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SITUATED COGNITION VIEW OF INNOVATION WITH IMPLICATIONS FOR INNOVATION POLICY

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Introduction

Herbert Simon, in his 1968 Karl Compton Taylor lectures at the Massachusetts Institute of Technology (Simon 1969), introduced the notion that there should be a science of those things that humans generated in addition to the science of those things that occurred naturally. He called this the *Sciences of the Artificial*. The science of innovation and innovation policy falls squarely into Simon's purview of the artificial. Like all sciences the science of such artificial constructs as innovation and innovation policy must commence with the recognition that there are phenomena to be observed and studied and about which testable hypotheses need to be generated and tested. If such hypotheses survive testing and are shown to have adequate predictive capacities they may be elevated to the status of theories. Scientific research into innovation and innovation policy is still at an early stage where there is not yet full agreement on what all the phenomena are, there is not an adequate set of testable hypotheses and the theories are still being developed rather than the outgrowth of tested hypotheses (Feller Section 1; Thomas Section 3.3). This is not unusual in immature sciences.

This chapter presents the view that one of the reasons for the current state is a lack of a sufficiently wide ambit in our understanding of the various phenomena that go to make up innovation and not simply immaturity.

As is usual in immature fields there is a lack of an agreed ontology for the field and as a consequence there is a lack of agreement on the terminology used to describe all the phenomena. The terms "creativity" and "innovation" are often conflated and this causes confusion. In this chapter we will distinguish them as follows: creativity is a process that produces novel, unexpected and useful ideas, often simply called "creative ideas", which may be multiple forms ranging from intellectual property in research papers and patents through to prototypes (Boden 2003; Gero 1990; Gero and Maher 1993; Runco 2006; Sawyer 2006; Sternberg 1998). Whilst innovation is the process that turns creative ideas into products or processes (Archibugi et al 1999; Edquist 1997). Innovation is the realization or embodiment of creative ideas. This separation of the phenomena of creativity and innovation is important. It allows us to deal with each of them separately both in terms of studying them and in terms of how they are dealt with in organizations. Both idea generation and idea realization may occur in various domains and across various life-cycle stages (Archer 1971; Roozenburg and Eekels 1995). In all cases, they involve a producer and one or more adopters of the creative idea and the producer and adopters of the embodiment of the creative idea – the innovation. The producer of the creative idea can be in the same organization as its adopter but need not be. The producer of the embodiment is rarely in the same organization as its adopters, ie, consumers. Where necessary to disambiguate the adopter of the creative idea from the adopter of innovation we will call the former the "innovator".

This chapter presents the argument that one phenomenon that has not been adequately accounted for in many approaches to innovation and hence innovation policy is the changing understanding of the producers and adopters of the creative idea and of its resulting innovation and the interaction of the creative idea and the innovation with the understanding of the adopters. This can be captured by taking a cognitive view of the processes involved. By cognitive view we mean a mental view. In order to develop this we need to have a brief introduction to an area of cognitive science called “situated cognition”.

Situated Cognition

Situated cognition (Clancey 1997) is a set of concepts that includes that what you think the world is about affects what it is about for you, ie, any system operates within its own worldview and that worldview affects its understanding of its interactions with its environment (Dewey 1896/1981; Clancey 1997; Gero 2008). When we say a person or group of people is “situated” (Smith and Gero 2005) we mean that they have a worldview that is based on their experience (rather than using the artificial intelligence meaning that it is embodied in an environment). Situated cognition involves three basic ideas: situations, constructive memory and interaction.

Situations

From this cognitive perspective situations are mental constructs that structure and hence give meaning to what is observed and perceived based on a worldview. This implies that the meanings of things are not in them but in the observer. Such meanings are personal and social constructions based on experience. If we call everything around an observer the environment then an observer, based on their situation, takes selective input from the environment and constructs meanings about the environment. This indicates that different observers in the same environment but with different situations will construct different meanings about the environment. We are familiar with this behavior. Take as an example the payment of substantial bonuses to individuals in the banking and finance industry as the environment. For those individuals the worldview from their situation lead them to perceive that the bonuses are justifiable compensation for the risks they have taken and the benefits they have brought to the company. For many in the general public the worldview from their situation leads them to perceive that these bonuses are unwarrantedly large.

