Where Schön and Simon agree: The rationality of design

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Simon and Schön are commonly seen to represent two conflicting views on design method, but this interpretation has been challenged in recent years. In this paper we discuss their differences and agreements in more depth. Both of them agree on a rationality which is distinct from science and its reliance on universal truth. They depend on a practical reason, and what Aristotle calls the calculative part of the soul, which deals with the contingencies of real world problems, and still let us know, and share, truth. One discrepancy remains between Simon and Schön. Simon does not tell us how we identify the changing goals of man. Schön addresses this by invoking the distinctly human power to see-as.

Keywords: design methodology, reflective practice, engineering design, philosophy of design, logic of design

Simon and Schön are two of the most cited authors on design methodology, interpreted and resituated in a range of disciplines by numerous authors. The differences between Simon's rational problem solving and Schön's reflective practice are often emphasised, for instance by Dorst and Dijkhuis (1995) and Johansson-Sköldberg et al. (2013) and not least by Schön (1983) himself. These differences have been challenged by Chua (2009) and Go (2012).

The works of Simon and Schön are important because they are relevant to a wide range of disciplines and traditions. They both suggest that their respective methodologies can potentially bridge the gap between the two cultures of science and the humanities (cf. Snow, 1961), in contrast to (e.g.) Cross (1982) who has attempted to establish design as a third culture distinct from both science and humanities. However, Cross also makes it clear, in later writings, that design should not be an isolationist culture. The challenge for design research is 'to help construct a way of conversing about design that is at the same time both interdisciplinary and disciplined' (Cross, 1996, 2019). This journal has held from the very start that 'design is a skill and an activity for all people' (Cross, 2019; Gregory, 1979).

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Effective conversation requires a common epistemology. It is difficult to agree on solutions when the experts have different notions of truth and of what constitutes a good and objective solution. Schön and Simon promise epistemologies to support such a 'way of conversing' that Cross asks for. Thus it is worth asking if there is a conflict between their respective views, or if the two epistemologies can be consolidated. Chua's (2009) review of Simon's position partly answers this in favour of consolidation, but we have not seen similar reviews of Schön's work. While Schön (1983) has been the most cited work in *Design Studies*, citations are often made in passing without any critical engagement (Chai & Xiao, 2012), and misattribution threaten the integrity of knowledge (Beck & Chiapello, 2018).

The aim for this paper is to identify the common essence of Schön's and Simon's methodologies. Consolidating their two views invariably leads us to ask if, and how, reason is compatible with the artistry and intuition emphasised by Schön. We shall try to answer these question by appealing to a broad selection of literature from different fields. In this light, we will show that Schön's methodology, like Simon's, is built on reason. Intuition has a place which does not contradict reason.

1 Background

Both Simon and Schön responded to a crisis in the professions, following the scientification which had reshaped virtually every professional discipline for the better part of the 20th century. Science provided us with a sound epistemology, giving confidence and objectivity to our knowledge, but it became evident that this knowledge did not cover all that we need to know as designers (e.g. Cross, 2001). Schön (1983, p. vii) criticised universities for not seeking knowledge in general, but dedicating themselves to a single epistemology.

The controversy around design as a science is closely related to the conflict between theory and practice, or between knowledge and art, which has been debated since antiquity. There is a long list of related dichotomies, such as propositional and tacit knowledge (Polanyi and also Schön (1983)), explanation and understanding (e.g. Kemp, 2013), and *Ausbildung* and *Bildung* (e.g. Wilhelm von Humboldt).

This paper considers design in a broad meaning. As Simon (1969, p. 55) puts it, 'everyone designs who devises courses of action aimed at changing existing situations into preferred ones'. When we consider design and designers in this paper, this is the definition we will use, so that design includes engineering, pedagogy, etc. Unlike scientists, who describe how things *are*, professionals are employed to shape the world of the future. They need to decide how things *ought to be*. We recognise David Hume's famous is-ought problem: How can we make moral inference (oughts) from factual statements? However, Simon barely addresses this problem explicitly. In fact, he argues that no particular logic of oughts is required (Simon, 1996, p. 115ff), and he continued to maintain that there is no rational basis for normative claims (Chua, 2014). Thus other concepts will be more central to our analysis.

