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Xinya You & David Hands

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A Reflection upon Herbert Simon's Vision of Design in *The Sciences of the Artificial*

Xinya You^a, David Hands^a

^aLancaster University

*Corresponding author e-mail: youxy429@hotmail.com

Abstract: This is a literature review reflecting upon Herbert Simon's vision of establishing a science of design in his book, *The Sciences of the Artificial*. The aim of this paper is to clarify the evolution of Simon's views of design in the three editions of this book and identify the value of the refinements he made in the later editions to design research. In addition to the three editions of Simon's book, the selected literature includes the major design publications explicitly criticised or supported Simon's views of design, as well as several relevant studies in the management field. It enables this paper to present a historical overview of design researchers' explorations of Simon's vision of design. Through this research, this paper demonstrates that revisiting and reimagining Simon's vision of design in his book (the third edition) may constitute a big step towards the further development of design theory and design thinking.

Keywords: Science of design, Herbert Simon, design theory, epistemology, design thinking

1. Introduction

Herbert Simon's seminal book *The Sciences of the Artificial*, which was first published in 1969 (Simon, 1969), is one of the most influential texts in the 50-year history of the development of design theory. Simon's vision of establishing a science of design made this book a reference point for subsequent academic writing about design and encouraged the emergence and development of design thinking. Simon has widened the scope of his discussions about design in the later two editions (1981, 1996) of his book. However, these significant refinements have not caught much attention from design researchers. As a result, in design literature, there exists a problem of serious ambiguity about Simon and his book. The aim of the present paper is to clarify the evolution of Simon's views of design in the three editions of *The Sciences of the Artificial* and identify the value of the refinements in the later editions to design research. The methodological approach taken in this study is literature review: rereading the three editions of *The Sciences of the Artificial* and then reviewing the design community's exploration of Simon's vision of design. Some of the relevant management literature have also been selected to support the argumentation. This paper is structured as follows. First, it introduces the historical context of the publication of *The Sciences of the Artificial* and reviews the

evolution of Simon's claims about design over the three editions of this book. Subsequently, it describes design researchers' explorations of Simon's vision of establishing a science of design, as well as their prominent criticisms of his epistemological views. Next, it shows some convincing academic voices that oppose these criticisms, and based on them, reassesses the other criticisms among design researchers about Simon and his book. Finally, an effort is made to identify the value of Simon's book in the future development of design theory and design thinking.

2. Simon's Vision of Establishing a Science of Design in *The Sciences of the Artificial*

During the 1950s and '60s, there was a flourishing of literature that showed a widespread interest in making design rigorous and systematic (Boulding, 1956) and an ambition to make it a science (Churchman, 1961). Some of the origins of this trend lay in technical developments such as computers, systems, and automatic controls that were new at that time (Jones, 1963). Those who had a strong aspiration to "scientise" design believed that Operational Research (OR) and Organisation and Methods (O&M) could transform design (Design Research Society, 2016), and intended to make design compatible with its neighbouring disciplines of management science and operation (Archer, 1968). This trend led to the "design methods movement" in the 1960s (Design Research Society, 2016). It was in this context that the first edition (1969) of *The Sciences of the Artificial* was published, representing part of Simon's broader project of unifying the social sciences with problem-solving (i.e., design) as the glue (Huppertz, 2015). His ultimate aim of writing this book was to build a science of design that broadened the capabilities of computers to aid design.

2.1 Simon's Original Ideas about Design in the First Edition of his Book

The most important view Simon (1969) described in the first edition of *The Sciences of the Artificial* is that we live in an artificial world, rather than a natural world. This is the subject of his discussions in Chapter 1 "Understanding the Natural and Artificial Worlds". According to his description, natural science concerns itself solely with how things are, whereas the sciences of the artificial are concerned with how things ought to be—"ought to be, that is, in order to attain goals, and to function" (Simon, 1969, p. 5). In light of this view, Simon devoted himself to developing artificial scientific knowledge about artificial objects and phenomena. According to his explanation, if an artefact's inner system is properly designed, it will be adapted to its outer environment, and its behaviour will be determined in large part by the behaviour of the latter. Moreover, he points out that people will have to be satisfied if design objectives are met only approximately because of the limits of the inner system's adaptation.

