System Dynamics at the Design-Science Interface: Past, Present and Future

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ABSTRACT

In this provocative paper, the authors argue that system dynamics is, and always has been, about design science. Design activities are aimed at changing and improving the world, not just describing and analyzing it, as is the overall goal of science. As such, design science is a research perspective that has been second nature to the engineering and medical disciplines, but that has been problematic for the social sciences, in particular the field of management and organization. This is because a design focus leads one to look for major real-world problems, where real-world relevance is high, but where academic rigor is often difficult to achieve.

System dynamics intends to improve the world based upon rigorous analysis of that world. Its design orientation has led to significant real-world impact and present-day business relevance, but has long hampered its academic respectability. These days, both goals appear to have been achieved. However, the academic success of SD has been largely accomplished by positioning SD as part of mainstream science. In the future, this positioning might lead to a reduced design orientation of academic SD researchers. In turn, this may split the field into two disconnected segments, one for practitioners and the other for academics, and, over time, lead to reduced successfulness in both areas. The authors outline how adopting an explicit design science methodology may reduce the likelihood of this future to enfold.

Industrial dynamics is the investigation of the information-feedback character of industrial systems and the use of models for the design of improved organizational form and guiding policy" (Forrester 1961: 13).

"Design ... is the principal mark that distinguishes the professions from the sciences. Schools of engineering, as well as schools of architecture, business, education, law, and medicine, are all centrally concerned with the process of design" (Simon 1996: 111).

The collaboration, and to some extent merging, of the natural sciences and the design and engineering disciplines in the last 60 years or so, have been the basis for the development of many modern technologies. As such, human beings have been affecting the parameters of the evolutionary process with extraordinary, although often unintended, results.

In the early 1960s, at the interface of science and design, Jay Forrester laid the foundation of what is now known as system dynamics to "provide a basis for the design of more effective industrial and economic systems" (Forrester 1961: 13). Since the pioneering work of Forrester, users of system dynamics and systems thinking have been increasingly adopting – or at least advocating – the metaphor of science to position their work. Herbert Simon (1996) observed a similar process in professional schools, particularly in engineering, business and medicine, where the sciences of the artificial were almost eliminated in the first twenty to thirty years after the second World War. An important factor driving this process was that professional schools in business and other fields hankered after academic respectability, when design approaches were still largely "intuitive, informal and cookbooky" (Simon 1996: 112).

Similarly, the call for more rigorous science in system dynamics (e.g. Andersen et al. 1997; Cavaleri and Sterman 1997; Richardson 1996; Winch 1993) appears to be based on the perceived need to increase the discipline's academic respectability. In recent years, this strategy also appears to have paid off, given the increasing number of publications in respected academic journals other than the System Dynamics Review (e.g. Berends and Romme 2001; Crossland and Smith 2002; Grizzle and Pettijohn 2002; Rudolph and Repenning 2002; Sterman et al. 1997; Sterman and Wittenberg 1999; Williford and Chang 1999). Over time though, this development may also be a risky one, as it may start to reduce SD's natural emphasis on design, on creating a better world, which is one of the cornerstones for its present day success.

This paper therefore intends to contribute to the debate about the position and development of system dynamics by looking at the development in SD in the past and future from the perspective of SD as a design science. The argument is organized as follows. First, science and design are described as two archetypical modes of engaging in research. Then we describe how SD's natural orientation toward design science has contributed to its impact in the world of management and organization but has, at the same time, limited its academic respectability. We also argue how this has been overcome by emphasizing the science aspects of SD in academic publications. Moreover, this tendency to downplay the inherent design nature of the field may in the future lead to a rift between SD academics and practitioners, and hence may limit further progress. Adopting an explicit design science perspective may reduce this risk.

The argument in this paper focuses on the application of SD to the social sciences, and more in particular, management, organization and business studies. The focus on the field of management, organization and business studies arises from the fact that this is our home base. We feel that our argument also applies to other parts of the social sciences, but this is up to others to assess and decide.

Design and Science

In The Sciences of the Artificial, Herbert Simon distinguished between science and design. According to Simon, science is interested in what natural objects are and how they work. Thus, science develops knowledge about the existing world, by discovering and analyzing existing systems and things (Simon 1996). By contrast, design starts with human beings using knowledge to create what should be, things that do not yet exist. Design is the core of all professional activities: the activity of changing existing situations into desired ones (Simon 1996). Historically and traditionally, says Simon (1996), the sciences research and teach about natural things: how they are and how they work. The engineering disciplines have been teaching about artificial things: how to design for a specified purpose and how to create artifacts that have the desired properties (see also: Baldwin and Clark 2000).