In the following sections, we will take different angles to discuss what an epistemology of design is or should be, resting primarily on the views of Simon's and Schön's.

2 *Science or judgement?*

Science has been very successful in developing universal knowledge with a high degree of confidence, enabling accurate prediction of natural phenomena. Design, in contrast, is concerned with *artificial* things, which are not given as facts of nature. Instead, they are moulded by goals and purposes (Simon, 1969, p. ix) as they are formed and reformed by human action, or as Simon phrases it:

> *If natural phenomena have an air of 'necessity' about them in their subservience to natural law, artificial phenomena have an air of 'contingency' in their malleability by environment.*

Thus, Simon sets up a dichotomy of two forms of knowledge. The natural sciences study the necessary or universal truths, while the sciences of the artificial study what is true, or right, in the presence of contingencies.

This dichotomy has previously been established by Aristotle (1999, Book 6). He divided the rational soul into two parts, one scientific (ἐπιστημονικὸν—*epistemonikon*) and one calculative or deliberating (λογιστικόν—*logistikon*). *Epistemonikon* is concerned with *episteme* (ἐπιστήμη), defined as *knowledge about things which could not be otherwise*, that is the necessary or universal truths. *Logistikon*, in contrast, is concerned with the particulars, and thus it engages in art and craft (*techne*—τέχνη) and practical wisdom or prudence (*phronesis*—φρόνησῐς). Aristotle (1999, Book 6, Ch. 1–2) asserts that both the *epistemonikon* and the *logistikon* concern truth. Both are opposed to judgement and opinion, in which 'we may be mistaken' (Aristotle, 1999, Book 6, Ch. 3). This gives us a tripartition of mental activity: (1) reasoning about universal truths (*epistemonikon*), (2) reasoning about variable truths (*logistikon*), and (3) judgement, which does not apply reason. The *logistikon*, that is the contingency based reason, has been disregarded by many Western thinkers, but there has also been waves of acknowledgement, notably Cicero's humanism, the Renaissance, and American pragmatism (Goldman, 2004).

The short-comings of universal truth in design processes is central for Simon (1969) and Schön (1983) alike, even though they use rather different words.

Schön addresses specific contingencies, such as conflicts of values, goals, purposes, and interests (Schön, 1983, p. 17). He observes that skilled professionals approach their problems as unique cases, rather than as instances of general classes of problems where universal theories necessarily apply. If Schön is seen as a defender of judgement and intuition against reason, this may be due simply to a failure properly to acknowledge the *logistikon* as a distinct mode of reasoning. Central to Schön's analysis is the dilemma of rigour and relevance in professional practice. Scientific theory is rigorous, but the universality renders it irrelevant to the contingencies of the real world. Judgement may be relevant, but the lack of rigour makes it error-prone. Like Simon, he is searching for the third alternative, which is both rigorous and relevant.

The ambiguity of the word 'science' causes us some grief. It is often used to refer to necessary and universal truths, and *episteme* is often translated as 'scientific knowledge'. When Simon studies the *Sciences of the Artificial*, it concerns contingencies, or particulars, and thus 'science' has taken a wider meaning. Apart from universality, the word 'science' also emphasises rationality and reason, as opposed to judgement or intuition, and this may be the emphasis Simon was seeking when he chose the word 'science'. We will not need to define 'science' for the purpose of this paper. Our concern is the distinction between universal knowledge and variable truths, which leads to two different modes of reason, whether or not we want to call one of them 'science'.