Human beings, as adaptive behaviour systems, are the most important subject Simon discusses in Chapter 2 "The Psychology of Thinking". According to him, humans' knowledge of behaviour (i.e., their thinking and problem-solving) is artificial because it is learned in a particular social environment. From a cognitive psychological perspective, his claim is that humans' problem-solving capability can be seen as a systematic search through a vast maze of possibilities, a maze that describes the outer task environment. Also, he points out that human brains' adjustments to their outer environment are limited by their adaptive capabilities of information-processing; thus, they have to rely on a selective search strategy to reduce the search space. Based on these findings, Simon claims that the theory of design is the general theory of search. Computers, as another kind of

information-processing systems, as well as an artefact, is considered a useful tool to imitate the thought processes of human brains in design activities and to enhance the efficiency and effectiveness of design processes.

Considering design's central role in creating artefacts, in Chapter 3 "The Science of Design", Simon proposes an inclusive definition of a designer: "Everyone designs who devises courses of action aimed at changing existing situations into preferred ones" (Simon, 1969, p. 55). Further, he emphasises the crucial role of design as a complement to natural science in all professional training: "Schools of engineering, as well as schools of architecture, business, education, law, and medicine, are all centrally concerned with the process of design" (p. 56). Simon further elaborates his vision of establishing a science of design from the perspective of positivism and technical rationality. That is, he suggests that professional schools work out and teach a science of design—"a body of intellectually tough, analytic, partly formalizable, partly empirical, teachable doctrine about the design process" (p. 58). What makes this vision reasonable is his description of design as a rational set of procedures that respond to a well-defined problem, which can be solved by decomposing systems as well as searching for and choosing alternatives.

Simon states that the goal of designers' problem-solving processes is to find satisfied alternatives in the face of a real-world complexity where optimisation is impossible. He assumes that it is possible to determine a desired state of affairs, which enables a designer to solve a problem by continually translating between the state and process descriptions of the same complex reality. For him, the key to solving a problem is representing it so as to make the solution transparent. Using the example of actual design processes run by computer programs, Simon argues that design processes can no longer make excuses by hiding behind the cloak of "judgement" or "experience" (p. 80), and that the professional problem solver can simply play the role of a controller or a manipulator. Through these analyses, he expresses his vision of teaching design as a unifying language that enables communication across fields. Finally, in Chapter 4 "The Architecture of Complexity", drawing on all of the above, Simon discusses the possibility of systematically constructing, designing, or even evolving an artefact as a complex system with a hierarchical structure.

2.2 The Refinements Simon Made in the Later Two Editions of His Book

The Sciences of the Artificial was revised by Simon and republished twice, once in 1981 and once in 1996 (Simon, 1981, 1996). In the second edition (1981), Simon developed and enriched his original thought on design as a problem-solving, process-oriented activity. He expanded his discussion of computer-aided design by engaging with the tools of heuristic search and operations research (OR) (pp. 35-36). Classic OR tools provide algorithms for choosing among predefined alternatives, while heuristic search provide alternative methods for generating alternatives to problems of design (p. 139). Then, he explains "judgement" and "intuition" from a cognitive behavioural perspective, which strengthens his argument for applying heuristic search in facilitating decision-making. According to his explanation, "judgment" in decision-making is mainly a non-numerical heuristic search that draws upon information stored in a large expert memory, and most sudden flashes of "intuition" that sometimes allow the expert to arrive immediately at the answer are acts of recognition (pp. 104-105).