The social sciences have traditionally viewed the natural sciences to be their main reference point. However, Simon argues that engineers are not the only professional designers, because "everyone designs who devises courses of action aimed at changing existing situations into preferred ones. The intellectual activity that produces material artifacts is no different fundamentally from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company or a social welfare policy for a state" (Simon 1996: 111).

The notions of science and design in the social sciences has been reviewed and outlined by Romme (2003). Table 1 summarizes these notions that, given the focus of the review, may be less relevant in the context of the natural sciences and technology. We will now discuss several characteristics of science and design that are relevant for our argument.

Science

The (mainstream) social sciences are built on the idea that the methodological language of the natural sciences should and can be the language of the social sciences. As such, this approach assumes that knowledge is representational in kind, that is, our knowledge represents the world as it is. The key research question then is whether knowledge claims are true (representations) or not. These knowledge claims involve phenomena as empirical objects with descriptive properties. Science thus assumes order to be empirically manifested as a set of stable regularities that can be expressed in the form of hypothetical statements. These statements are usually been conceived as revealing the nature of the empirical objects studied, namely as a set of objective mechanisms underlying diverse social realities. In addition, what a system consists of, and the objectives it aims to achieve, are either taken for granted or regarded as being externally imposed.

With regard to the notion of causality, science focuses on general causal relationships among variables. Causal propositions or inferences tend to be rather simple ("if x and y, then z"). However, because variations in effects may be due to other causes than those expressed in a given proposition, causal inferences are usually expressed in probabilistic equations or expressions (e.g. "x is negatively related to y"). This concept of variance causality helps to explain and understand any observed phenomenon, but in itself cannot account for qualitative novelty (Bunge 1979; Ziman 2000).

Drawing on the humanities, postmodern and other critical theorists have been explicitly criticizing the representational nature, and thus findings, of science-based inquiry (e.g. Gergen 1992; Tsoukas 1998). The resulting debate on the nature of knowledge (e.g. Czarniawska 1998; Elsbach et al. 1999; Tsoukas 2000; Weiss 2000) has primarily addressed epistemological issues and has turned attention away from the issue of research objectives, that is, our commitments as researchers (Wicks and Freeman 1998).

Moreover, an increasing number of authors has been arguing that research is better captured and guided by more pluralistic and sensitive methodologies than by exclusive images of how science should be done or is actually practised. In this respect, there appears to be no unique or exclusive methodology for any of the (social) sciences, because there is no way to determine what constitutes 'better' forms of meaning creation, in either epistemological or moral sense (Fabian 2000; Gibbons et al. 1994; Hodgkinson et al. 2001; Nowotny et al. 2001; Ziman 2000; Weick 2001).

Table 1: Science and Design as Ideal-Typical Modes of Engaging in the Social Sciences (adapted from: Romme 2003).

	Science	Design
Contribution & Purpose	To understand social systems, by uncovering the forces and structures that determine their characteristics, functioning and performance	To shape social systems by developing (and drawing on) a vision or model of what those systems could and should be
Role Model	Natural sciences (e.g. physics) and other disciplines which have adopted the science approach (e.g. economics)	Design and engineering (e.g. architecture, aeronautical engineering, computer science)
View of Knowledge	Representational: our knowledge represents the world as it is	Pragmatic: knowledge in the service of design and intervention
Causality Concept	Variance causality: study of cause-effect relationships by analyzing variance among variables across time and/or space.	Design causality: study of how relatively invariant patterns arise, and of ways to change these patterns, to produce knowledge that is actionable as well as open to validation.
Object	Social systems as empirical objects with descriptive properties	Social systems as artificial objects with descriptive as well as imperative properties
Nature of Thinking	Descriptive and analytic (drawing on the concept of variance among variables)	Normative and synthetic; producing knowledge that is actionable as well as open to validation
Focus on	Explaining the actual/historical characteristics and performance of a (population of) agent(s) or social system(s); key question is whether or not a knowledge claim (e.g. "x is neg/pos related to y") is valid for a certain population	Producing (states of) systems that do not yet exist, with help of ideal target solutions bringing novel values and purposes into the design process; key question is whether an integrated set of design propositions (e.g. "in S, to achieve C, do A") 'works' in a certain practical context

Design

In *The Sciences of the Artificial* Herbert Simon argued that science develops knowledge about what already is, whereas design involves human beings using knowledge to create what should be, things that do not yet exist. Design, as the activity of changing existing situations into desired ones, therefore appears to be the core competence of all professional activities (Simon 1996).