Many authors have battled with the same problem, seeking to reinterpret rationality to be able to handle the contingencies—the wicked problems—of the real world. Coyne (2005) provides a more extensive discussion of the different approaches. Simon takes the mathematical models, known from science, as his starting point, and real world problems are viewed as 'tricky variants' (Coyne, 2005). Schön, in contrast, rejects this approach, and starts instead by observing existing professional practice, to search 'for an epistemology of practice implicit in the artistic, intuitive processes which some practitioners do bring to situations of uncertainty, uniqueness, and value conflict' (Schön, 1983, p. 49). Thus artistry and intuition is not sufficient for Schön. Rather, he suggests that hidden in the artistry, there are rational processes whereby the practitioner can *know* truth, and these processes can be captured in an epistemology. Simon does not appear to disagree with this, as he also talks about a 'design process hiding behind the cloak of "judgment" or "experience."' (Simon, 1969, p. 80), and 'so-called "judgment" turns out to be mainly a non-numerical heuristic search that draws upon information stored in large expert memories' (Simon, 1996, p. 28). With such similar goals, the different starting points needn't mean that they end up with very different solutions.

3 *Goals and rationality*

Design is the devising of sequences of actions which create new (and better) situations. Rational design is thus a case of practical rationality (practical reason), the reasoning from facts or beliefs to actions. In Aristotle's terminology this includes both *techne* and *phronesis*, making a clear distinction between what we make and what we do. Both are concerned with particulars, and the distinction is blurred in Schön's and Simon's writings. Making and doing come together as decision making, which, 'is as close to acting as reasoning can possibly get you' (Broome, 1999). Decision making is also the central theme throughout Simon's work (Feigenbaum, 2001). Therefore, we can think of practical rationality as reasoning from facts and beliefs to decisions.

Schön directed his critique against the mindset which he called *Technical Rationality*, a concept which may originate from Marcuse (1941). This idea, which Marcuse interchangeably calls *technical* and *technological rationality*, is further developed in his 1964 book (Marcuse, 1991). Marcuse uses the word 'technology' in its original meaning, as the rules or knowledge (logos) of the tools and methods used in art and craft (techne).[1] Thus it does not refer primarily to the technical apparatus, but rather to a social process. In Marcuse's dystopian view, human beings lose their freedom and individuality to the technological assumptions, and he writes (Marcuse, 1941, p. 142):

> *The efficient individual is the one whose performance is an action only insofar as it is the proper reaction to the objective requirements of the apparatus, and his liberty is confined to the selection of the most adequate means for reaching a goal which he did not set.*

A key point is the role of the 'goal', which is fixated in the technological process, be it the rational bureaucracy of Max Weber, the scientific models underpinning professional practice, or the technical tools we depend upon. When we no longer question our goals, rationality is reduced to *instrumental reason*, i.e. deciding on appropriate actions to reach *given goals*. Weizenbaum (1976) addresses this same problem, labelled as the 'Imperialism of Instrumental Reason'.

None of these authors claim that instrumental reason is a bad thing. It certainly has a place, it is just that this place is limited, and it needs to be complemented by rational methods to decide on goals. Schön (1983, p. 165) phrases it as follows,

> *technical problem solving occupies a limited place within the inquirer's reflective conversation with his situation; the model of Technical Rationality appears as radically incomplete.*

Schön (1983, p. 165) observes that in reflection-in-action, the inquirers 'identify both the ends to be sought and the means to be employed'. Thus Schön already points towards the more recent work on co-evolution of problem and solution (e.g. Dorst, 2019; Maher et al., 1996).

Simon has made important contributions to instrumental reason, particularly within the field of artificial intelligence, and one can be led to believe that he considers design to be only instrumental reason. This is not true (Chua, 2009). Simon (1981, p. 186) puts it in plain words, under the header of '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.*

That goals should not be taken at face value is a common view in design theory. For instance, Norman (2013, p. 218) asserts that 'good designers never start by trying to solve the problem given to them: they start by trying to understand what the real issues are.' However, where Norman views design as a two-phase process, which first sets and then solves the problem, Simon (and also Schön) clearly see problem setting as a continuous evolution throughout the design activities.

This idea was not entirely new in the 1981 edition. Simon (1969) had already likened the design process with natural evolution, and the evolutionary model was further developed in 1981. Each stage in the evolution gives a new situation which gives new insight and new opportunities. Whatever goals one previously held, they have to be reconsidered in light of new information. 'The idea of final goals is inconsistent with our limited ability to foretell or determine the future.' (Simon, 1996, p. 163).

