts as well as a better understanding of the limitations of the project given time and resources available (*embracing uncertainty, learning orientation*). They conducted the second round of data collection using focus groups to consolidate their understandings from the first round of interviews and again reflected on their research questions. Through this they identified social benefits that were arising from the project, and avenues for further strengthening these benefits in future projects, shared with the community group and with the government project officers (*learning orientation*, *stakeholder engagement*). Throughout the project the students met regularly (at least weekly in class, but also outside class times) to debrief on their work, consider new learning that was arising, revisit their research questions and ongoing plan, and adjust accordingly. Their research framework is illustrated in Fig. 2.

This project demonstrated a number of strengths, particularly a strong commitment to engaging with, and learning from both those in power (government officials) and those affected by the development (the community group). The stakeholder engagement with the government officials facilitated both effective boundary setting through collaboratively framing the research question, generating new opportunities for the students and the government representatives to investigate and learn. Similarly, the community members had the opportunity to contribute their experiences to future planning in a structured way, that may not otherwise have been sought. Although limited in scope, within the resources available they were able to

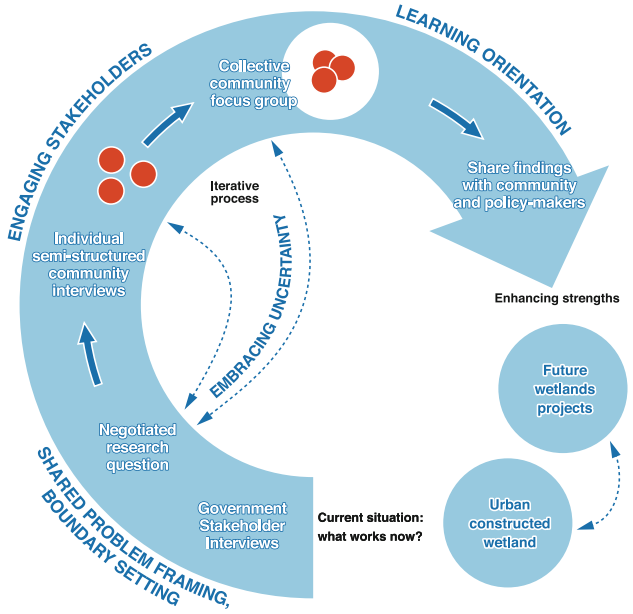

Fig. 2 Urban wetlands student project research framework

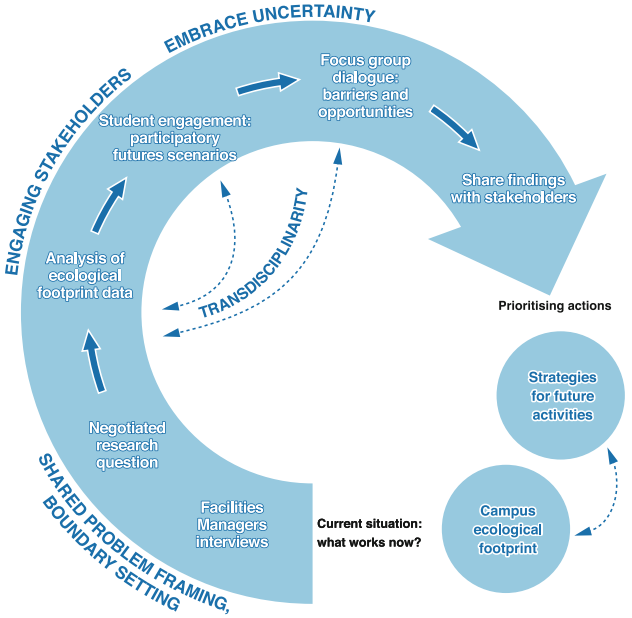

Fig. 3 Ecological footprint student project research framework

develop good relationships and identify relevant issues that were deemed useful by government stakeholders in the development of further wetlands in the area. In this sense the researchers were able to place themselves within the complexity of the socio-ecological system they were examining, and play a key role in articulating an aspect of wetland development that was relevant to, and shared with, decision-makers for future action.