Moreover, Simon expands his discussion of problem-solving from puzzle-like tasks, which could be performed without significant dependence on memory or skills previously learned, to problems in the semantically rich domain, which require large amounts of specialised knowledge retrieved from memory (p. 102). He points out that the searching process for solving the latter kind of problems is

conducted alternately in each of two environments: the problem solver's long-term memory and the task environment. Information gained from one environment is used to guide the next step of the search in the other (p. 105). Thereby, he suggests regarding human memory as an extension of the environment in which human thought processes take place and indicates that it is composed of both data and skills, which can both be acquired in dealing with environmental change—that is, “learning” (pp. 118-119). Further, Simon argues that the objective problem-solving approach of design also applies to ill-defined problems—that is, the class of ill-structured problem-solving tasks that have relatively ill-defined goals and to which the process of making discoveries belongs. He provides a new idea, “Designing Without Final Goals”: “A paradoxical, but perhaps realistic, view of design goals is that their function is to motivate activity which in turn will generate new goals. ...Each step of implementation created a new situation; and the new situation provided a starting point for fresh design activity” (pp. 186-187).

Also broadly discussed is the extended role of design in the social domain, especially in organisations. Correspondingly, the role of a professional problem solver as a controller or a manipulator is expanded upon as well. In particular, Simon writes that when conflicts of interest or uncertainties in professional judgement are present in social design (either in the design of large social systems or in smaller-scale design tasks), the designing and implementing processes become essentially dynamic games between the designers and the people they design for. In this situation, the latter are also designers who are seeking to further their own goals (pp. 177-178). Thus neither the former nor the latter can act as controller or manipulator. Moreover, Simon also acknowledges the value of untutored intuitions about self-regulation without central direction in these kind of artificial systems in human societies. He points out that some complex social systems mostly just “grow” in response to myriads of individual human decisions, such as markets and medieval cities, which, as he puts it, are designs without a designer (p. 40).

Fifteen years later, in the third edition (1996), Simon updated some material and added some new references to support his opinions. He also articulates his vision of establishing a science of design more confidently: “In substantial part, design theory is aimed at broadening the capabilities of computers to aid design, drawing upon the tools of artificial intelligence [(i.e. heuristic search)] and operations research” (p. 114).

3. Design Researchers' Explorations of Simon's Vision of Establishing a Science of Design

3.1 Following Simon's Vision of Establishing a Science of Design

Over the past half-century, the three editions of *The Sciences of the Artificial* have encouraged many scholars to explore the possibility of establishing systematic and formalised design methodologies in many fields, such as architecture (Schön, 1988), public policy (Jones, 2002), and computer sciences (Kruchten, 2004). Among design professionals, inspired by Simon's thinking, many engineering scholars (e.g., Dym (1994) and Adams, Turns, and Atman (2003)) have contributed to developing a scientific design methodology in their fields. Their success is not surprising, considering that engineering, as a discipline, is characterised by a high degree of prescriptive knowledge (Pandza & Thorpe, 2010), and objectivity is moderately attainable in engineers' practices (Cross, 2001). These explorations in engineering have contributed to the development of a research paradigm in which designing is viewed as a scientific activity (Cross, 2001).

Furthermore, Simon places an emphasis on engineers' routine in designing technical artefacts in his book. This emphasis encouraged some management scholars to explore the concept of a design science to find an answer for the enduring debate about management studies' relevance to practice (Hatchuel, 2001; Pandza & Thorpe, 2010). As Pandza and Thorpe (2010) points out, some management scholars (e.g., Tsang and Kwan (1999), Romme (2003) and Van Aken (2005)) proposed ways to link science and design by redefining research hypotheses as design propositions or technological rules that could be tested in real settings through replication methods, much as engineers traditionally solve problems. Similar ideas are also popular among some scholars of design thinking, especially those who have management education backgrounds. For example, Martin (2009), who introduced a model of the "knowledge funnel" that design thinking is rooted in, claims that design thinking is an ongoing cycle of generating ideas, predicting consequences, testing, and generalizing.

