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CROSSING THE BRIDGE OF DREAMS:
System Dynamics at the Design-Science Interface

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ABSTRACT

In this paper the authors argue that system dynamics is, and always has been, a form of design-driven research. 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 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 academic rigor is often difficult to achieve.

System dynamics aims 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, not as a form of design research. 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. Similar developments have taken place in other, originally design-oriented, fields of study. The authors outline how the field of SD would benefit from adopting an explicit design research methodology.

Keywords: methodology, design science, history of SD, SD community, business relevance.

CROSSING THE BRIDGE OF DREAMS: System Dynamics at the Design-Science Interface

As in a spring night
ended my dream
of a floating bridge
in the sky a bank of clouds
split off from the mountain peak
Fujiwara Teika, (1162-1241)

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 (SD) to "provide a basis for the design of more effective industrial and economic systems" (Forrester 1961: 13). In the decades after the pioneering work of Forrester, academic users of system dynamics and systems thinking have been increasingly adopting – or at least advocating – the metaphor of science to position their work. A similar process has been observed by Herbert Simon (1996) in professional schools, particularly in engineering, business and medicine, where "the sciences of the artificial", as Simon calls them, 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 and informal.

Similarly, the call for more rigorous science in SD (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 appears to have paid off, given the increasing number of publications in respected academic journals other than the *System Dynamics Review* (e.g. Akkermans and Vos 2003, 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, ultimately, creating a better world. The latter emphasis can be seen as one of the cornerstones of SD's present day success.

This paper intends to contribute to the debate about the position and development of system dynamics by looking at the development of SD in the past and future from the perspective of SD as a form of design research. Our argument is organized as follows. First, science and design are described as two archetypical modes of engaging in research. Subsequently, we picture how SD's natural orientation toward design has contributed to its impact in the world of management and organization while, at the same time, limiting 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. Developing an understanding of SD as a research approach at the interface of science and design may reduce this risk.

By focusing on the differences and interface between design and science, we will avoid dichotomies such as fundamental versus applied research, science versus art, and 'hard' versus 'soft' research (e.g. Andersen et al. 1997, Coyle 1996, Richardson 1996, Winch 1993). These dichotomies may be useful for understanding the state of the art of the social sciences. From an epistemological point of view, however, SD is best captured in terms of (the interface between) design and science. In this respect, SD originates from Jay Forrester's background in engineering where interfaces between design and engineering and the (natural) sciences are much more important than in the social sciences.

The argument focuses on SD in the social sciences, and more in particular, management and business research. The focus on the latter disciplines 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. By contrast, design starts with human beings using knowledge to create what should be, things that do not yet exist. Design lies at 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 phenomena: what 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 emphasizes 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 have been reviewed and outlined by Romme (2003). Table 1 summarizes the main differences between these modes of engaging in research. We will now turn to those characteristics of science and design that are directly relevant for our argument.

The Science Mode

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 conceived as revealing the nature of the empirical objects studied, namely as a set of objective mechanisms underlying diverse social realities. However, what a system consists of, and the objectives it aims to achieve, is either taken for granted or regarded as 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 therefore the findings, of science-based inquiry (e.g. Gergen 1992, Tsoukas 1998). Unfortunately, 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, several authors have been arguing that research is better captured and guided by more pluralistic and context-sensitive methodologies than by exclusive images of how science should be done or is actually practiced. This is so because there appears to be no unique or exclusive methodology for any of the (social) sciences, as there is no way to determine what constitutes 'better' forms of meaning creation, either in an epistemological or a moral sense (Fabian 2000; Gibbons et al. 1994; Hodgkinson et al. 2001; Nowotny et al. 2001; Ziman 2000; Weick 2001).

The Design Mode

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 a core competence of all professional activities (Simon 1996). It draws 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 that 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 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 C, do A" (Argyris 1993, Argyris et al. 1985).

Design research therefore focuses on the development of design propositions developed through testing in practical contexts as well as through grounding in the empirical findings of science research (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.

INSERT TABLE 1 AROUND HERE

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 long after a new program or structure has been introduced the causality of the old and the new structure will tend to co-exist. These two characteristics of design causality tend to complicate and undermine the development and empirical testing of design propositions (and the ideal target systems they are linked to).