Campus ecological footprint study

In this study the students worked together to identify the 'best bets' for reducing their campus' ecological footprint (Fig. 3). The 'action imperative' was framed by the campus' ongoing commitment to reduce its ecological impact across the university's range of activities and to demonstrate leadership in the pursuit of sustainability. The student work involved collecting and synthesising relevant quantitative data regarding the inputs and outputs of the campus, identified through consultation with the relevant campus management employees (*stakeholder engagement*). This data was then used as a basis for a participatory futures scenarios exercises (*embracing uncertainty*, *transdisciplinarity*) and focus group dialogue with students, to generate ideas for how these environmental impacts might be addressed (*stakeholder engagement*) with a particular focus on the feasibility of addressing different sources of impact. The futures thinking techniques, combined with the ecological footprint results and following dialogue, articulated the possible futures for the campus, drawing on both the quantitative and qualitative data (*embracing uncertainty*, *transdisciplinarity*). Through this process they identified those areas of ecological impact that were most amenable to change, and reported those findings back to the campus managers (*stakeholder engagement*, *learning orientation*). They also used class time to reflect on progress and ongoing learning, to reassess their strategies and revisit their research questions and approaches, although reliance on existing data for the quantitative aspect of the study meant they had less flexibility in this area.

The strengths of this project lay in a useful combination of methods that explicitly addressed some of the key integrative research principles. Ecological footprints represented the quantitative dimensions of environmental impact that were relevant to stakeholders; futures techniques allowed student participants to consider possible actions whilst taking into account uncertainty; and focus group dialogue around those scenarios developed a qualitative basis from which to reinterpret the quantitative ecological footprint, i.e. a transdisciplinary combination of methods. In contrast, the previous study had used conventional methods of interviews and focus groups, crafting their project so that uncertainty was incorporated in the overall research design, rather than through specific techniques.

Discussion

The student projects presented above indicate both the efficacy and the limitations of the integrative research framework. In a positive sense, the principles of the integrative research framework served to orient the students

towards asking questions that went beyond 'regular' research design questions. They prioritised consideration of how the research may actually contribute to change, through engaging with existing commitments and 'change agents'; they developed and applied research techniques and tools that worked effectively with stakeholders who did not have the power to effect change; they reflected upon the ongoing research process and adapted their projects as new insights emerged; and they considered uncertainty in their research contexts and incorporated processes for addressing it. While each of these examples are small-scale and relatively simple (reflecting their origins in undergraduate research projects) they do demonstrate that projects do not need to be complex in their design and scale to be able to adopt an integrative stance that reflects the principles and processes outlined here.

In terms of limitations, they also illustrated the challenges of effective research in complex arenas. Many of these challenges are well known and extensively discussed elsewhere (see, for example, Lang et al. 2012; Talwar et al. 2011; van Kerkhoff and Lebel 2006). This framework certainly does not eliminate the difficulties associated with varying timelines, lack of resources, communication across disciplines or sectors, power disparities, institutional barriers to change or the many other factors that may fall between research and outcomes. These were all experienced to some degree by the students. It is arguable (probably doubtful) whether either of these projects generated results "sufficient for significantly contributing to solving the sustainability problem" (Wiek et al. 2012) as a more rigorous analysis would examine. Yet from the perspective of teaching, the relevant outcomes are also in students' capacities to identify the characteristics their research designs and processes should demonstrate—it is as much about asking questions that can engage with the complexity of socio-ecological dynamics and contribute to broader action processes as it is about 'finding a solution', and experiencing these challenges of effective sustainability science first-hand.

In this sense, the integrative research framework is as much about processes and practices of designing and engaging in research as it is about creating a readily identifiable integrative 'output'. However, it did assist students to develop and apply the underlying thinking of how to approach complex problems in *potentially* transformational ways, making the connections between aspirations towards transformational sustainability science and research design and practice.

Conclusions

Integrative research to date has typically been used as a general description for research that seeks to counter the dominant research approach of fragmentation, between disciplines, between researchers and practitioners, and between research-based knowledge and action. The principles-based approach presented here, coupled with the preliminary tasks of problem framing and boundary setting, offer a foundation from which we can design research that is flexible and dynamic, yet structured in the sense that there are guiding goals and practices to give shape and direction to the research as it unfolds. It also offers a basis from which students and researchers alike can engage with the vast array of literature across this domain. Placing this literature in the context of complexity science draws functional connections across these fields, that researchers can use to consider more fully why these approaches are needed, and how they can be brought together in research design and practice. This article has focused on the application of this approach in an educational context. Future work could explore the usefulness of this approach as an analytical or evaluative framework, or for larger-scale sustainability science project design and development. While it is not proposed as a panacea for the resolution of complex sustainability problems, it allows us as sustainability science researchers to engage with the complexity of the issues we are concerned with, rather than just observing that complexity, and to incorporate the many facets of integration presented in the original proposition of sustainability science. In doing so, the framework approach presented here can draw on and complement other research approaches, conceptual frameworks and methods, yet also gives researchers permission to be creative and active in their pursuit of sustainability science.