Further, the same observer in the same environment at a later time when their situation has changed may construct a different meaning for the same environment. We are also familiar with behavior. Take as an example the reading of a research paper. Sometimes, during the initial reading of the paper we might think that the paper has nothing to offer. However, a later reading will change our view of it. The paper hasn’t changed we have changed our situation in between the first and last reading.

Take the case where you having just been dismissed from your job on the same day that your spouse has called to say that your child has been found to have stolen items from school and that the credit card company has sent a letter reducing your credit limit. You may well think the world is out to get you. As you are walking down the street you notice a person walking towards you but before they reach you they cross the road even though there is no crossing there. You may well think “even that person doesn’t like me”. Now take the case where your boss has called you in to say that you will be one of the few in your division to be awarded a bonus this year on the same day as your spouse has called to say that your child has just made letter grade at school and that the credit card company has sent a letter waiving a disputed charge. As you are walking down the street you notice a person walking towards you but before they reach you they cross the road even though there is no crossing there. You may well not even consciously think about that person. What is happening here is that the observed external worlds is the same but the meanings given to what was observed depend on the situation of the observer.

Slightly more formally, we can state that situations may be thought of as the set of concepts and their relationships that embody the ontology of the world under consideration. This ontology includes the value systems associated with the concepts that build expectations about the behavior of the world and are used to take decisions in and about that world (Gero and Kannengiesser 2009). Changing situations changes the value system of the world. Situations can change in one of three ways to produce a change in value system:

- concepts can be added or deleted;
- relationships between existing concepts can be added, deleted or modified in strength; or
- concepts can be substituted either for a subset of existing concepts or for all existing concepts.

Constructive memory

In 1896 Dewey published a seminal work on human thinking which languished for a while and was only rediscovered relatively recently. In that work he introduced the concept which today is called "constructive memory". This concept is best exemplified by a quote from Dewey via Clancey (Clancey, 1997):

> "Sequences of acts are composed such that subsequent experiences categorize and hence give meaning to what was experienced before".

Bartlett (1932/1977) demonstrated that human memory was not like a filing system full of cards with data on them that could be accessed by knowing an index for the card (which is very much like the memory of a computer). Rather than being simply a storage location memory was a process that constructed a memory when there was need to have a memory and when there was no sensate experience and no need for that memory, then that memory did not exist.

> "Remembering is not the re-excitation of innumerable fixed, lifeless and fragmentary traces. It is a … reconstruction, or construction, built out of the relation of our *attitude* towards a whole active mass of organised past reactions or experience, and to a little outstanding detail which commonly appears in image or in language form." Bartlett (1932)

The implication of this is that memory is not laid down and fixed at the time of the original sensate experience but is somehow a function of what comes later as well. It may be viewed as follows. Sensate experience is stored as an experience. Memories are constructed initially from that experience in response to demands for a memory of that experience but the construction of the memory includes the situation pertaining at the time of the demand for the memory. The effect of this is that the memory is not just a function of the original experience it is also a function of what has happened since the original experience and of the situation that prevails when the demand for the memory is made. Each memory, after it has been constructed, is added to the experience so that the experience is augmented by memories of it. These memories require processing of the experience as opposed to factual recall of aspects of the experience. These we will call "fact memories" rather than just "memories". New memories of the experience are constructed as a function of the original experience, the previous memories of it and the current situation. New memories can be viewed as new interpretations of the augmented experience.

Emergence occurs when properties are observed that are not directly derivable from the elemental properties of a system (Chalmers 2006). Emergence may be seen as one example of constructive memory in that it can be viewed as new interpretations of the experience.

This conception fits well with Gombrich's view of emergence as seen in the works of creative people.

> "In searching for a new solution Leonardo (da Vinci) projected new meanings into the forms he saw in his old discarded sketches" (Gombrich, 1966).

Take the three images in Figure 1. Figures 1(a) and (b) show two images. Figure 1(c) shows the two images next to each other and a third image, the white wine glass shape, emerges as a consequence of the juxtaposition of the two original images but is not part of either of them.

(a) (b) (c)

Figure 1. (a) and (b) individual images, (c) the two images from (a) and (b) juxtaposed, the white image of a wine glass emerges from their juxtaposition.