3.2 The Prominent Criticisms of Simon's Epistemological Views of Establishing a Science of Design

Since the 1970s, however, professional designers in other design-relevant disciplines, such as architects (e.g., Alexander (1971)), rejected to base design on positivism and technical rationality as the underlying epistemological notion. There were some engineering designers (e.g., Jones (1977)) also joined their camp. They became pragmatists and borrowed some of John Dewey's concepts, such as reflexivity, intentional operations, and the relationship between science, art, and practice. Their main argument, borrowed from Rittel and Webber (1973), is that scientific design methods that have been developed to deal with "tame" problems have proved inadequate for real "wicked problems" in practice, such as problems of social policy. This argument has been enriched by many design scholars, such as Archer (1979), Cross (1982) and Rowe (1987). Some of them explicitly criticised Simon's epistemological view on design in *The Sciences of the Artificial*.

One of the most distinguished scholars among them is Schön (1983), whose theory of "reflection-in-practice" is often juxtaposed with Simon's "rational problem solving" (Dorst & Dijkhuis, 1995). Schön's point is that the perspective of technical rationality sees professional practice as a process of problem-solving but ignores problem-setting, the process by which the designer defines the decision to be made, the means that may be chosen, and the ends to be achieved. He also points out that, in real-world practice, problems do not present themselves to the practitioner as given, and must be constructed from the materials of problem situations, which are puzzling, troubling, and uncertain. Finally, Schön presents his theory of reflection-in-action, which highlights a designer's specific capability for reflection-in-action, featuring a willingness to frame new questions and new ends in the midst of design. He writes, "Let us search, instead, for an epistemology of practice implicit in the artistic, intuitive processes which some practitioners do bring to situations of uncertainty, instability, uniqueness, and value conflict" (Schön, 1983, p. 49).

Another representative scholar is Buchanan (1992), the author of "Wicked Problems in Design Thinking". In this paper, he suggests understanding design as a liberal art and an integrative discipline that contributes to combining theory with practice for new productive purposes. Buchanan holds that "The significance of seeking a scientific basis for design ...lies in a concern to connect and integrate useful knowledge from the arts and sciences alike, but in ways that are suited to the problems and purposes of the present" (Buchanan, 1992, p. 6). As a pragmatist following Dewey's thought, he affirms Simon's contribution to an early understanding of the disciplines of design in the contemporary world. Meanwhile, Buchanan criticised Simon's positivist and empiricist views as making him unable to grasp the radical sense in which designers explore the meaning of the artificial in human experience. Buchanan (1992, p. 6) suggests, "Designers, are exploring concrete integrations

of knowledge that will combine theory with practice for new productive purposes, and this is the reason why we turn to design thinking for insight into the new liberal arts of technological culture”.

Cross (2001) is another influential design scholar who explicitly criticised Simon’s underlying epistemology of positivism and technical rationality. Much as Buchanan does, he agrees with Simon’s suggestion for developing a science of design as a fundamental common ground for interdisciplinary study in creating an artificial world. He also points out that there are forms of knowledge special to the awareness and ability of a designer (i.e., “designerly ways of knowing”) independent of the different professional domains of design practice. Then, building on Schön’s theory of reflection-in-action, he proposes “a science of design based on the reflective practice of design: design as a discipline, but not design as a science” (Cross, 2001, p. 54), meaning design studied on its own terms and within its own rigorous culture.

These scholars’ contributions have established a new research paradigm in design studies: design activities as the subject of scientific investigation (Cross, 2001). This paradigm also dominates research in design thinking, in which the philosophical position of pragmatism is considered a conceptual scaffold for design thinking (Dalsgaard, 2014). For this reason, Simon’s book is often referenced just as one of the starting points of design thinking. The above design scholars’ views are directed at the first edition (1969) of *The Sciences of the Artificial*. From this perspective, they are indeed fair and objective evaluations.

3.3 Some Academic Voices Supporting Simon’s Epistemological Position

Many design researchers (e.g., Lloyd, Lawson, and Scott (1995) and Kimbell (2011)) have noted that Simon advanced his account of problem-solving by including ill-defined and ill-structured problems, which are similar to wicked problems, in his later works, beginning in 1972 (e.g., Human Problem Solving (Newell & Simon, 1972), “The Structure of Ill Structured Problems” (Simon, 1973) and the second and the third editions of *The Sciences of the Artificial*). Some of them (e.g., Coyne (2005), Dorst (2004), Hatchuel (2001) and Lloyd et al. (1995)) maintained their impression of Simon as a technocratic designer. Their argument is that Simon (1981) conceives of these problem-solving tasks, an example of which is the making of discoveries, as composed of the same repertoire of heuristics that can be found in the usual solving of well-structured problems. But it is noteworthy that, in the later editions of *The Sciences of the Artificial*, Simon’s understanding about design is advanced in many other aspects, which could reverse their impression of him. In fact, based on these changes, there have already been a few academic voices to emerge against the critiques of Simon’s epistemological views.