References

Agyeman J, Evans B (2004) 'Just sustainability': the emerging discourse of environmental justice in Britain? Geogr J 170:155–164

Allen P, Maguire S, McKelvey B (eds) (2011) The SAGE handbook of complexity and management. Sage, London

Allenby BR, Sarewitz DR (2011) The techno-human condition. MIT Press, Cambridge

Anon (2012) Co-designing knowledge: a common understanding of integrated global change research. Online report http://www.nkgcf.org/files/pdf/4%20pages%20Integration%20WS%20%20%28web%29.pdf. Accessed 10 June 2012

Bammer G (2005) Integration and implementation sciences: building a new specialization. Ecol Soc 20:6

Bardwell LV (1991) Problem-framing: a perspective on environmental problem-solving. Environ Manage 15:603–612

Blackstock KL, Carter CE (2007) Operationalising sustainability science for a sustainability directive? Reflecting on three pilot projects. Geogr J 173(4):343–357

Blackstock KL, Kelly GJ et al (2007) Developing and applying a framework to evaluate participatory research for sustainability. Ecol Econ 60(4):726–742

Brundiers K, Wiek A (2011) Educating students in real-world sustainability research—vision and implementation. Innov Higher Educ 36(2):107–124
Cartledge K, Dürrwächter C, Jimenez VH, Winder NP (2009) Making sure you solve the right problem. Ecol Soc 14:r3
Cleland D, Dray A, Perez P, Cruz-Trinidad A, Geronimo R (2012) Simulating the dynamics of subsistence fishing communities: REEFGAME as a learning and data-gathering computer-assisted role-play game. Simul Gaming 43:102–117
Cooperrider DL, Whitney DK (2005) Appreciative inquiry: a positive revolution in change. Berrett-Koehler, San Francisco
Evely AC, Fazey I, Lambin X, Lambert E, Allen S, Pinard M (2010) Defining and evaluating the impact of cross-disciplinary conservation research. Environ Conserv 37:442–450
Hadorn GH, Hoffmann-Riem H, Biber-Klemm S, Grossenbacher-Mansuy W, Joye D, Pohl C, Wiesmann U, Zemp E (eds) (2008) Handbook of transdisciplinary research. Springer, London
Ison RL (2010) Systems practice: how to act in a climate change world. Springer/Open University, London
Jahn T, Bergmann M, Keil F (2012) Transdisciplinarity: between mainstreaming and marginalization. Ecol Econ 79:1–10
Jerneck A, Olsson L et al (2011) Structuring sustainability science. Sustain Sci 6(1):69–82
Jones NA, Perez P, Measham TG, Kelly GJ, D'Aquino P, Daniell KA, Dray A, Ferrand N (2009) Evaluating participatory modeling: developing a framework for cross-case analysis. Environ Manage 44:1180–1195
Kasperson RE (2008) Coping with deep uncertainty: challenges for environmental assessment and decision-making uncertainty and risk. In: Bammer G, Smithson M (eds) Multidisciplinary perspectives. Earthscan, London, pp 356–367
Kasperson JX, Kasperson RE (2005) The social contours of risk. Earthscan, London
Keen M, Brown VA et al (2005) Social learning in environmental management : towards a sustainable future. Earthscan, London
Kolb DA (1984) Experiential learning: experience as the source of learning and development. Prentice-Hall, Englewood Cliffs
Kueffer C (2006) Integrative ecological research: case-specific validation of ecological knowledge for environmental problem solving. GAIA 15:115–120
Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P, Swilling M, Thomas CJ (2012) Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustain Sci 7(Suppl 1):25–43
Leach M, Scoones I, Stirling A (2010) Dynamic sustainabilities: technology, environment, social justice. Earthscan, London
Liu Y, Gupta H, Springer E, Wagener T (2008) Linking science with environmental decision making: experiences from an integrated modeling approach to supporting sustainable water resources management. Environ Model Softw 23:846–858
Loorbach D (2010) Transition management for sustainable development: a prescriptive, complexity-based governance framework. Governance 23(1):161–183
Mathews LG, Jones A (2008) Using systems thinking to improve interdisciplinary learning outcomes: reflections on a pilot study in land economics. Issues Integr Stud 26:73–104
McDonald D, Bammer G, Deane P (2009) Research integration using dialogue methods. ANU E-press, Canberra