The Design-Science Interface

One result of the collaboration between the natural sciences and the design and engineering disciplines has been that the human race has profoundly changed the parameters of the evolutionary process. 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 being grounded in the laws and empirical findings of aerodynamics and mechanics (Van Aken 2004). Evidently, the collaboration between science and design does not only produce intended artefacts, but also has many unintended (e.g. ecological) consequences. In any case, the science-design interface appears may well turn out 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 have almost driven 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 in this process has been that professional schools in business and related fields hankered after academic respectability, at a time 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 highly skilled work in the area of design and engineering was being performed increased enormously, which in turn 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 all these forces, the social sciences have developed a research and teaching culture in which the "tradeoff between relevance and rigor" is an important rhetorical concept (Ackoff 1979). For example, Donald Schön (1983) 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 rooted in the epistemological differences between the science and design mode as well as in design work 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 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 unique 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, been taking an unambiguous design perspective. 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). A basic tenet of this paper is that it is these design characteristics that have, from the beginning, promoted the societal and practical relevance of SD, while at the same time limiting growth of its academic respectability.

Regarding SD's 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) in the first decade of SD's existence as a field 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. Also, that SD failed to make "predictions about the relations of variables which have not been previously observed" (Ansoff and Slevin 1968: 395). In short, Ansoff and Slevin criticized SD for being more a design approach than a scientific approach. Forrester replied by questioning Ansoff and Slevin's definition of a theory and by stressing "the impossibility 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 remained very much true to SD's original design orientation and even more true perhaps to its focus on tackling those real-world problems that really matter. In Donald Schön's dichotomy, this choice of topics 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 from the early days of SD is that it has developed the methodical self-awareness and literacy of the SD community. This is evident from, for instance*, Elements of the System Dynamics Method*, a cornerstone of SD methodology dating from this period (Randers 1980). Interestingly, this appears to be 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 in the long run, since it prevents them from growing "too rapidly, overextending themselves before their members develop enough skill, understanding and confidence" (p. 336).

SD's Success in Achieving Business Relevance

Business relevance for SD has really taken off from the late 1980s onwards. Why not sooner? First, the 1970s was a period in which the SD community focused its attention mainly on non-business problems, for example urban and world dynamics and macroeconomic analysis (e.g. Forrester 1969 and 1971; Meadows et al. 1972; Mass 1975

Second, early SD practitioners striving to improve real-world business practice initially stumbled over the same implementation roadblocks that so many other modeling practitioners have encountered: the problem of getting results from an expert-mode of modeling accepted by the stakeholders affected (Greenberger et al. 1976). In many areas (e.g., Ackoff 1979), but especially in the SD community, this failure to get real-world acceptance of design research findings has resulted in a period of serious rethinking. The consensus that has emerged is 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 within Shell (De Geus 1990). A host of SD case studies has since confirmed this fundamental insight into the modeling process (Morecroft and Sterman 1994; Anderson et al. 2000; Akkermans and Vennix 1997). At the same time, all these publications, many of them based on successful case studies of SD in action, reflect the increasing popularity of system dynamics with the business community in the first half of the 1990s.

A third explanation of the business success of SD from the latter half of 1985 onwards appears to be 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 of the 1980s, which is the work done at Shell (De Geus 1990) 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. This group includes people like John Morecroft, Peter Senge and David Kreutzer. So, it may well have taken the SD community over a decade to arrive at a modest-sized population of well-trained and design-driven SD model-builders (as a result of the usual delays in training people and gaining experience).

Fourth, there is the marked increase in quality of SD toolkits. Essential elements of such a toolkit are remarkably user-friendly simulation packages such as Ithink and later Vensim and Powersim. But major tools also involve conceptual modeling tools such as causal loop diagrams, behavior over time graphs and archetypes (Senge 1990, Richmond 1997), as well as process facilitation insights (e.g., Andersen et al. 1997, Vennix 1996, Akkermans and Vennix 1997).