Interaction

The third plank of situated cognition is the notion of interaction: changes in situations and changes in memory are a consequence on interactions between adopters and producers, between producers and the creative ideas they produce, between adopters and the creative ideas they turn into innovations and finally between consumers as adopters of innovations as products.

We can observe the effects of interaction changing our view of the world in our daily lives. Imagine the following scenario. You are at the movies with a friend and while watching the movie you think to you yourself "This is the worst movie I have ever seen" and try and look at your watch in the dark to ascertain how much longer you have to suffer. However, as you are exiting the cinema your friend says "What an amazing movie! Did you grasp the symbolism in the … ? Did you see the how the camera shot Hitchcockian angles?" and goes on to extol the virtues of the movie in strong terms. It is likely that you will go home thinking that you had a different experience than the one you sensed at the time of watching the movie itself and will tell the people at home "I just saw this amazing movie. Superficially it has nothing to offer, but the symbolism … ". Because of the interaction subsequent to your sensate experience during the movie, your situation – your view of the world – has changed.

Innovation as Understood from Situated Cognition[1]

The central hypothesis of this chapter is that innovation is a process that changes the value systems of both producers and adopters. The values are encapsulated in the situation that producers and adopters construct using their individual or collective views of the world they interact with.

We can categorize creative ideas and innovations as artefacts that have been intentionally produced. In order to talk about such artefacts in a consistent manner independent of their form and domain it is useful to describe them and their production using an ontology. One ontology for intentionally produced artefacts, which we will now just cal artefacts, is the Function-Behavior-Structure (FBS) ontology (Gero 1990, Gero and Kannengiesser 2004). We will use this ontology both to describe artefacts and to locate value systems associated with artefacts.

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[1] Much of this and the next section is drawn from Gero and Kannengiesser 2009.

The FBS ontology provides all the constructs needed to represent the properties of an artefact. We will initially use examples from the design of physical artefacts as they are easier to comprehend than conceptual artefacts but these concepts apply equally to virtual artefacts, such as processes, strategies and instructions.

- *Function* (F) of an artefact is its teleology ("what it is for"). An example is the function "to control access" that humans generally ascribe to the behavior of a door.
- *Behavior* (B) of an artefact is the attributes that can be derived from its structure ("what it does"). An example of a behavior of physical artefact is "weight", which can be derived directly from the product's structure properties of material and geometry.
- *Structure* (S) of an artefact is its components and their relationships ("what it consists of"). For physical artefacts, it comprises geometry, topology and material. For conceptual artefacts can comprise concepts and their connections.

Humans construct relationships between function, behavior and structure through experience and through the development of causal models based on both reasoning about and interactions with the artefact. Function is ascribed to behavior by establishing a teleological connection between the human's goals and measurable effects of the artefact. Behavior is causally related to structure, i.e. it can be derived from structure using physical laws, heuristics or experience. This may require knowledge about external effects and their interaction with the artefact's structure. There is no direct relationship between function and structure.

The FBS ontology does not distinguish between different embodiments of an artefact. All artefacts can be captured as function, behavior and structure, no matter whether they are embodied in a symbolic computational environment, a symbolic language environment or in the physical world. This makes the FBS ontology an appropriate basis for describing artefacts at any stage in their life cycle.

Value systems can be defined in terms of artefact properties that relate to the notion of usefulness for adopters in the life cycle of an artefact. In the FBS view of the world, this includes function, as it captures the usefulness of artefacts by definition. It also includes behavior as a measure for the potential of an artefact to achieve the function. Structure is not a part of a value system, because it is not related to usefulness in a strict sense. However, structure can be viewed as an implicit value system, since its design is driven by intended function and behavior.

Value systems are encapsulated in situations that may be different for every adopter. Situations are the carriers of the value systems. As such they produce expectations which guide interpretations. One way to comprehend this is to conceive of the world as being composed of three kinds of sub-worlds: the world external to us – the "external world", the world internal to us – the "internal world" and within the internal world is a world of expectations that are the designs of the artefacts we are generating – the "expected world".

The external world contains symbolic or physically embodied value systems made available for interpretation. The value systems may be explicit or implicit. Explicit value systems include function or behavior. Implicit value systems are externally embodied structures that afford certain behaviour and function.

