

Counter-intuitive Design Thinking: Implications for Design Education, Research and Practice

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This paper reports research analysing recent changes to design practice, research and theory in Art and Design fields, relating to increased involvement in the territory of complex socio-technical systems design. The analyses suggest this extension into these new and very different territories of design imply it is necessary for Art and Design fields to re-envisage their theories, research and practices in light of the understanding of design in this complex arena from the field of complex systems design. The findings of these research analyses broadly challenge many of the traditional claims of design theory, practice, research and education in the literatures of sub-fields of Art and Design.

Keywords: complex socio-technical systems design, counter-intuitive design thinking, Art and Design, design theory foundations.

Introduction

Human thinking, intuition and feeling that is the basis of design activity is compromised by cognitive biases, biological limitations and fallacies (see, for example, Fernandez-Armesto, 2004; Gilovich, 1993; Klein, 1996; Knight, 1999; Labossiere, 1995; Schacter, 1999; Stroessner & Heuer, 1996; Warren, 1976). These cognitive limitations are grounded in the evolutionary development of human beings (Damasio, 1994, 1999; Fernandez-Armesto, 2004). Human biology is the result of selection processes from less technological eras. Our human cognitive and affective processes have developed to equip us to respond quickly to direct, simple, causally-obvious challenges in which outcomes are close in time and space and the immediate result of obvious causes. Biologically, these cognitive processes used in design activity do NOT equip us to envisage, predict or make judgments about complex situations in which causes of outcomes are complex, multiple and hidden with outcomes and causes are remote in time and location. In fact, they delude us into erroneous understanding and faulty design judgments when design situations are complex. These limitations of human functioning are an important understanding of the limitations of designers working on complex systems design.

There is little evidence that design professionals in Art and Design fields are aware of, and take account of, these biologically-based limitations of human thinking, intuition and feeling in design education, design practice, generating design solutions, design methods and design theory-making. In contrast, the field of complex systems design (particularly sub-field that focuses on complex socio-technical systems design) has committed extensive effort into understanding the design implications of these human limitations and developing specific design methods to address them. Awareness over time of the high level of failures of complex systems design failures

has led the complex systems design fields to identify, and develop design methods to address, the limitations of human cognitive and emotional functioning in designing in the realm of complex situations.

Recently, design practice, research and theory in all Art and Design sub-fields has crossed extensively into complex design with new sub-fields such as design strategy, design management, ergonomics, post-modern design, rhetoric, participatory design, user-based design, collaborative design processes, reflexive design, reflective design practice, design evaluation, interactivity, interaction design, mass customization, and open source design. This transition brings the Art and Design subfields into the territory addressed by the design research, design practices and design education of complex systems design

To précis, the above indicates that:

- Findings of complex socio-technical systems design research apply to all Art and Design fields involved in this transition into complex systems design.
- Previous tacit assumptions about design practice and the basis of design theory and research across all Art and Design fields may be inappropriate, inadequate and incorrect in terms of addressing these new territories of complex design.
- Outcomes of design activity in Art and Design fields can be improved and failures reduced
- Design education in Art and Design fields may need substantial change along with a deep revision of design research and theory in those fields.

To explain these issues in more detail, this paper focuses on *counter-intuitive design*, a core element of complex systems design research. This focus provides a basis for identifying other aspects of complex systems design important for Art and Design fields and, at a larger scale than addressed in this paper, provides a template for including them into Art and Design theories, practices, education and research.

Changes in the Scope of Art and Design fields

Until recently, the focus in design in Art and Design fields has been on form, attractiveness, simple functionality and responding to non-complex design brief criteria. Design methods and theories of Art and Design have focused on the immediate and close at hand where causes are direct (for example, a user interacts with a computer screen on the basis of what they think and feel that the screen will do in response to their activities in the now). This kind of design activity is an activity for which human brains are evolutionarily well-adapted. To date, design education in Art and Design fields has aimed at refining human skills in this kind of design activity.

Recently, Art and Design fields have increasingly targeted creating designs whose influences and effects are remote in time and place, with multiple causal factors often with feedback loops especially in the socio-technical arena. In parallel, many conventional design situations in Art and Design fields are now increasingly viewed with more sophistication than they were and designers are increasingly expected to take into account complex socio-technical design factors with multiple feedback loops. These changes to the scope of Art and Design

fields' activities reposition many previously 'normal' design issues addressed by Art and Design designers as complex systems design problems to which the findings of the complex systems design field apply.