4 Intuition or rationality

The concept of reason or rationality has so far been left undefined. We have used it to refer to processes whereby we claim to know truth, at least with some degree of confidence, as opposed to judgement or opinion where we may be mistaken. What, then, are the characteristics which let this rationality guarantee truth?

One answer to this question is offered by Kahneman (2011, p. 49), citing Toplak et al. (2011). In their view, rationality is opposed to superficial or 'lazy' thinking. Many problems are prone to bias, because our fast mode of thinking, the so-called System 1, is easily satisfied with a false conclusion. This is not a problem in itself. System 1 makes itself useful by being highly efficient and producing good conclusions most of the time. It becomes a problem when the initial conclusion is uncritically accepted. Rational thinking, for

Toplak et al. (2011), means taking the effort to double-check the solution and review the evidence, using a slower, but more reliable mode of thinking, the so-called System 2.

Schön does not use the words 'reason' or 'rationality' to describe his epistemology. Instead he writes about rigour, a term which he also leaves undefined and uses in at least two different meanings (Rolfe, 2016), initially referring to technical and experimental rigour. Spencer (2009), in his analysis of rigour in design practise, describes the 'unfettered' meaning of rigour as 'the quality of being extremely thorough and careful'. With intellectual rigour he associates applied consistency, scepticism to accepting anything on trust, and keeping claims in proportion to valid evidence. This broadly matches Kahneman's notion of rationality, as the thorough double-checking of initial hunches. In Schön's reflection-in-action, there is an experimental methodology which ensures rigour by thoroughly testing ideas and moves.

System 1 is subconscious and fallible. In other words, it has features that we associate with judgement and intuition. It generates suggestions for System 2 (Kahneman, 2011, p. 24), and System 2 may or may not endorse these judgements. Because System 1 is subconscious, it is impossible to suspend it. We cannot not make intuitive judgements, but we can choose either to lazily accept them, or to validate them rigorously. This is what we see in Schön's reflection-in-action. The professional does use judgement and intuition, moving quickly from one idea to the next, but Schön emphasises the experimental method, whereby the ideas are rigorously tested using System 2. Thus Schön is far from endorsing uncritical use of judgement and intuition. Judgement plays an important role, but it is not allowed to make final conclusions.

The intuition of System 1 involves no magic. Kahneman (2011, p. 11) quotes Simon to explain how an expert reaches intuitive conclusions in the blink of an eye:

> *The situation has provided a cue; this cue has given the expert access to information stored in memory, and the information provides the answer. Intuition is nothing more and nothing less than recognition.*

By casting intuition and judgement as information processing, Simon makes it harmless and compatible with reason. There are few texts where Simon clarifies the role that intuition should have in decision making, but the example of chess playing (Simon, 1972) may be one. Simon distinguishes between the move generator and the move evaluator. The evaluator carefully elaborates possible continuations to assess a given move, in what is clearly a System 2 process. The generator is described only casually: 'By scanning a chess position, features can be detected that suggest appropriate moves.' This phrase seems to allow for moves suggested by subconscious intuition (System 1) as well as conscious suggestion (System 2). Either way, the suggestions are rationally reviewed by the move evaluator.

In the above discussion, we recognise Reichenbach's (1938) separation of the context of discovery from the context of justification. In the context of discovery, the fallible System 1 is allowed to operate, and we do not necessarily know why we discover a given hypothesis or move. In the context of justification we need to avoid mistakes, and therefore we depend on rigorous reason to weed out bad discoveries.

Cross (1999) suggests that the concept of intuition may be a shorthand for *abductive reasoning*. In contrast to inductive and deductive reasoning, which are well understood in logic, abductive reasoning allows us to leap to conclusions which introduce concepts which were not present in the premises. In other words, abductive reasoning requires us to retrieve concepts from memory and match them to the problem, because they do not exist in the present frame. This abductive reasoning is a critical aspect of design according to Cross.