The interpreted world provides an environment for analytic and associative activities, related to current and previous value systems. It uses interpretation and memory processes, both of which are represented in Figure 2 using "push-pull" arrows to account for their dynamic character as an interaction of data-push and expectation-pull (Gero 1999). As a result, interpretations and memories can change over time, which then affect subsequent interpretations and memories. It is in this dynamic world where implicit value systems may become explicit, i.e. where structure, once interpreted, is turned into behavior that then may have functions attributed to it.

The expected world (within the interpreted world) forms goals through focussing on parts of the interpreted value systems, and predicts the effects of actions to modify the (explicit or implicit) value systems in the external world.

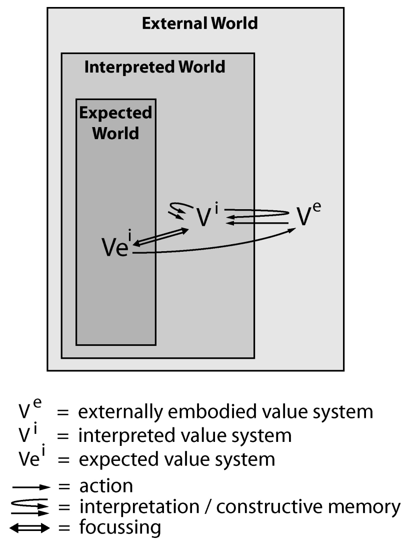

Figure 2. Value systems (V) encapsulated in a situation (interpreted and expected worlds), interacting with externally embodied value systems

The situation changes as a result of interactions between the three worlds (and "push-pull" interactions within the interpreted world). In turn, changes in the situation set up expectations that drive both interpretations and what situations can be constructed in the future. This means that the same external world with different situations produces different interpreted worlds and then different expected worlds. As the situation changes, the encapsulated value systems change accordingly.

Inducing Change of Value Systems

How are changes of value systems brought about? Given that value systems are encapsulated in a situation, this question is not the same as: how can we produce artefacts with novel functions or behaviors?. Exploring how value systems can be changed requires an understanding of the interactions between producers and adopters that can affect situations. These interactions can be viewed as part of a two-way communication process in which producers aim to influence adopters (Crilly et al. 2008) and adopters provide direct or indirect feedback to producers.

Changing Adopter Situations

There are three ways of inducing change in adopter situations:

1. *Social influence*: this is based on presenting explicit value systems (V^e) that the adopter accepts without much self-reasoning. Examples include product marketing, peer pressure (which may be part of a "viral marketing" strategy), and product tests or recommendations from trusted authorities (e.g., newspapers, consumer groups and industry associations).
2. *Affordance*: this is an adopter's interpretation process that makes implicit value systems (V^e) explicit in the way intended or unintended by the producer. This process can be

characterised as entailing a small amount of interaction between data-push and expectation-pull in this process. In other words, the data presented is consistent with the adopter's grounded expectations (or conventions) (Brown and Blessing 2005). Hence, affordance is very much correlated with the notion of sustaining changes. For example, a mobile phone of reduced physical dimensions affords "better portability", sustaining the adopter's existing needs.

3. *Emergence*: this comprises interpretation and constructive memory processes with more significant amounts of interaction between the adopter's expectations and the (explicit or implicit) value system (V^e). It can be viewed as a form of "unintended" innovation, based on mechanisms such as analogical reasoning. An example of an emergent innovation is Scotch Tape, whose initial function "to mend books" was transformed by the end user into a number of different functions, such as "to wrap packages" and "to curl hair" (Schön 1983). Other examples of emergent innovations, according to Redström (2008), include the record player (originally a sound reproduction device, turned into a musical instrument by DJs) and the skateboard (originally a children's scooter, but the handles accidentally fell off and children experimented with it).

These three types of change apply both to the adopters of creative ideas, the innovators, and to the adopters of innovative artefacts, although most commonly they are associated with the latter.

Changing Producer and Innovator Situations

In general, it is advantageous for producers and innovators to monitor and analyse changes in adopters' value systems. Original producers use this information to refine their creative ideas. Innovators use this to refine their innovations. Current and future competitors use the same information to identify the key technologies and assess their own capabilities for entering the market with similar innovations but improved characteristics. In addition, producers may generate new creative ideas based on their analyses of innovator's value systems. Innovators may generate new innovations based on the same creative ideas based on their analyses of adopters' value systems. These ideas may target existing markets or the creation of new markets.