Historically and traditionally, says Simon (1996), the sciences research and teach about natural things and the engineering disciplines have been dealing with artificial things: how to design for a specified purpose and how to create artifacts that have the desired properties. The social sciences have traditionally viewed the natural sciences to be their main reference point. However, Simon argues that engineers are not the only professional designers, because "everyone designs who devises courses of action aimed at changing existing situations into preferred ones. The intellectual activity that produces material artifacts is no different fundamentally from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company or a social welfare policy for a state" (Simon 1996: 111).

Design is based on pragmatism as the underlying epistemological notion. That is, design research develops knowledge in the service of action; the nature of design thinking is thus normative and synthetic in nature – directed toward desired situations and systems and toward synthesis in the form of actual actions. Design thus focuses on artificial objects with descriptive as well as imperative properties. The imperative properties also draw on broader purposes and ideal target systems. The pragmatic focus on changing and/or creating artificial objects rather than analysis and diagnosis of existing objects makes design highly different from science. The novelty of the desired (situation of the) system as well as the non-routine nature of actions to be taken imply the object of design inquiry is rather ill-defined.

The key question in design is whether a particular design 'works' in a certain setting. Such a design can be based on implicit ideas (cf. the way we plan most of our daily activities). However, in case of ill-defined (e.g. business) issues with a huge impact, a systematic and disciplined approach is required (Boland 1978). A systematic and disciplined approach involves the development and application of propositions, in the form of a coherent set of related design propositions. Design propositions are depicted, for example, as follows: "In situation S, to achieve consequence C, do A" (Argyris 1993; Argyris et al. 1985).

Design research therefore focuses on design propositions developed through testing in practical contexts as well as grounding in the empirical findings of science (Baldwin and Clark 2000). The causality notion underlying design research is critical in this respect. Argyris (1993: 266) suggests the concept of design causality, involving the production of knowledge that is both actionable and open to validation.

This notion of design causality appears to be less transparent and straightforward than the concept of variance causality underpinning mainstream science. This is due to two characteristics of design causality. First, design causality explains how patterns of variance among variables arise in the first place, and in addition, why changes within the pattern are not likely to lead to any fundamental changes (Argyris 1993). Argyris' models I and II are examples of a model of a certain category of structures in which organizational processes are embedded. They each define a relatively invariant pattern of certain values, action strategies, group dynamics and their outcomes. Second, when awareness of another design program as an ideal target system is created, design causality implies ways to change the causal patterns. That is, ideal target systems such as Model II of Argyris can inspire, motivate and enable agents to develop new organizational processes and systems. Both Argyris (1993) and Endenburg (1998) emphasize that the causality of the old and the new structure will co-exist, long after a new program or structure has been introduced. These two characteristics of design causality tend to complicate and undermine the development and testing of design propositions (and the ideal target systems they are linked to).

The Design-Science Interface

The human race has been profoundly changing the parameters of the evolutionary process, particularly as a result of the collaboration between the natural sciences and the design and engineering disciplines. At the interface between science and design, technologies in agriculture, food processing, civil construction, transport, aerospace, information and (tele)communication have been developed and are continually being renewed (cf. Lyneis et al. 2001). In this respect, effective partnerships between science and design in the technical domain lead to tested technological rules grounded in scientific knowledge – for example, the design rules for aeroplane wings being tested in engineering practice as well as grounded in the laws and empirical findings of aerodynamics and mechanics (Van Aken 2003). Evidently, the collaboration between science and design does not only produce the intended improvements to human civilization, but also has many unintended (e.g. ecological) consequences. In any case, the science-design interface appears to be the breeding ground of the future of humanity.