The research described in this paper has identified a disjoint between the new scope of Art and Design fields with their transition into the complex systems design arena, and the limitations of traditional Art and Design approaches that are inappropriate to complex systems design. In addition, it was identified from the literature that there seems to be extensive blindness across Art and Design fields of these limitations and a naïve presumption that traditional design concepts, theories, design methods, analyses and educational programs typical of Art and Design's earlier eras apply to these new complex systems design situations.

Together, these present a significant problem. Design practitioners and research are using theories and tools that do not work in the new complex systems design arenas in which they are increasingly involved. Worse, design educators are setting up design students to fail.

The Problem: Errors of Thought, Feelings and Intuition in Design

To recap from the first section, humans throughout our evolution have adapted as a result of selection pressures from our environments. This development has biologically limited our cognition, emotions, feelings, intuitions and reflexes to deal with situations that are simple, close in time and space, and where causes are directly and obviously linked to outcomes (e.g. touch a fire and your finger gets burned). Our brains have, however, also learned to occasionally adapt to forecasting the outcomes of situations, but only those with a **single feedback loop** and this has provided designers with the biological attributes by which they can design simple technology unaided by technical support (the room temperature rises, a thermostat cuts in and turns off the heating and the room temperature goes down until that the thermostat cuts in and restarts the heating).

The absolute limit of human thinking and intuition seems to be biologically limited to understand situations with **less than two feedback loops**. Only the most experienced complex systems practitioners are able to intuitively assess the behaviour of a situation with two feedback loops and then only approximately. These biological limitations of human thinking, intuition, feeling and understanding apply to designers as much as non-designers. A simple test: Peter has \$1.10 and buys two items. The first item costs \$1 more. How much is the second item? Most readers answer 10 cents. This is a very simple uncluttered **single feedback loop** problem shaped in arithmetic. The answer is \$1.05 and 5 cents. To test if one can easily predict the behaviours of a simple **double feedback loop** situation try <http://web.mit.edu/jsterman/www/Bathtub.pdf>.

Most contemporary non-trivial complex design problems, however, commonly have dozens or hundreds of feedback loops (see for example, <http://www.shiftn.com/obesity/Full-Map.html>). Traditionally, designers from Art and Design fields have dealt with this problem by several approaches, all of which can be seen to be invalid and produce faulty design outcomes:

- Define the bounds of the design context so that they exclude feedback loops
- Ignore feedback loops by calling the situation a 'wicked problem'

Avoid thinking about the feedback loop issues and instead attempt to use traditional design tools of bodily feelings, intuition and visualisation that are only appropriate to non-feedback loop problems
Attempt to use consultation with multiple stakeholders as a substitute for understanding the situation and the behaviours of proposed designs. This is seductive but unsuccessful: multiple individuals all misunderstanding the behaviour of a situation is no better as a design method than one person misunderstanding the situation.

All of the above four common design approaches used in Art and Design fields to address complex systems design problems result in faulty design solutions in design situations involving 2 or more feedback loops. Experience has shown that many of them will produce results opposite to those intended by the designers.

Humorist Henry Mencken is quoted as capturing the essence of this issue,

‘For every complex problem, there is a solution that is simple, neat and wrong.’

The usual design approaches of intuition, visualizing and feeling ones way round a solution do not help when a designer is unable to fully envisage how the solution will behave. Evidence shows that people intuit the wrong answer whilst believing absolutely (on the basis of their feelings and mental comfort) that they are correct.

Meadows (1999) a key author of the seminal book ‘Limits to Growth’ (D. H. Meadows, Meadows, Randers, & Behrens III, 1972) that sparked off much of the present ecological, environmental and green movements, quoted Forrester,

‘Time after time I’ve done an analysis of a company, and I’ve figured out a leverage point [the location of the most effective design intervention] - in inventory policy, maybe, or in the relationship between the sales force and productive force, or in personnel policy. Then I’ve gone to the company and discovered there is already a lot of attention to that point. Everyone is trying very hard to push it *in the wrong direction!*’

This is a significant problem of design research practice and education. Designers falsely feel and believe they can intuitively understand and predict the behaviour of systems with multiple interlinked feedback loops. Erroneously our minds and bodies both give clear indications that we can understand and predict complex design behaviours with 2 or more feedback loops when we cannot.

An additional problem is that complex multi-feedback loop designs ARE produced and designed by designers across all Art and Design sub-fields using the approaches suited to non-feedback loop problems. These designed products, services and systems usually fail. The gap in time between their initial production and their failure are typically such, however, that the failures are not attributed to the designers. Commonly, complex designs function well at first and later when problems emerge due to the actions of the feedback loops, the design failures are blamed on something else.