Abduction is used in two different meanings in the literature (Douven, 2021), and it is not entirely clear which one Cross has in mind; possibly, he includes both. Charles Peirce described abduction in the context of discovery. In more modern literature, abduction is more frequently used in the context of justification (Douven, 2021). In the context of discovery, abduction can take the form of intuition in Simon's sense, as recognition in expert memory. Applied to justification, abductive reason evaluates hypotheses according to how well they explain the premises (observations) (Douven, 2021), and this can be achieved with rigour.

Reason in design is not perfect, for two reasons. Firstly, we are not concerned with necessities, and this rules out the use of deductive reason. The conclusions of abductive (and also inductive) reason are not necessary consequences of the premises. Other conclusions can be equally valid. Secondly, our rationality is bounded, as Simon pointed out in the 1950s.[2] In the case of abduction, bounded rationality means that we cannot expect to discover and process all possible hypotheses. Hence there is no guarantee that we have found the best conclusion possible. Simon introduced the term *satisficing* to refer to this search for satisfactory solutions or conclusions. What we can require from a rational approach is the careful and thorough review of tentative moves, to make sure they are consistent with available evidence.

5 *Search and experiment*

To further explore the reasoning of design, we consider the process where it takes place. This process, as Simon so famously put it, devises a *sequence of actions* which changes the current situation into a preferred one. This choice of words is significant. It is not sufficient to identify the preferred situation. We also need to identify the actions to realise it.

Both Simon and Schön describe iterative processes, alternating between move generation and move evaluation (Simon) or testing (Schön). The object of evaluation is rarely final solutions, and individual moves are evaluated primarily to inform further search (Simon, 1972). Simon describes this as an evolution, where each move creates new opportunities. At each iteration, the choice of actions is constrained by the current situation and history. Schön, in contrast, describes it as a conversation with the situation. The designer makes a move, and the situation 'talks back' so that the designer gradually understands the consequences of the move.

Evolution and conversation are processes with memory. The moves are only expected to be meaningful in the current situation at a given point in time. In a different situation, earlier or later in the process, they may not be feasible, or not sensible. We can only understand the system if we know something of the history of its evolution (Simon, 1996, p. 47). For every generation, moves are evaluated in their own local context. Again, we are pointed towards abduction, which contrary to inductive reason, does not claim to make general conclusions (Shank, 1998). We are consistently working with particular responses to particular situations.

As discussed in the previous section, rational decision making depends on thorough checking of tentative decisions, and this gives rise to the experimental methodology. Experiments take several roles in Schön's framework, including both exploratory experiments and actual move testing. A complete account of the experimental paradigm is out of scope, but move testing deserves comment, because it relies, to a large extent, on the same principles as the epistemology of science. Every experiment has a chance to reveal a flaw in the move. When a move survives a wide range of experiments, we can have some confidence in its merits. This requires that the designer is open to the possibility of being mistaken (Schön, 1983, p. 153). Thus, judgement being prone to mistakes is no reason to reject it. Schön embraces the possibility of making mistakes, and experimental rigour refers to the conscious effort to seek experiments to reveal these mistakes.

The knowledge produced by reflection-in-action is objective in the sense that it can be disconfirmed (Schön, 1983, p. 166). It is subjective in the sense that other designers may disagree. However, the experimental method ensures an inner consistency. Other designers can confirm that the solution is consistent with good practice even if they disagree with the result (Schön & Wiggins, 1992). The underlying principle is the same as for Popper's falsification criterion. Theories are scientific when they leave themselves open to falsification by new experiments. Simon (1996, p. 169) suggests 'defensibility' in a similar meaning. Solving complex problems (limits on automotive emissions in Simon's example), one will often have to resort to gross simplifications and approximations, which makes it impossible to demonstrate that a solution is 'correct'. However, it can be made defencible in the sense that it be consistent with available evidence.