As described earlier, the social sciences have adopted the natural sciences as their most important role model. In this respect, the natural sciences almost drove design from professional school curricula – particularly in business and management studies – in the first twenty to thirty years after the second World War (Simon 1996). An important factor driving this process was that professional schools in business and related fields hankered after academic respectability, when design approaches were still largely "intuitive, informal and cookbooky" (Simon 1996: 112). In addition, the enormous growth of the higher education industry after the second World War created large populations of scientists and engineers who spread out through the economy and took over jobs formerly held by technicians and others without academic degrees (Gibbons et al. 1994). As a result, the number of sites where competent work in the area of design and engineering was being performed increased enormously, which in turn has undermined the exclusive position of universities as knowledge producers in this area (Gibbons et al. 1994). Another force that contributed to design being (almost) removed from professional school curricula was the development of capital markets offering large, direct rewards to value-creating enterprises, and as such, large incentives for human beings to cooperate for the purpose of creating economic value (Baldwin and Clark 2000). In other words, design in the technical as well as managerial and social domain moved from professional schools to a growing number of sites in the economy where it was viewed as more respectable and could expect larger direct economic rewards.

As a result of these forces, the social sciences have developed a research and teaching culture in which the "tradeoff between relevance en rigor" is an important rhetorical concept (Ackoff 1979). For example, Donald Schön observed that the dilemma between rigor and relevance “arises more acutely in some areas of practice than in others. In the varied topography of professional practice, there is a high, hard ground where practitioners can make use of research-based theory and technique, and there is a swampy lowland where situations are confusing “messes” incapable of technical solution. The difficulty is that the problems of the high ground, however great their technical interest, are often relatively unimportant to clients or to the larger society, while in the swamp are the problems of greatest human concern. Shall the practitioner stay on the high, hard ground where he can practice rigorously, as he understands rigor, but where he is constrained to deal with problems of relatively little social importance? Or shall he descend to the swamp where he can engage the most important and challenging problems if he is willing to forsake technical rigor?” (Schön 1983: 42).

In sum, the gap between relevance and rigor in the social sciences appears to be a rooted in the epistemological differences between the science and design mode (see Table 1) as well as in the design orientation moving away from academia to other (professional) sites in society. As such, the design-science interface is less well developed for the social sciences than for the natural sciences. We will argue that the interface between science and design in the social sciences is the place to be for SD. As a simulation modeling approach that focuses on the dynamic and reciprocal interaction of variables over time, SD appears to have a special capability to bridge the different knowledge and causality concepts of science and design.

SD’s Past: Striving For Rigor and Relevance

System dynamics has, from its very beginning over forty years ago, taken an unambiguous design stance, focusing on problems that really matter in society. Back in 1958, Jay Forrester clearly stated that “my primary concern here is not with techniques and prescriptions. Rather, I am interested in the development of a professional approach to management.” (Forrester 1958: 23). Later, in “Industrial Dynamics”, he wrote that SD “should provide a basis for the design of more effective industrial and economic systems” (Forrester 1961: 13, emphasis added). A basic tenet of this paper is that these design characteristics of SD have, from the beginning, promoted the societal and practical relevance of SD, while at the same time limiting its academic respectability.

Regarding the design orientation, although only a very small number of trained professionals were around in the early years, the early successes of SD in business were impressive. Roberts (1978) gives a good overview of these early contributions to practice, many of which have remained relevant for subsequent research and practice.

Regarding the academic respectability of SD, the fierce debates between Forrester (1968a, 1968b) and leading academics such as Ansoff and Slevin (1968) are legendary. Again, these debates appeared to focus on the differences in perception between a science and a design orientation. The critique from mainstream management science focused on perceptions that SD “is not a well circumscribed body of theory” (Ansoff and Slevin 1968: 383). Moreover, SD was said to rely on verbal statements from managers as the basis for model validation, rather than statistical analysis of real-world data, and hence “predictions about the relations of variables which have not been previously observed” (Ansoff and Slevin 1968: 395) were largely absent. Forrester replied by questioning

Ansoff and Slevin's definition of a theory, by stressing "the impossiblity of positive proof" with regard to the issue of validity (Forrester 1968: 614).

Basically, this controversy has continued for most of the 1970s, when the work in urban dynamics and world dynamics was even more true to SD's original design orientation and its focus on tackling those real-world problems that really matter. In Donald Schön's dichotomy, this led SD only further into the swamp of really important and challenging problems, as far as the proponents of rigorous academic research were concerned.

One longer-term positive result of this antagonistic atmosphere is that it has considerably sharpened methodical self-awareness and literacy in the SD community. This is evident from, for instance, Elements of the System Dynamics Method, a cornerstone for SD methodology from this period (Randers 1980). Interestingly, this is in line with Sterman and Wittenberg's (1999) findings that research paradigms with high intrinsic potential that face intense competition during their early stages of development benefit from this, since it prevents them from growing "too rapidly, overextending themselves before their members develop enough skill, understanding and confidence" (p. 336).