Restrepo and Christiaans (2004), for example, argue that Simon’s problem-structuring for ill-defined or ill-structured problems is a process of drawing upon knowledge or searching for external information that may contribute to the construction of the problem space. As they note, it is not significantly different from what is presented in the paradigm of design as a reflective practice initiated by Schön. Meng (2009) holds a similar view with Restrepo and Christiaans. Moreover, having revisited the three editions of Simon’s book, Meng found that Schön overlooked Simon’s description of the limitation of human rationality, or “bounded rationality”, that challenges people’s wish to optimise, his suggestion to the designer to “satisfice” as an alternative, and his openness to the contributions of our intuitive faculties. Another design scholar, Huppatz (2015), has also recognised that Simon left a small opening in the second edition of his book for social involvement and creativity in the new chapter “Social Planning: Designing the Evolving Artifact”. Additionally, he points out that Simon writes that his aim of social planning is “to leave the next generation of

decision makers with a better body of knowledge and a greater capacity for experience. The aim here is to enable them not just to evaluate alternatives better but especially to experience the world in more and richer ways" (Simon, 1996, pp. 163-164). Huppertz claims, "Simon's [The] Sciences of the Artificial confirms a shift away from his technocratic designer ideal to an acknowledgement of design's ethical foundation" (Huppertz, 2015, p. 40).

These convincing academic voices are insightful because many design scholars (e.g., Harrison, Back, and Tatar (2006), Hassi and Laakso (2011) and Johansson - Sköldberg, Woodilla, and Çetinkaya (2013)), influenced by the mainstream view of Simon as a technocratic designer, have underestimated the value of *The Sciences of the Artificial*, especially the revised editions. Moreover, some of these scholars (e.g., Bayazit (2004), Dorst (2004) and Hatchuel (2001)) cite different editions of the book in their works. This allows the misleading information concerning Simon and his book to continue to spread. However, this situation has not been recognised by the majority of design scholars. Re-evaluating the latest edition of Simon's book and its value to design research should be put on the list of research priorities in the future years, especially considering that design theory has been progressing based on a certain degree of ambiguity about Simon and his book. Specifically, the changes Simon made in the revised editions of his book are especially valuable for researchers who intend to establish a "science of design" and reflect on the concept of design thinking, which has been fiercely criticised in recent years among design scholars (e.g., Norman (2010) and Nussbaum (2011)).

4. Reassessing Design Researchers' Criticisms about Simon's Descriptions of Design Professionals

When more design researchers shifted their attention to the practices of professional designers, some of them (e.g., Hatchuel (2001), Kimbell (2009) and Pandza and Thorpe (2010)) criticised Simon's descriptions of design professionals in *The Sciences of the Artificial*. These criticisms point out Simon's limited understanding of design practices in the first edition of his book. Considering the significant changes Simon made in the later two editions, it is necessary to reassess these criticisms before further discuss the value of the book to the future design research.

The first criticism is that Simon's emphasis on engineering and architecture is inadequate to serve as the basis of his vision to develop a science of design (Kimbell, 2009). Based on her research on the first edition of Simon's book, Kimbell points out that Simon's generalised discussion of design not only tends to blur differences between professional design fields but also fails to clarify to what extent it describes the design activities in the work of professional designers (p. 3). In general, Kimbell's criticism of Simon is partly objective because he did overemphasise engineers' and architects' routinized ways of problem-solving. However, the reason Simon selected these two design professions was to explain his view of systematically constructing, designing, and even evolving an artefact as a complex system with a hierarchical structure. In addition, his vagueness in different fields of professional design can be explained by his view of the theory of design as the general theory of search and by his vision of teaching design as a unifying language to enable communications across fields.