> *One may regard 'defensibility' as a weak standard for a decision on a matter as consequential as automobile emissions. But it is probably the strictest standard we can generally satisfy with real-world problems of this complexity*. (Simon, 1996, p. 168, p. 168)

Weak or not, this kind of defencibility has an important property. The defence requires us to name the reasons and assumptions made. Thus the defence is susceptible to rational attacks, which can add new information and complement the set of reasons and assumptions. Such an attack does not invalidate the original analysis, but builds upon it to evolve the solution. Tacit judgement is not open to such a rational attack because the reasons are hidden from comparison and deliberation.

The experiments in Schön's analysis take the form of thought experiments. This is illustrated, for instance, in the protocol where Quist and Petra discuss the design of a school building (Schön, 1983). In the sketches, Quist *sees* the actual building *as if* it were built, and he imagines himself as a student or teacher walking the corridors and using the building. This allows him to assess what the building would *mean* to real human users. Schön and Wiggins (1992) elaborates on this *seeing-as*, a concept attributed to Wittgenstein (1986).

Schön pointed out that the designer can often see more in the sketches than what was invested in their making, something which Menezes and Lawson (2006) has confirmed empirically. Making a move, the designer is not necessarily aware of all the domains affected by the move (Schön & Wiggins, 1992). By fully imagining and experiencing the design experimentally, these cross-domain consequences can also be evaluated.

Schön highlights *surprises*, and this notion is significant as we find it recurring in a wide range of relevant contexts. We experience surprise when System 1 is proved wrong in Kahneman's model. Dorst and Cross (2001) suggests that surprise 'keeps a designer from routine behaviour' and drive the originality and creativity in the project. This, they say, is analogous to natural evolution, which is now also seen to be driven by a reaction to surprise. Peirce emphasises surprise in his abductive inquiry, where surprise brings us 'outside our prevailing presuppositions' (Shank, 1998). In a sense, the aim of both Schön's experimental framework and the rationality of Toplak et al. is to search for evidence which breaks these presuppositions. If we look to the hermeneutic circle according to Gadamer (2004), the surprise can be seen to create a tension between the familiar and the strange, and such tension is the source of all learning. Note that these surprises, particularly in Schön's context, can be either positive or negative. Unexpected consequences of a move may be either desirable or damaging. Either way, the surprise gives insight to direct further search.

Surprises prompt, or even force, reinterpretation of the problem. By seeing the design as a human user, the designer is able to review human goals and requirements. This may lead to new goals and a reframing of the problem. Simon may not have room for surprise. In his models for solving ill-structured problems (Simon, 1973), reframing (or redefinition) of the problem is the result of *recognition*, rather than surprise. His problem solver has an instrumental inner loop which operates in working memory, and an outer retrieval loop which relies on recognition in long-term memory, interrupting the inner loop to reframe the problem. In this model, everything is essentially known, and difficulty arises from complexity which exceeds our computational power. Schön, in contrast, views design as exploration of the unknown and the unprecedented.

Even if Schön gears his reflection-in-action towards unique problems, it should still work on routine problems. The experiments will simply fail to surprise, and thus affirm the routine preconceptions. The experimental rigour is still required if we believe Kahneman's demonstrations that System 1 is prone to bias. The assumption that a problem be routine is also a judgement which has to be confirmed by rigorous testing. In contrast, Simon's approach may have a problem in unprecedented cases. The retrieval system has access to past experience in long-term memory, but this may have little relevance when new and unprecedented situations evolve in an innovative design process. It also has access to the environment, wherein human behaviour can be observed. It is not clear, however, how human goals can be observed and identified by the mechanistic retrieval algorithm that Simon presents. Simon (1996, p. 130) associates differing goals with differing design styles, and such style information can be stored in long-term memory. While this may cater for contradictory goals, it does not tell us how to identify *new* goals as they are generated from the design process.