Business relevance for SD has really taken off in the 1980s. Why not sooner? Here a number of explanations come to mind. First, the 1970s were a period in which the SD community focused its attention mainly on non-business problems, but rather on urban and world dynamics and on macroeconomic analysis (Forrester 1969 and 1971; Meadows et al. 1972; Mass 1975).

Second, SD practitioners striving to improve business practice stumbled increasingly over the same implementation roadblocks that so many other modeling practitioners encountered: the problem of expert-modeling (Greenberger et al. 1976). Especially in the SD community, perhaps partly because its inherent drive for design and for improving things in the real world, this resulted in a period of serious rethinking and the result was that modeling should not be done for, but with managers. SD modeling should help management teams learn, Peter Senge stressed in his business bestseller in 1990, and Arie de Geus confirmed this for planning processes in particular (De Geus 1990). A host of SD case studies confirmed this picture (Morecroft and Sterman 1994; Anderson et al. 2000; Akkermans and Vennix 1997). All these publications reflect the increasing popularity of system dynamics with the business community in the first half of the 1990s.

But, more was needed than a different attitude towards the modeling process. For instance, a third explanation of the business success of SD from the latter half of 1985 onwards is the increased availability of top-class SD modelers. Of course, highly skilled practitioners such as the consultants at Pugh-Roberts Associates (Lyneis 1999, Lyneis et al. 2001) or High Performance Systems (Richmond 1997) had been doing great work for quite some time before. But, it is interesting that the breakthrough application of SD in the business world, the work done at Shell (De Geus) in the area of scenario development and strategic thinking, was done by a small number of MIT faculty and Ph.D. students, again under the guidance of Jay Forrester: John Morecroft, Peter Senge and David Kreutzer. It may well have taken over a decade to arrive at a modest-sized population of well-trained and eager SD model-builders (as a result of the usual delays in training people and gaining experience).

Fourthly, there is the marked increased quality of the SD toolkit: Ithink and later Vensim and Powersim were essential from a software perspective. Conceptual modeling tools such as policy functions and Systems archetypes have also been highly instrumental for the growth of SD use. And, the field has benefited greatly from process facilitation insights (e.g. Schein 1997) that emerged from a growing body of knowledge on group model building (e.g., Andersen et al. 1997, Vennix 1996, Akkermans and Vennix 1997).

Finally, it is important to point at the increased dynamic complexity and uncertainty that organizations are encountering and for which the "conventional" analytic frameworks are clearly becoming less and less appropriate (Waldropp 1992, Gleick 1999). In this respect, the rise of SD should be seen as one in a group of new appraoches to organizational issues such as aspects of complexity science (e.g., Stacey 1995; Axelrod 1997; Brown and Eisenhardt 1998) or scenario planning (van der Heijden 1996) and biological approaches to business (Kelly 1994, De Geus 1997).

For SD, progress in academic respectability has been lagging behind considerably with progress in perceived business relevance. In the field of management and organization, Roger Hall and John Morecroft set off this track with several publications in leading journals such as Administrative Science Quarterly, Strategic Management Journal, Decision Sciences and Management Science in the first half of the 1980s (Hall 1976; Hall and Menzies 1983; Hall 1984; Morecroft 1983, 1984 and 1985). John Sterman followed shortly with key publications on his experimental research in 1989 and 1993 (Sterman 1989; Paich and Sterman 1993).

But, really in the second half of the 1990s SD-based research articles in leading journals appear to have taking off. In 1997, Sastry translated for *Administrative Science Quarterly* an organizational theory into SD and Sterman et al. (1997) described unintended side effects of quality programs in *Management Science*. Soon after, other publications followed in, again, *Administrative Science Quarterly* (Rudolph and Repenning 2002), in *Management Science* (Moxnes 1998, Oliva and Repenning 2002) and Strategic Management Journal (Crossland and Smith 2002) and in Organization Science (Stermana and Wittenberg 1999, Repenning 2002). Also, when we look broader than just the specialized field of organization and management, an exponential growth pattern with a cyclical component appears to characterize SD-related research output. One excellent group of time series data, although unfortunately not updated for the last few years, can be found at the SD Society's own website (Systemdynamics.org 2003).

This diversity of SD-driven research efforts can also be observed for several of the more specialized fields in management and organization, such as, for instance, operations management (OM). Here, Production and Operations Management, one of the leading journals in this area, has published several SD research articles in a few years time (Anderson and Morrice 2000; Anderson et al. 2000; Akkermans and Vos 2003).