Merali Y, Allen P (2011) Complexity and systems thinking. In: Allen P, Maguire S, McKelvey B (eds) The SAGE handbook of complexity and management. SAGE, London, pp 31–52
National Office of Atmospheric Administration (2004) ICM basics: what does 'integrated' mean? Online source: http://icm.noaa.gov/story/icm_inte.html [Accessed 12 June 2012]
National Research Council (1999) Our common journey: a transition toward sustainability. The National Academies Press, Washington, DC
Plsek PE, Wilson T (2001) Complexity science: complexity, leadership, and management in healthcare organisations. Br Med J 323:746–749
Reason P, Bradbury H (eds) (2008) The SAGE handbook of action research: participative inquiry and practice. SAGE, London
Reed J (2007) Appreciative inquiry: research for change. SAGE, Thousand Oaks
Robinson J (2008) Being undisciplined: transgressions and intersections in academia and beyond. Futures 40:70–86
Roux DJ, Stirzaker RJ, Breen CM, Lefroy EC, Cresswell HP (2010) Framework for participative reflection on the accomplishment of transdisciplinary research programs. Environ Sci Policy 13:733–741
Rowe D (2007) Education for a sustainable future. Science 317: 323–324
Russell AW, Wickson F, Carew AL (2008) Transdisciplinarity: context, contradictions and capacity. Futures 40:460–472
Schoolman ED, Guest JS, Bush KF, Bell AR (2012) How interdisciplinary is sustainability research? Analyzing the structure of an emerging scientific field. Sustain Sci 7:67–80
Shackley S, Wynne B, Waterton C (1996) Imagine complexity: the past, present and future potential of complex thinking. Futures 28:201–225
Sherren K, Fischer J, Clayton H, Schirmer J, Dovers S (2010) Integration by case, place and process: transdisciplinary research for sustainable grazing in the Lachlan River catchment, Australia. Landsc Ecol 25:1219–1230
Spangenberg JH (2011) Sustainability science: a review, an analysis and some empirical lessons. Environ Conserv 38(3):275–287
Stark R, Mandl H (2007) Bridging the gap between basic and applied research by an integrative research approach. Educ Res Eval 13:249–261
Stauffacher M, Walter A, Lang D, Wiek A, Scholz RW (2006) Learning to research environmentalproblems from a functional socio-cultural constructivism perspective: the transdisciplinary case studyapproach. Int J Sustain Higher Education 7:252–275
Stock P, Burton RJF (2011) Defining terms for integrated (multi-inter-trans-disciplinary) sustainability research. Sustainability 3:1090–1113
Talwar S, Wiek A et al (2011) User engagement in sustainability research. Sci Public Policy 38(5):379–390
Tress B, Tress G, Fry G (2005) Researchers' experiences, positive and negative, in integrative landscape projects. Environ Manage 36:792–807
Ulrich W, Reynolds M (2010) Critical systems heuristics. In: Reynolds M, Holwell S (eds) Systems approaches to managing change: a practical guide. Springer, London, pp 243–292
van de Fliert E, Braun AR (2002) Conceptualizing integrative, farmer participatory research for sustainable agriculture: from opportunities to impact. Agric Hum Values 19:25–38
van Kerkhoff L (2005) Integrated research: concepts of connection in environmental science and policy. Environ Sci Policy 8:452–463
van Kerkhoff L, Lebel L (2006) Linking knowledge and action for sustainable development. Annu Rev Environ Resour 31:445–477
Watkins JM, Mohr BJ (2001) Appreciative inquiry: change at the speed of imagination. Jossey-Bass/Pfeiffer, San Francisco
Wickson F, Carew AL, Russell AW (2006) Transdisciplinary research: characteristics, quandaries and quality. Futures 38:1046–1059
Wiek A, Withycombe L, Redman CL (2011) Key competencies in sustainability—a reference framework for academic program development. Sustain Sci 6(2):203–218

Wiek A, Farioli F, Fukushi K, Yarime M (2012a) Sustainability science: bridging the gap between science and society. Sustain Sci 7:1–4

Wiek A, Ness B et al (2012b) From complex systems analysis to transformational change: a comparative appraisal of sustainability science projects. Sustain Sci 7(Suppl. 1):5–24

Wuelser G, Pohl C, Hadorn GH (2011) Structuring complexity for tailoring research contributions to sustainable development: a framework. Sustain Sci 7:81–93