Counter-intuitive Design

In the complex systems design field, the creation of designs that address the problems of humans' limitations in thinking, feeling and intuition of situations involving two or more feedback loops is known as 'counter-intuitive thinking' and the results are counter-intuitive designs.

The idea of counter-intuitive thinking was raised by Forrester in the realm of Industrial Dynamics as long ago as 1969 (Forrester, 1971). Industrial Dynamics, which later became called System Dynamics, is a core theory and method foundation of the complex systems design field. Counter-intuitive designs (and the methods for identifying them) is the process of addressing what are known and avoided Art and Design fields 'wicked problems'. In parallel, Zwicky (1969) developed 'morphological analysis' as a supporting counter-intuitive design methodology for addressing 'wicked problems' that identified the real design space of a 'wicked problem' by excluding design options that are not viable regardless of their apparent attraction.

Forrester and later Meadows (1999) identified there were an uncommonly large number of instances in which highly competent designers, planners and managers involved in creating or intervening in complex socio-technical and organisational systems designed solutions that in the longer term resulted in movement away from the intended outcomes rather than towards them. The same issues are found in all areas of design involving two or more feedback loops. For example, in the arenas of manufacturing design and organisational design, Deming (1986, 1993) identified it was common for designers and managers of manufacturing systems to make similar errors in the direction of their judgments when asked to resolve production problems and improve the quality of output. In the environmental design field, designers, planners and managers of third world development of food production suffered similar misguided design decision making (Harrison, 1987).

The only approach that has proven success in designing in situations with 2 or more feedback loops is the use of mathematically-based formal representational systems modelling techniques by which the detailed behaviour of designed outcomes in a multi-feedback loop situation can be predicted. Evidence of both the counter-intuitive failure phenomenon and the success of the mathematically-based system dynamics models is particularly strong in the design of social and socio-technical systems.

Complex System Design

Over the last 50 years or so, across complex systems design fields, a range of design and analysis tools have been developed that enable designers to work with design situations involving more than one feedback loop. An example is the use of System dynamic causal loop modeling shown in Fig 1 below that shows the feedback loops in the analysis of a design for a university research motivation scheme. The causal loop model comprises entities (in boxes) and causal relationships (arrowed lines) between them. Feedback loops comprise any closed loop of

arrow-headed lines in the Figure regardless of the direction of the arrows. There are dozens of feedback loops in Figure 1. The number of feedback loops is the total number of combinations of lines that make continuous loops.