The second criticism is that Simon's one-sided portrayal of engineers' routinized practices of designing technical artefacts fails to account for the generation of creativity, invention, and novelty in design activities (Hatchuel, 2001; Kimbell, 2009; Pandza & Thorpe, 2010). This criticism is directed

at Simon's description of prescriptive knowledge in engineering. However, in the second and third editions of his book, Simon provides an interpretation of "novelty" in his discussion of the searching process during problem-solving in semantically rich domains: "What constitutes novelty depends on what knowledge is already in the mind of the problem solver and what help is received from the environment in adding to this knowledge" (Simon, 1981, p. 123). Additionally, Simon explains that search guided by the most general heuristics of "interestingness" or novelty is an entirely realisable activity, using scientific discovery, oil painting, and urban planning as examples (Simon, 1981, pp. 185-187). In these two editions, he also admits the value of intuition several times (section 2.2).

The third criticism is that Simon undervalues the core role of artificial objects in the design process of professional designers (Kimbell, 2009). It is true that objects do not feature strongly in Simon's account of design in the first edition of his book. He only discusses the representation of the problems related to physical objects by means of floor plans, engineering drawings, renderings, or three-dimensional models (Simon, 1969, p. 79). However, in the later two editions of his book, Simon strengthens the role of objects in the process of design when he discusses semantically rich domains. He points out that, in highly specialised domains, practitioners often have to use external reference aids in their work to reduce memory burden. His example is architecture, where much of the information an architect requires is stored in reference books and the architect has to incorporate the emerging partial design in a set of external memory structures (e.g., sketches, floor plans, drawings of utility systems). Moreover, he points out that, at each stage in the design process, the partial design stored in these documents serves as a primary stimulus for suggesting to the architect the direction of new sub-goals (Simon, 1981, p. 109).

The fourth criticism is that Simon overlooked the social contexts in which design activities take place and the situated and contingent process of most design practices ((Hatchuel, 2001; Kimbell, 2009)). Hatchuel claims that Simon's design theory is restricted to problem-solving within a bounded rationality perspective, which is only a moment in a design process. He suggests that substantial steps towards a design theory should engage with a concept of "expandable rationality" and a principle of collective action. Similarly, Kimbell argues that Simon's accounts of design emphasise individual, rational action and neglect the social contexts in which design activities take place. Thus, she suggests rethinking design and design thinking by attending to the situated and embodied routines carried out by different kinds of design professionals and multiple stakeholders who engage with designs. The fact is, in the later editions of his book, Simon expands his initial understanding of professional problem solvers as controllers or manipulators. In this way, he explains the nature of social design as a distributed social accomplishment (section 2.2).

In general, these four interrelated criticisms indicate the importance of understanding design and design thinking by analysing different professional designers' routinized doings and sayings. On the other hand, if a researcher revisits a later version of Simon's book, he or she will find these criticisms are largely untenable. Unquestionably, Simon's claims about design in the 1981 and 1996 editions of his book have some intersections with design scholars' pragmatist views. Here we conclude that revisiting and reimagining Simon's vision of design in *The Sciences of the Artificial* (the third edition) may constitute a big step towards the further development of design theory and design thinking. Although most design researchers who have explored the possibility of establishing a science of design since the 1970s have given up Simon's vision in *The Sciences of the Artificial*, their research findings can still be discussed in the framework of the second and the third edition of Simon's book.

5. Future research

This paper reassessed the value of the three editions of Herbert Simon's *The Sciences of the Artificial* indicates. It enables the researchers to map out the connections between the mainstream research paradigms shaped in the half-century's design research and Simon's vision of design (Figure 1).