How did this increase of the number of publications in leading journals, solid albeit lagged indicators for academic respectability, come about? Well, first of all, because these publications contained very good work. They carefully build on existing work in the mainstream literature in these fields, and took into account valid concerns with their methodological approach.

Secondly, these studies focused on topics of considerable relevance, where existing methods clearly were not making any significant progress. The increased inadequacy of existing frameworks to address the complex dynamic problems that organizations are facing today is evidently also perceived by the academic community. In this respect, complexity science became popular first in academia, and only later with managers.

Thirdly, the successes of SD in dealing with these issues in the business world no doubt have helped in gaining academic credibility, although few journal editors would probably admit it. Fourthly, from that same perspective, as more of these publications were and are being published, the body of SD-driven work published in leading journals that every new author can refer continues to rise.

There are also more subtle accumulation processes at work, similar to the changes underlying the business success of SD. In this respect, a fifth reason for the relatively sudden academic success of SD is the growing group of (experienced) SD researchers working at leading universities and business schools, motivated and eager to operate in a publish-or-perish culture – "publish" here means articles in leading mainstream journals. The size and quality of this group is, again, a function of the growing body of SD researchers, a certain percentage of whom is bound to be interested in an academic career.

SD's Present: Mission Accomplished?

These days, it would appear that after a 40+ year history, the field of system dynamics is increasingly succeeding in achieving both academic respectability (or "rigor" in terms of Schön 1983) and real-world impact ("relevance"), at least in the field of organization and management.

In terms of real-world impact, system dynamics is now an accepted problem-solving methodology used by many of the leading multinational firms and is being courted by several of the leading management consultancies (e.g., Doman et al. 1995, Lyneis 1999, Akkermans 2001). It is being taught in rapidly increasing numbers at the graduate and undergraduate level in many universities and business schools throughout the world (see www.systemdynamics.org/ courses_in_sd.htm). Moreover, as we have observed in the previous section, the number of system dynamics articles now regularly published in leading management and organization journals has increased substantially.

What is perhaps even more remarkable, given the problems that other disciplines have in this area, such as OR/MS for instance, is the strength of the consensus that still exists today between the leading SD practitioners in academia and those in business and government. One need only look at the list of future challenges, cited by George Richardson (1996), for the field of SD and observe that he strikes a balance between the required advances in both SD theory and practice. Similarly, John Sterman, whose research group at MIT is responsible for a large part of recent output in mainstream journals, remains as concerned as ever about real-world implementation of system dynamics insights (Sterman 2000 and 2002). In other words, it appears that SD's orientation on both rigor and relevance is, finally, starting to pay off.

SD's Future?

Seasoned system dynamicists understand that a trend may long remain unobserved, only to emerge apparently quite suddenly out of nothing, due to the nonlinear development of trends. So, the fact that we observe some level of (implicit) consensus between practitioners and academics does not mean this is bound to remain so for ever and always. A more explicit system dynamics perspective may be helpful to see under what circumstances a “rift” between academics and practitioners might become more likely. Therefore we have summarized the developments sketched in the previous section in a causal loop diagram, as shown in Figure 1.

A central position in this diagram is taken by the variable DESIGN ORIENTATION OF SD, which is driven by the intrinsic motivation to tackle major real-world issues which has characterized the field from its beginning. This design orientation of SD serves as a key variable linking at least ten positive feedback loops (labelled R1-R11). But, there are also two currently not very visible counteracting loops in this diagram (B1 and B2), which both originate from an understandable desire for academic respectability, with the unintended side effect of undermining the design orientation mentioned before.

R1: *Success to the successful in business.* On, the business side, its design orientation helps to make SD relevant for business, especially as the dynamic complexity of the business environment continues to increase. In addition, there are several positive feedback loops at play here. One is that every successful application makes SD more credible for additional applications.

R2: *Accumulated learning from real-world applications.* Another side effect is that the lessons learned from real-world applications lead to higher quality of the accumulated SD insights, which make SD all the more relevant for organizations.

R3: *Effective cross-fertilisation between academic and practitioners.* Here it is important to point at the excellent communication between practitioners and researchers in SD regarding the state-of-the-art of the field, which results from a strongly shared design orientation. This strengthens the quality of the accumulated SD insights, which lead to more academic respectability (R9) and business relevance.

R4: *Business relevance reinforces the design-orientation.* Indeed, it is safe to say that the opposite is also true: not only does the design orientation of the field lead to business relevance, but its clear relevance for organisations strengthens the belief that this design orientation makes sense.