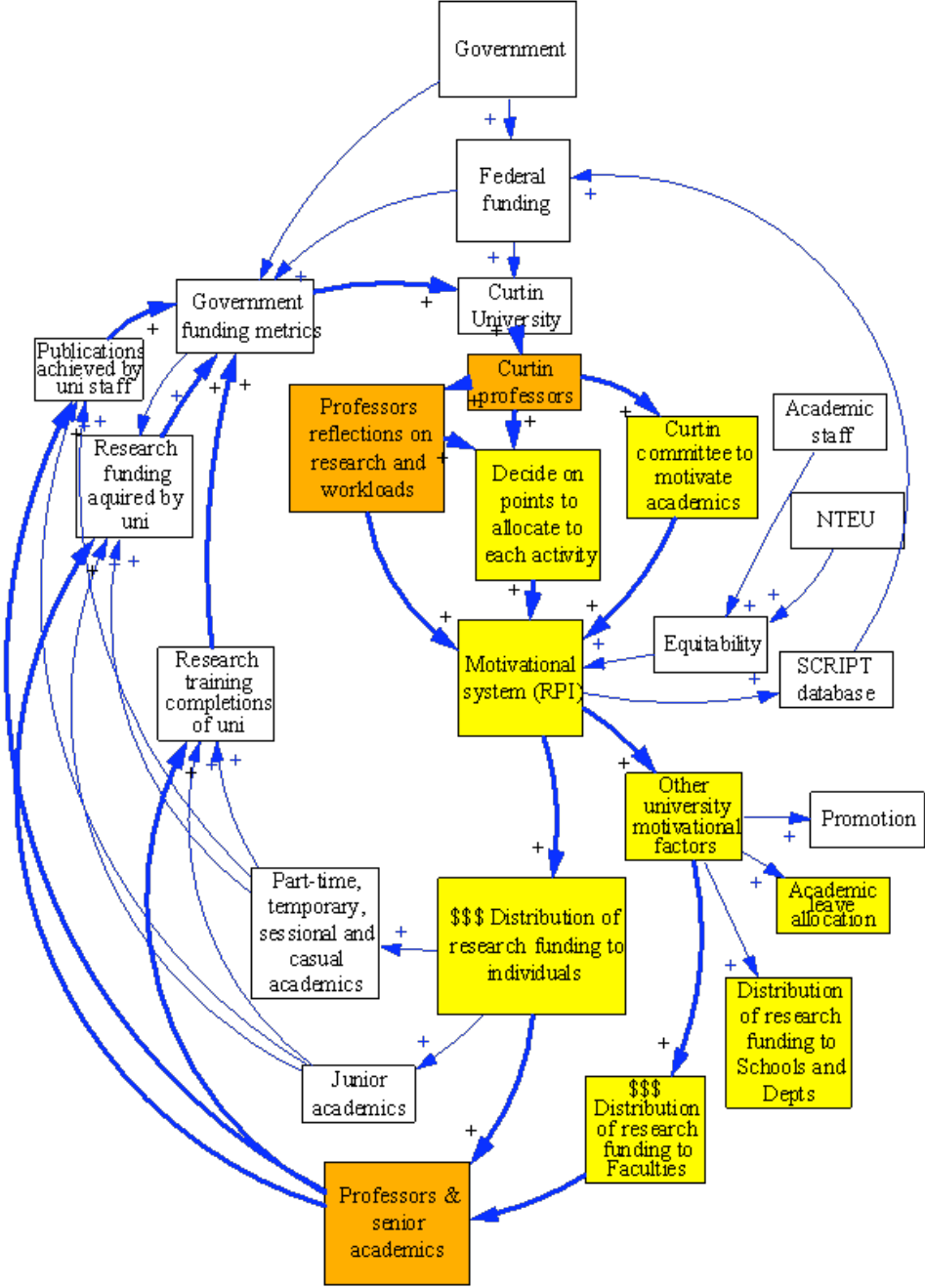


Figure 1: Analysis of a multi-feedback loop design of a university motivational information system (Love & Cooper, 2008)

The casual loop model has value in itself for assisting with ‘thinking out’ the causal relationships and checking that the thoughts and opinions and beliefs of all contributors and collaborators in a consultative process have been included. In the form above in Figure 1, the causal loop diagram provides a visible basis for designers to start to understand the feedback loop relationships at least to the point that they can infer the direction of likely

changes in outcomes. This is an important first step in avoiding designing solutions that act in opposition to what is intended.

The more important advantage of the above causal loop model, however, is that it can be converted into a working predictive design tool. The causal loop model in Fig 1. is capable of being developed further into a fully-fledged active system dynamics design model that can be used by designers to predict the behaviour over time of their designs in ways that include all the actions of the multiple feedback loops of the situation.

The problems of counter-intuitive design thinking and the failure of conventional design techniques in complex socio-technical systems design or interventions is particularly significant for new sub-fields of design in Art and Design whose focus is on complex design situations. These new design subfields include, e.g. Design Strategy, Design Thinking and participatory/ collaborative approaches to design. The findings and analyses of the research outlined in this paper suggest the above new design sub-fields are promoting benefits that are likely to be illusory and short term when applied to designing situations involving more than one feedback loop.

Resistance to Change

It can reasonably be asked,

‘If the above issues and problems are so obvious and so significant, why they are not already mainstream thought in design education and design practice in Art and Design fields?’

Several answers can be inferred from observation; most of which have political and personal dimensions:

- The problem of counter-intuitive thinking and the limitations of current design approaches to multi-feedback loop design situations exposes much of what is currently considered ‘design cognition’ and the design and emotion literature to be compromised and in need of significant review in relation to new complex areas of Art and Design.
- The nature of many Art and Design fields and their history in craft, which is normally not complex, along with designers’ well-established central roles in creating new products and services, all these make it hard for designers and observers of design in Art and Design fields to identify that design thinking, research and education is compromised by human limitations.
- It takes a particular kind of perverse thinking to counter-intuitively identify falsely successful design outcomes. For example, that designed technologies that apparently encourage social interaction and collaboration, for example, iPods and iTunes, result in the opposite: the social isolation of individuals predominately listening to music or watching videos by themselves rather than spending that time engaging in social interactions with others (its primary role is as a ‘personal’ media device (<http://www.apple.com/au/itunes/>)).
- Without awareness of the phenomena of cognitive bias and the relationships to counter-intuitive design thinking and feedback loops, it is hard for us to see cognitive biases and

biologically-based human limitations on design practices. The lack of design education on this topic leaves designers to presume the phenomenon does not exist.