Mainstream research paradigms and Herbert Simon's vision of design					
The 1960s	The 1970s	The 1980s	The 1990s	The 2000s	The 2010s
Research paradigm: Developing scientific design methods to make design rigorous and systematic (e.g., Jones, 1963; Archer, 1968)	Research paradigm: Confirming the value of designerly ways of knowing (e.g., Alexander 1971; Archer, 1979)	Research paradigm: Considering design activities as the subject of scientific investigation (e.g., Cross, 1982)	Research paradigm: Investigating "reflective practice" in design thinking research (e.g., Buchanan, 1992)	Research paradigm: Exploring the plurality of design activities (e.g., Cross, 2001; Hatchuel, 2001; Kimbell, 2009)	Research paradigm: Reflecting upon the half-century development of design research (Design Research Society, 2016)
Simon and design research: Simon (1969) called for the establishment a science of design in his book <i>The Sciences of the Artificial</i> .	Simon and design research: Designer scholars (e.g., Rittel and Webber, 1973) proposed opposite views to Simon's vision of design.	Simon and design research: The second edition of <i>The Sciences of the Artificial</i> acknowledged design's ethical foundation (Simon, 1981).	Simon and design research: Some key ideas of design thinking were derived from the first edition of <i>The Sciences of the Artificial</i> (Buchanan, 1992). Simon published the third edition (1996) of his book.	Simon and design research: Design researchers (e.g., Restrepo and Christiaans, 2004; Meng, 2009) noticed that Simon had revised his epistemological views about design in the later editions of his book.	Simon and design research: More design researchers (e.g., Huppatz, 2015) reflected upon Simon's vision of design described in the later editions of his book.

Figure 1. The connections between mainstream research paradigms and Herbert Simon's vision of design.

The reassessment of Simon's book also points towards two potential research directions for design theory. One is that researchers can use the outcomes of design studies to enrich Simon's vision of establishing a science of design. For example, the two prominent research paradigms in design studies, viewing designing as a scientific activity and viewing design activities as the subject of scientific investigation, echo Simon (1969) in his call to work out and teach a science of design that is "partly formalizable" and "partly empirical" (p. 58). Additionally, it is easy to find that the latter constitutes a larger proportion in design studies than the former, because most problems in practice are "wicked". This suggests that the future of design science should be in small part "formalizable" and in large part "empirical". The other potential research direction is that design researchers can apply Simon's argumentation framework to drive design research in broader directions. For instance, as Meng (2009) points out, a closer and more appreciative re-appraisal of Simon's revised design theory could contribute to the articulation of a distinctive "designerly way of knowing".

There is also another reason that design scholars should pay more attention to *The Sciences of the Artificial*. It is that each section of the book is interrelated and interwoven with each other and,

together, they constitute Simon's vision of the sciences of the artificial. More specifically, the book covers a broad range of scientific domains, including artificial intelligence, decision-making, problem-solving, information processing, complex systems, and organisation theory, which make it of profound influence in many fields. However, seldom have design researchers fully exploited the book, and instead design researchers tend to grab small pieces from it to support their own research topics with their own interests. It seems that the big picture that Simon depicted has wilfully ignored. This is probably a consequence of the mainstream opinion among design scholars that Simon is a technocratic designer. A more careful analysis of the full argument can help design researchers to connect the fragmented contributions made by researchers from different fields based on Simon's intellectual legacy. The significant changes Simon made in the later two editions have also removed some barriers.

Overall, through this research, we have not only re-evaluated the different views about Simon in the design community but also established a more objective and comprehensive understanding of Simon's vision of design. The major of this study limitation is that the discussion has mainly drawn upon literature within design and management research and has rarely attended to the relevant studies in the other fields. While this approach is, we believe, appropriate for discussing Simon's vision of establishing a science of design, further work from different perspectives is needed to generate rich theoretical and empirical accounts of that vision.

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About the Authors:

Xinya You is a PhD student at Lancaster University. Previously, she worked for two years as an analyst at Siegel + Gale. She obtained her MA in Design & Branding Strategy (Brunel University) and BA in Industrial Design (Tsinghua University).

Dr David Hands is Course Leader for MA Design Management at Lancaster University. His research interests are varied and diverse, encompassing design policy development; design briefing; design leadership; designing against crime; and new product development.