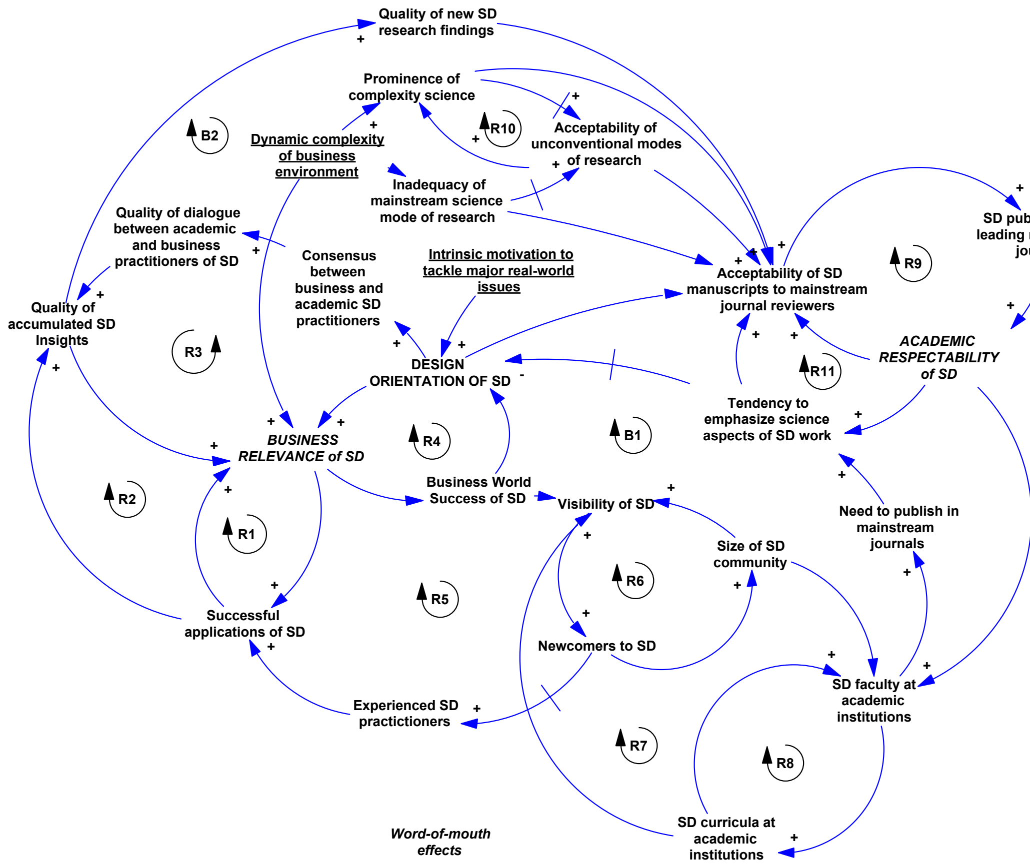

Figure 1: A causal loop diagram of factors affecting business relevance and academic respectability of SD.

R4: *Business relevance reinforces the design-orientation.* Indeed, it is safe to say that the opposite is also true: not only does the design orientation of the field lead to business relevance, but its clear relevance for organisations strengthens the belief that this design orientation makes sense.

R5: *The growth of the SD community.* Such business success does not go unnoted. Quite beside from its considerable intellectual appeal, SD also attracts new talent because of its success in the business world, which leads to more visibility of SD in general. Over time, the growth of the SD community has led and continues to lead to human-resource-related reinforcing loops in multiple areas:

R6: *The growth of experienced practitioners.* For one, the bigger the size of the SD community, the larger the number of experienced practitioners that grows over time. These then will apply SD successfully, leading to only further visibility of SD and hence further growth of the SD community.

R7: *More prominence in curricula.* Another effect of the increased visibility of SD is the growth of SD courses in academic institutions, not just from a perspective of demand for SD courses but also from the supply side: deans who see the business success of SD and consider it wise to set up courses for this new field.

R8: *More SD faculty needed to teach.* As the SD community growths, a certain percentage of students are naturally drawn to a career in academia. This leads to a growth of SD faculty, needed to meet this increased number of SD curricula. Also, this faculty will see opportunities for additional and more specialized SD-inspired courses.