What is common in all of these cases is that the producers' and innovators' value systems can change based on changes in their situations. There are three ways of inducing change in innovator situations:

1. *Direct feedback*: this may be available through questionnaires, customer support, complaint forms or other feedback provided by adopters. This feedback represents explicit value systems (V^e), and can be viewed as a direct form of communication from adopters to producers. Participatory design methodologies integrate explicit user feedback in the process of designing, aiming to identify opportunities for improvement and novel ideas in the early stages of innovation.
2. *Observations*: this can be seen as a form of indirect feedback, based on studying the intentional use of an innovation by adopters. A good example is Scotch Tape, mentioned earlier. Here, the various modes of use invented by the adopters (wrapping packages, curling hair, etc.) were observed (and interpreted as functions) by the innovators. They then refined their product by creating a range of product variations that were adapted to the specific functions: "As a result, 3M (the company of the producers) came out with a hair-setting Scotch Tape, a medical Scotch Tape used for binding splints, a reflective Scotch Tape for roads, and so on" (Schön and Bennett 1996). This new range of products can be seen as a consequence of changes in adopters' value systems followed by changes in the innovator's value systems.
3. *Emergence*: this generates value systems that are novel with respect to producers, innovators and adopters. They result from the producers' or innovators' interpretation and

constructive memory processes and their interactions with the adopters' value systems. For example, when Sony introduced the Walkman they explicitly changed the size of portable music devices by eliminating the loudspeaker and replacing it with earbuds. However, in doing so they produced an emergent value: listening to music became a private rather than a public activity and consequentially spawned an entire industry based on the private listening of music. This flowed onto other forms of private listening artefacts.

The products resulting from the changes in the producers' and/or innovators' value systems can again lead to innovation, by subsequently changing the adopters' value systems. This shows that innovation involves a set of interactions between producers, innovators and adopters, which can be viewed as a process of reflective conversation (Schön 1983).

Effects of Changes of Value Systems

Schumpeter in his seminal book *Capitalism, Socialism and Democracy* (Schumpeter 1942) described innovation as a form of "creative destruction" where the innovation destroys the existing product or process through displacement. This matches our cognitive notion of changing situations and its value system through concept substitution. However, an innovation has potentially three forms of acting on the existing order: augmentation, partial substitution or displacement through total substitution, Figure 3. Only the latter matches Schumpeter's "creative destruction", Figure 3(d).

(a) (b) (c) (d)

Figure 3. (a) Original situation S_o, (b) new situation, S_n, that augments existing situation, (c) new situation that substitutes part of existing situation and hence destroys part of it, and (d) new situation that substitutes previous situation completely and hence destroys it.

We can observe such behavior as innovations occur. The case shown in Figure 3(b) is common, where new values are added to existing ones. This can be seen, for example, when new features are added to products and then those features become the norm not only for new consumers but also for existing consumers, who now see the product they currently own as incomplete. An example was the addition of GPS capability to cell phones. This innovation had the effect of devaluing existing phones that did not have that capability. This is one way in which innovation generates market growth. The case shown in Figure 3(c) is common in mature markets where one feature substitutes for an existing feature, often with the same functionality. This has a similar effect as adding a feature in that it changes the expectations of both new and existing consumers. Voice dialing replacing finger-based dialing on phones is an example of such a substitution. However, transformative innovations are those where one entire set of values is displaced by a new set, Figure 3(d). A totally new situation then exists, one that does not simply grow a market but creates new markets. The introduction of the laptop computer is one such example of this. Prior its introduction there was no market to be addressed, however, its introduction completely replaced the notion of moving desktop computers around and opened up a completely new set of values associated with computers, values that had not existed before.

Studying Innovation and Innovation Policy

The cognitive view described here cannot be modeled using formal causal models as what has been described are phenomena that are a consequence of individual or group acts for which we do not have casual models. What has been presented is the social effects of individual cognitive behavior. There is an emerging field that deals with this and it is called "computational sociology" or "computational social science". Computational social science models social interactions and simulates the resulting social behavior through the use of computational agents rather than equation-based methods, utilizing a multi-agent system (Castelfranchi 2001; Casti 1999; Epstein 2007; Epstein and Axtell 1996; Gilbert and Conte 1995; Gilbert and Doran 1994; Hegselmann et al 1996; Macy and Willer 2002; Miller and Page 2007; Sosa and Gero 2008a). It has the capacity to produce phenomena that are the consequence of social interaction rather than based on causal models.