As a final explanation for SD's relatively late but remarkable rise in popularity in the world of businesss one may point at the increased dynamic complexity and uncertainty that organizations are encountering. In this respect, the conventional analytic frameworks are becoming less and less appropriate (Waldropp 1992, Gleick 1999). In this respect, SD can be seen as one member of a group of new approaches to organizational issues such as complexity science (e.g., Stacey 1995, Axelrod 1997, Brown and Eisenhardt 1998), scenario planning (van der Heijden 1996) and biological approaches to business (Kelly 1994, De Geus 1997).

SD's Late Recognition by the Academic Community

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 in the first half of the

1980s with publications in leading journals such as *Administrative Science Quarterly*, *Strategic Management Journal*, *Decision Sciences* and *Management Science* (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).

However, it took until the second half of the 1990s before SD-based research output in leading journals has really taking off. In 1997 Sastry translated an organizational theory into SD for *Administrative Science Quarterly* and Sterman et al. (1997) described unintended side effects of quality programs in *Management Science*. Soon after, publications followed in, for example*, Administrative Science Quarterly* (Rudolph and Repenning 2002), *Management Science* again (Repenning 2002) and *Strategic Management Journal* (Crossland and Smith 2002). Several graphs depicting the development of the number of SD publications over time are available at the System Dynamics Society website (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 one should empasize that these publications contain very good work. They carefully build on existing work in the mainstream literature in these fields, and take into account valid concerns in their methodological approach.

Secondly, in the true spirit of SD, these studies focus on topics of considerable relevance, where existing methods clearly are not making 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 at large.

Thirdly, the successes of SD in dealing with these issues in the business world most probably have helped in gaining academic credibility. Fourthly, from that same perspective, as more of these publications are being published, the body of SD-driven work published in leading journals that every additional publication can refer to continues to rise.

There are also more subtle and indirect accumulation processes at work, similar to the changes underlying the business success of SD addressed earlier on. For instance, 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 history of more than forty years, the field of system dynamics has succeeded in achieving a certain level of academic respectability as well as real-world impact in the field of business and management.

In terms of real-world impact, system dynamics has become an accepted problem-solving methodology used by many of the leading multinational firms and is being courted by several leading management consultancy firms (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, number of system dynamics articles 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, is the relative consensus that apparently still exists today between leading SD scholars in academia and those in business and government. For example, the future challenges for SD listed by Richardson (1996) underscore a balance between the required advances in both SD theory and practice. Similarly, Sterman – whose research group at MIT is directly responsible for a considerable 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 still strong.

SD's Future?

Seasoned system dynamicists understand that an exponential growth trend may long remain unobserved, only to emerge apparently quite suddenly, due to the nonlinear development of such behavioral patterns. So, the fact that a considerable consensus between practitioners and academics in SD may exist today does not mean this is bound to remain so. A more explicit system dynamics perspective is required to see under what circumstances a "rift" between academics and practitioners might develop.

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 an intrinsic motivation to tackle major real-world issues which has characterized the field of SD from its beginning. This design orientation of SD serves as a key variable linking eleven 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 SD lead to business relevance, but its clear relevance strengthens the belief that this design orientation makes sense.

R5: *The growth of the SD community.* Such business success does not go unnoticed. SD 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 (subsequently addressed).

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.

INSERT FIGURE 1 AROUND HERE

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 to their peers from other areas, and hence will continue to emphasize 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 operations research and management science. 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

SD is a powerful research method that enables researchers and practitioners to look at an artificial world move forward into the future. It provides a laboratory, safe from the risks of the real system, for testing out hypotheses and interventions and making predictions. Earlier in this paper, we argued that SD appears to have the rather unique capacity to bridge the different knowledge and causality concepts of science and design – representationalism versus pragmatism and variance versus design causality. SD can therefore obtain an exceptional position in the social sciences, by carefully developing and exploiting this bridging role.