R9: *Success breeds success in academia.* Teaching is one aspect of one's job at an academic institution; research and publishing is another. Once inside the university, SD faculty is subject to the prevailing publish-or-perish culture. Given the strong science orientation of leading journals, they are strongly encouraged to emphasize the science aspects of their research. Fortunately for SD faculty, as more and more SD publications in leading academic journals appear, the acceptability of their work for journal reviewers increases further.

R10: *Rise of complexity science helps SD.* One parallel development which is helping academic respectability of SD is that, in response to the increased dynamic complexity of the business environment mentioned before, is making it increasingly apparent in academia that established theoretical frameworks are inadequate to deal with these new challenges. As a result, we are witnessing the rise of new methodologies such as complexity science, which, as it is strongly driven from science disciplines such as physics, biology and mathematics, helps to make journals more receptive to unconventional modes of research.

R11: *Social conformity tendencies in academia.* Once SD faculty have attained academic respectability, its is only human that they will tend to conform in their research style with their peers from other areas, and hence will continue to emphasise the science aspects of their SD work.

B1: *Unintended side effects: less emphasis on design.* Over time though, this may lead to an unintended side effect. As more and more leaders of the field are known primarily through their detached, descriptive and analytical publications, the perceived design orientation of the field of SD may be reduced in favour of a more science-oriented style of research, such as has happened with the field of OR/MS. This, again over time, will via loops R1-R8 start to limit future growth of the field.

B2: *More science in SD: today's success, tomorrow's roadblock?* Specifically, and again in line with what has happened with fields such as MS/OR, more science and less design orientation may lead to a rift between science-oriented academics and design-oriented practitioners of SD. This in turn will limit the quality of new SD research, and hence limit the further growth in quality of SD research, its acceptability to mainstream journal reviewers, and so forth.

Discussion and Invitation

This paper is written to challenge the SD community to take an explicit position with regard to the methodological issues the social sciences are currently facing. The argument in this paper, and the resulting causal loop diagram in particular, serve as a first step in this respect. Members of the international community of SD scholars are invited to comment on the preliminary diagram in Figure 1 with regard to:

- its overall structure; are different 'archetypical' structures at play with regard to rigor-relevance dynamics in SD than those represented here?
- any missing links within this diagram?

We will gather comments and feedback on the preliminary causal loop diagram during the 2003 conference in New York to build consensus around a second version of the diagram. The latter diagram will then also serve as the basis for a simulation model.

At this stage, without the availability of a simulation model, it is too early to arrive at any specific (policy) conclusions and recommendations. The preliminary version of the causal loop diagram in Figure 1 suggests that SD will benefit from building a design science approach that is grounded in similar methodologies in the social sciences. This involves positioning SD explicitly at the interface of science and design, and thus of academia and practice. A truly integrated methodology at this interface would have to reinforce the (methodological) consensus within the SD community, retain the positive influence of Design Orientation on Business Relevance (R4 in Figure 1), and interrupt – or at least reduce – its negative impact on the causal loops regarding academic respectability (R9 and R11 in Figure 1).

Earlier in this paper, we argued that SD appears to have a special capacity to bridge the different knowledge and causality concepts of science and design – representationalism versus pragmatism and variance versus design causality. In the social sciences, SD has therefore obtained an exceptional position that we should carefully develop and exploit to a larger extent than has been done in the past.

Conclusion

In this intently provocative paper, we invited the SD community to reflect on its past, present and future at the interface between design and science. Design activities are aimed at changing and improving the world, not just describing and analyzing it, as is the overall goal of science. As such, design science is a research perspective that has been second nature to the engineering and medical disciplines, but that has been problematic for the social sciences, including the field of management and organization. This is because a design focus leads one to look for major real-world problems, of which relevance is high but for which rigorous research is often difficult to achieve.

System dynamics intends to improve the world based upon rigorous analysis of that world. Its design orientation had led to significant real-world impact and present-day business relevance, but has long hampered academic respectability. These days, both goals appear to have been achieved. However, the academic success of SD tends to have been accomplished by positioning SD as being part of mainstream science. In the future, this positioning might lead to a reduced design orientation of the academic part of the SD community; in turn, this may split the field into two disconnected segments, one for practitioners and the other for academics, and, over time, lead to reduced success in both areas.

In this paper we have developed a preliminary causal loop diagram describing the dynamics of these dilemmas over time. This diagram suggests that an integrated design science methodology is needed to support both sustained business relevance and further growth of the academic respectability of SD. SD's design orientation stems from its intrinsic desire to tackle problems that really matter.

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