- It is deeply disturbing to our sense of self as individuals to realise that one's thinking is compromised and likely to be 100% wrong in one's areas of expertise, especially in situations in which by previous design training one is absolutely sure of something and feels that one's judgement is absolutely correct. Sudden awareness of these deep personal failures in the processes of an individual's design judgement typically results in strong emotionally-based and ego-protective forces from within the individual that act to push aside this awareness of their faulty design thinking.
- In cases of obvious failure of complex designs created using design approaches only suited to problems of less than one feedback loop, there are two common responses by design fields. Experience has shown that designers, design researchers, theorists, sponsors and users will typically be persuaded that the problems do not exist (by sleight of media hand) or will claim that the failure of the design is due to some extraneous reason that could not have possibly been seen at the time of the design, for example, that they are 'wicked' problems.

Wicked Problems in Art and Design fields

The above analyses raise a challenge to a core assumption in professional design practices in Art and Design fields. Since 1971, the idea of 'wicked problems' has been central to defining the boundary of difficulty in design in Art and Design (see, for example, Buchanan, 1992; Coyne, 2005; Rittel, 1971; Rittel & Webber, 1974; Rittel & Webber, 1984).

The idea of 'wicked problems' has acted both as a designer's escape clause from responsibility and as a safety belt protecting designers from prosecution. When a design situation can be classified as a 'wicked problem' then it has been assumed by the thinking of Art and Design culture, that the outcomes of design work can only be speculative and designers cannot be expected to guarantee good design solutions.

In essence, a 'wicked problem' is one with multiple feedback loops. A limitation of the design methods of Art and Design sub-fields has been that 'wicked problems' cannot be satisfactorily addressed by the design methods approaches of the fields of Art and Design. In part this has been what has defined the idea of 'wicked problems' in Art and Design fields. In contrast, the 'wicked problems' of Art and Design are typically seen in systems design fields as conventional design issues to be addressed by the design methods of complex socio-technical systems design.

This invites the question whether wicked problems are not wicked at all. It may be that the idea of 'wicked problems' is best seen as a politically convenient fiction. Redirecting blame, as in the last point of the list in the previous section, raises the question as to whether design failures in the case of wicked problems are merely due to lack of competence in designers. It opens up the question of whether wicked problems could be addressed as a matter of course in Art and Design fields, if designers from those fields used readily available complex systems design methods.

The evidence from complex systems design field as it applies to design fields in Art and Design is that apparently wicked problems can be understood and addressed that this suggests failure to do so lays the responsibility for design failures not on extraneous factors but rather firmly in the hands and bank accounts of designers, design educators and design businesses in Art and Design fields.

Implications

The implications of all of the above analyses reach deeply into and challenge many contemporary practices and beliefs in design education, research and professional practices in Art and Design.

To recap, at their simplest, the findings from the fields of complex systems design indicate that when humans, designers or not, try unaided to understand complex systems, predict their behaviour and create designs that interact with complex situations they will fail. Experience shows that most system outcomes involving two or more feedback loops are counter-intuitive.

Designers will typically produce solutions that are faulty, and they will suggest design improvements in the opposite direction from those necessary those that will produce the intended design behaviours. In addition, designers will typically be falsely confident about their ability to identify the most critical points of the design situation and their design solutions.

Resolving these issues requires designers in Art and Design fields to understand that:

- Human brains are not adapted for envisaging or intuiting understanding of multiple feedback loop systems
- Complex systems with two or more feedback loops is an area of design in which design fails dramatically when it is based on human subjective thinking, intuition, feelings and emotions
- Counter intuitive outcomes are the norm
- Design methods not usually used by designers in Art and Design can help identify and address counter-intuitive design issues that are beyond the limitations of designers brains, intuition and feelings.
- Conventional design methods from Art and Design fields do not work in the complex design arena involving two or more feedback loops.

The analyses also suggest that many design tools, methods and theories, particularly in the areas of design cognition and design thinking, are deeply flawed in ways that are not, or have been not, obvious to students, Art and Design educators, design theorists and design practitioners. This suggestion comes from a realisation that many common design activities in Art and Design fields can be, and are now being, reinterpreted through a lens of complexity. This is particularly obvious in the uptake of 2nd order cybernetic approaches in which the designed object results in learning and a reshaping of what it is to be human. This results in interpreting designs

in terms of multiple feedback issues that by implication then need to be incorporated into design research, theory and competent professional design activity. Conventional design methods and theories of Art and Design fields that are suited to non-complex design situations do not have the scope to address these issues and hence are now insufficient for the design issues for which they were previously developed.