Schön's use of *seeing-as* is as close as we get to a solution to the is-ought problem in our analysis. The thought experimenter does not primarily see the design as it is in itself, but as it *is to* real people. The designer infers what ought to be designed, not from facts as such, but from the meaning it has to human beings. Unfortunately, this has brought us out of the domain of propositional knowledge. Joseph Weizenbaum, who was, like Simon, a great pioneer in artificial intelligence, pointed out that there are things which 'people come to know only as a consequence of having been treated as human beings by other human beings' (Weizenbaum, 1976, p. 209). This knowledge is inherently tacit, although it may possibly be shared through the *mimesis* (imitation) and *seeing-as* employed in reflection-in-action and also in poetics.

Lastly, we should emphasise the notion of *stable forms* from Simon's evolutionary model. In the course of evolution, many different complexes come into being, and some of them are stable and can serve as building blocks for new moves (Simon, 1981, p. 207). The form being stable entails that it is persistent, so that it is remembered and made available to future steps of the search. Stable forms also have an interpretation in Schön's experimental framework. The sketches and drawings subjected to an experiment need to be well-defined and stable so that they resist change and can 'talk back'. Schön (1987, p. 140) makes this point in the context of a student presenting a rudimentary design to her supervisor. She is very proud of certain features of the design, but the supervisor refuses to evaluate the idea because the sketch is rudimentary. The loosely defined geometry can adapt to the story, and thus fail to reveal inconsistencies. Confident assessment is only possible with a detailed and precise floor plan. This reliance on stable forms calls for documentation of intermediate stages of development. Schön and Simon may have different reasons, but they both require it.

6 Propositional or tacit

Schön and Simon agree that there is a form of reasoning which is appropriate for design, and which is distinct from the scientific reasoning about universal truths and also distinct from the less reliable judgement. We can talk about 'art', which is a common translation of *techne*, which is one of Aristotle's states of the rational mind. Of course, we are aware that art, in modern usage, is often indistinguishable from purely subjective judgement, and thus not associated with rationality. One reason for this is that artistic reasoning tends to be tacit. When the artist does not reveal their reasoning, it is hard for an outsider to tell if there is any reasoning at all. As we have seen, both Schön and Simon say that reasoning is often 'hidden' or 'cloaked'.

An important contribution of Schön's is to identify and emphasise the tacit knowledge, and tacit reasoning, underpinning professional practice. As he says (Schön, 1983, p. 50), 'both ordinary people and professionals often think about what they are doing, sometimes even while doing it'. Much of this thinking, as it is presented by Schön, is already propositional in the sense that sentences are formed mentally, even if the sentences are not actually spoken. This justifies the view of the professions as art, rather than judgement. Still, unspoken reasoning leaves other problems, when proposed solutions cannot be validated by others. Part of the background for the crisis in the professions, as Schön (1983, p. 4) describes it, is that

Professionals themselves have delivered widely disparate and conflicting recommendations concerning problems of national importance.

Professional recommendation appears as contested opinion, rather than objective and reproducible knowledge. To have any hope of resolving conflicts of opinion, it is necessary to document the reasoning, so that the source of disagreement can be identified. Many conflicts of opinion are due to differences in the information available and in the assumptions made, leading to different premises for the reasoning. Only when the reasoning is documented can these differences be identified and resolved. Tacit reasoning does not support the conversing which we addressed in the introduction (citing Cross, 2019, 1996), and the reasoning needs to be both interdisciplinary and disciplined, like the conversing ought to be. Thus we need a design method which is not only rational, but also verbalised.

7 Bootstrap problem

The iterative process has been discussed at length, and we have seen how the system evolves through a series of moves, with each move born from the current frame to create a new frame. But wherefrom comes the initial frame?

Neither Simon nor Schön addresses this question in detail, but Schön (1983, p. 81) makes an important observation when Quist tells the student Petra to 'begin with a discipline, even if it is arbitrary'. To get started on a solution, Petra has to constrain the problem to a frame which is manageable and comprehensible. This is more important than choosing the right frame, because the frame can always be changed later. In order to get started, an arbitrary frame does just fine. Boaler (2015) has also pointed out that the most successful people in the world are those who make the most mistakes, and Ball and Christensen (2019) have shown that speculative trial and error is a useful strategy in design. This should not be surprising, neither in Schön's nor Simon's framework, since those who try to avoid mistakes may not dare to make the first move.