The causal loop diagram in Figure 1 suggests that SD will benefit from building an epistemological position at the interface between design and science. 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). This implies that the SD community needs to spend more time and resources in developing an integrated epistemology of SD. In simple terms, the

SD community should stick to doing what it has been doing very well in the past: strive for methodical rigor and real-world relevance at the same time. This means, to continue to be driven by an intrinsic desire to improve things that really matter, while at the same time upholding the highest technical standards in conducting research and communicating about it. It implies the SD community should not become shy in letting both sides of our existence shine through in its communications to any audience. In this way, SD will truly be crossing a bridge of dreams…

Conclusion

This provocative paper invites the SD community to reflect on its past, present and future at the interface between design and science. Design activities focus on changing and improving the world, not just describing and analyzing it, as is the overall goal of science. As such, design research 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.

SD's 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 part of mainstream science. This positioning may 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 causal loop diagram describing the dynamics of these dilemmas over time. This diagram suggests that an integrated epistemology at the interface of design and science is needed to support both sustained business relevance and further growth of the academic respectability of SD.

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TABLES AND ILLUSTRATIONS

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

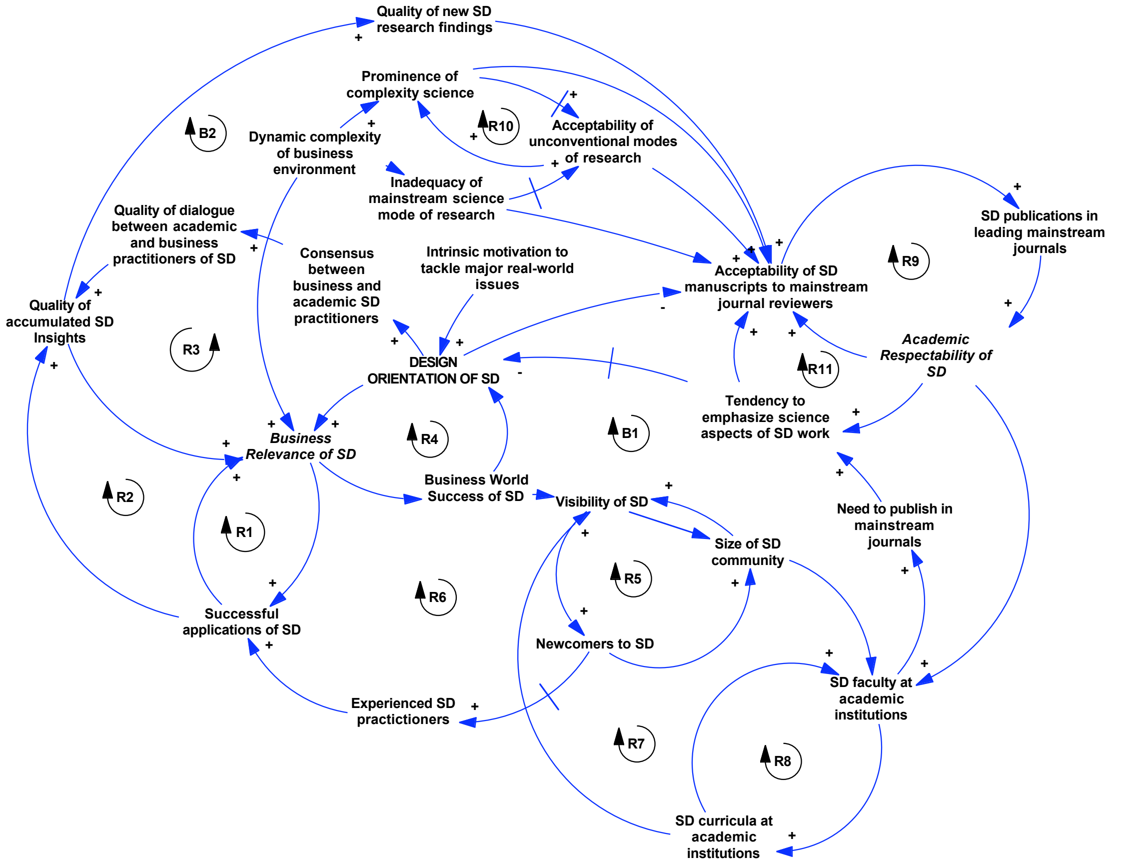

Figure 1: A causal loop diagram of factors affecting business relevance and academic respectability of SD.