Part of the blindness towards these failures is as a result of the biologically-based delusion by which designers, design educators and design researchers will incorrectly feel good about what they do, feel that it is correct what they do, and designs will appear initially to function. It is later, after handoff of a design, that the influences of a design's multiple feedback loops will emerge, the designs will fail or will produce outcomes that are different or even opposite to those intended (see, for example, the iPod example above).

Implications of these understandings for design education in Art and Design fields include:

- It is important to educate designers, and for designers in practice to be aware, that designing solutions involving systems with two or more feedback loops cannot be thought through, inferred or successfully undertaken by design thinking, designers' intuition or feeling-based design methods.
- It will be important to teach designers to be aware that when there are two or more feedback loops in a design situation, the characteristics of successful designs will most often display counter-intuitive relationships that will 'feel' or be thought of as wrong.
- It is important for design educators and students to be able to distinguish between *complex* design situations involving two or more feedback loops and merely *complicated* design situations, where 'complicated' means design situations with a lot of simple non-feedback factors, as distinct from complex situations with multiple feedback loops (and perhaps less design factors).
- An important aspect of design education and design practice is for designers to be able to identify when they are designing in 'complex' rather than 'complicated' realms.
- It is likely important for design educators to understand that design thinking, feelings and intuition are typically a handicap rather than useful skill in designs involving multiple feedback loops. Traditional design expertise in being able to intuitively feel one's way around a design is mistaken in these types of situations. Designers cannot feel their way around a solution and identify correct solutions by feelings because emotion-based designerly judgement is false in situations involving two or more feedback loops. Solution will be either wrong or sub-optimal. In the case of interventions in designed systems, designers' feelings and intuition-based skills are likely to suggest interventions that will move the solution in the opposite or a different direction from that which they intend in spite of the fact that they will feel happy with the solution at the time of designing.
- Design educators will likely find it useful to emphasise that in design practice the designed system's BEHAVIOUR is the primary issue, and that explicitly understanding how and why a design behaves the way it does is essential to being able to design successfully in a competent and comprehensive manner. In complex designs involving multiple feedback

loops, craft-based design methods that do not require this depth of explicit understanding of behaviour do not result in the solutions that align with designers' intentions or visions.

- It is likely to be important that when designing in complex situations, designers in Art and Design sub-fields are taught to use appropriate design tools from complex systems design fields that describe and model behaviours of the design and its feedback loops. Two appropriate complex systems design tools are 'Causal Loop modelling' and 'System Dynamic modelling'.
- It is important for design educators to be aware there are two different classes of systems tools: **information-gathering** systems design tools and **behaviour-modelling** system design tools. Most systems design tools identify **information** about system parameters and boundary conditions of specific responses. All of this information is necessary in preparation for using behaviour modelling system design tools. They are different from the relatively small group of system design tools used to model and predict system **behaviours**. Designers who only use information-gathering systems design tools such as soft systems methods will not be able to understand or predict the behaviour of a designed system using these tools. They will face identical design problems to those that do not use any systems tools because they will be depended only on traditional design approaches such as feelings, intuition, group discussion responses as in participative design. As described earlier, these and similar design approaches fail in complex systems because of the limitations of all human brains in situations involving two or more feedback loops.

Conclusions

This paper has described research reviewing the insights from the complex systems design field to Art and Design fields that are increasingly involved in designing in complex design spaces involving two or more feedback loops. The paper draws attention to the implications of these findings of the field of complex systems design for recent developments in Art and Design fields. The paper has identified limitations to the design methods, practices and theories of traditional Art and Design fields when applied in complex socio-technical systems arenas. It has suggested that these will consistently result in faulty design outcomes and, from experience, that a range of socially-based illusions and deceptions are used to deflect criticism of these failures.

The analyses outlined in the paper suggest changes are needed within design education and practices in Art and Design fields towards more sophisticated understanding of complex systems design and prediction of the behaviours of design outcomes in complex design solution spaces that involve multiple feedback loops through the use of mathematically-based complex systems tools to address counter-intuitive behaviours relating to usability, emotions, user participation, interactions with other design objects, platform designs, design strategy, and design thinking.

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