Something similar can be observed in iterative algorithms in artificial intelligence (e.g. genetic algorithms and neural networks). They typically start with a random assignment which is gradually improved for each iteration. In practice, the initial state rarely matters, and similar results are achieved from different starting points. It is much more important that the algorithm is efficient enough to allow the iteration to converge in reasonable time.

We can also ask if it is at all possible to choose the initial frame, or more accurately, what constitutes the actual starting point. After all, the designer is a human being, and therefore has some prior experience and understanding which cannot necessarily be suppressed. In a sense, this constitutes a pre-existing frame, however rudimentary. Is the reframing from such a pre-project frame to 'initial' frame any different from reframing later in the process?

We are not going to hazard an answer to this question in this paper. It is possible that some answer can be found in the three-fold *mimesis* of Ricœur (1984). *Mimesis* is the Greek word for imitation, and it refers to a creative imitation rather than to a copy (cf. Aristotle's *Poetics*). A design concept (even a preliminary and partial sketch) is a *mimesis* of a (potential) situation, just like works of art and literature. What Ricœur tells us, is that the audience already possesses a prior understanding, the *mimesis I* or pre-figuration. The work of art or design is *mimesis II* or the con-figuration. Studying this work we reinterpret the situation, and arrive at a re-figuration or *mimesis III*. Kemp (2006) has recast this idea in the context of learning and education. The student is already educated. There is never a *tabula rasa*. We shall leave this as a speculative idea for further research.

8 Closing remarks

Design depends on practical reason. Neither judgement, which is fallible, nor science, in the sense of universal knowledge, is sufficient to deal with the contingencies and uniqueness of the real world. Both Schön and Simon search for the third alternative, Aristotle's *logistikon*, and viewing them as opponents in a war between science and intuition is not very fruitful.

The relationship between science and design is a complex one. As we said at the beginning, Simon and Schön opposed the trend where science was supposed to solve every problem. In more recent years, Farrell and Hooker (2012, 2015) have argued that design is everything, or at least that science is essentially a form of design. After all, (research) scientists make theories for an audience. Successful results are designed to be comprehensible, meaningful, and/or useful, one way or another, to the audience. Thus there are contingencies which determine what theories to research and how to present them. Farrell and Hooker's first paper sparked an interesting debate with Galle and Kroes (2014, 2015).

Our analysis takes a different angle. We aim to explore the reasoning and the epistemology that Schön and Simon promote, looking for a common essence. Thereby we hope to further Simon's and Schön's vision of design as a common culture, spanning the two cultures of sciences and humanities. As professionals and academics, we are in constant danger of resorting to justifications which are only meaningful within our own cultural niche, and this is of little use when we make solutions intended for wider use. The need for interdisciplinary conversation is particularly important in the development of new technology, where we need both the scientific understanding of how it works, and the designerly understanding of what it means to real people, and these two questions cannot be fully separated. The rational methodologies that Schön and Simon propose give the means to name and share reasons, also between disciplines, and this allows the reasons to be reviewed, validated, and attacked. Disagreement about conclusions can be translated into disagreement about premises, which can then be reviewed. Simon and Schön largely agree on how to design a rational methodology of experiment and evaluation, in spite of different starting points.

We have identified one key point where Simon and Schön deviate. They agree that goals change during the evolution of new designs, but only Schön proposed any means to identify new goals. His approach of *seeing-as*, in terms of a human individual, is far from the prevailing scientific paradigm. Disciplines which are rooted in the humanities, may well know how to apply these methodologies in practice, and reassess human goals. Engineering, and other disciplines rooted in the sciences, may have something to learn. We have only been able to scratch the surface in this paper, and more work is needed to adapt this human perspective on evaluation to different disciplines.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Notes

1. An early definition of the word 'Technologie' is found in *Technologisches Wörterbuch* by Johan Karl Gottfried Jacobsson from the late 18th century.
2. Bounded rationality is central to the work for which Simon won the Nobel Prize in economics in 1978 (Carlson, 1978).

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