With computational social science providing the means by which we can model the processes of the production of creative ideas, the interactions between these ideas and their take-up by innovators, the interaction between innovators and adopters and the interactions between the adopters and the innovations they are adopting, between the innovators and the consumption by adopters of their innovations and the interactions between the producers of the creative ideas and their consumption in innovations, we are in a position to study and test this cognitive approach to innovation and to innovation policy (Gero and Gomez 2009; Sosa and Gero 2005; Sosa and Gero 2007; Sosa and Gero 2008b). Much of phenomenological behavior, as a consequence of social interactions, is emergent. Innovation and innovation policy can be studied as a driver of this emergent behavior. It can also be studied initially as an emergent phenomenon itself, as a consequence on multiple small effects whose drivers can only be viewed at a macro level.

The science of innovation policy requires both theoretical models and empirical data on which to found and test those theoretical models. Generally, models of innovation and innovation policy are presented qualitatively and are often untestable (Akintoye, and Beck 2008; Archibugi et al 1999; Branscomb and Keller 1999; Dubberly 2008; Llerena and Mireille 2005). A situated cognition-based multi-agent system has the capacity to be a workbench to test innovation policies.

A Workbench to Test Innovation Policies

Innovation policies can be presented as multiple, variable inputs to a large-scale, interacting social system of creators of ideas, innovators who take up those ideas to generate products and adopters of those products. In addition to these there may be other actors in the system such as research funding bodies who interact with creators of ideas, venture capitalists who interact with innovators, development funding bodies who interact with innovators, marketers who interact with innovators and adopters, and retailers who interact with innovators and adopters.

A situated cognition, multi-agent computational system, where agents represent the different classes of actors in the chain of innovation from creators of ideas and their funders through to adopters, can be designed and implemented that has innovation policy as exogenous inputs and emergent behavior as endogenous inputs. In this system each class of actor has a set of agents whose behavior is programmed but changeable so that different behavioral hypotheses can be tested to determine their effects on innovation and innovation capability. Each agent has the capacity to observe some of the other agents and hence indirectly interact with them. This produces social interactions that can result in emergent behavior (i.e., behavior that is not programmed). Viral marketing is an example of an emergent behavior.

A workbench based on this situated cognition, multi-agent computational system can have all its exogenous inputs specified and then it runs a simulation of the policy represented by those inputs based on various assumptions about the behaviors of the various classes of actors in the system. The agents change their situations as the simulation proceeds and as they develop more knowledge about the behavior of the other agents. Exogenous inputs to such a simulation would include such variables as funding agency policies, availability of venture capital, R&D tax policies and so on. Endogenous inputs to an agent would include such variables as the behavior of other members of its class, and the strength of social ties of that class. Different ranges for the values of the inputs can be used to run a set of simulations to observe the systemic behavioral effect of that policy variable.

The workbench can be built at any level of granularity modeling for which data either exists or can be reasonably estimated. The system can be further disaggregated and by focusing on the innovator it can be used to study innovation processes. Multi-agent systems of this kind can be readily scaled up so that social systems involving thousands and even tens of thousands of agents are computationally tractable.

Such a workbench provides a tool to determine the phenomenological behavior of the changes in the value systems of creators, innovators and adopters driven by an innovation policy and hence test the innovation policy itself.

References

Akintoye, A and Beck, M (2008) *Policy, Finance & Management for Public-Private Partnerships (Innovation in the Built Environment),* Wiley-Blackwell.

Archer, BL (1971) *Technological Innovation: A Methodology*, Inforlink.

Archibugi, D, Howells, J and Michie, J (eds) (1999) *Innovation Systems and Policy in a Global Economy,* Cambridge University Press.

Bartlett FC (1932 reprinted in 1977).) *Remembering: A Study in Experimental and Social Psychology* Cambridge University Press.

Boden, M (2003) *The Creative Mind: Myths and Mechanisms (2nd edn),* Routledge.

Branscomb, LM and Keller, JH (eds) (1999) *Investing in Innovation: Creating a Research and Innovation Policy That Works,* MIT Press.

Brown, DC and Blessing, LTM (2005) The relationship between function and affordance, *ASME 2005 Design Theory and Methodology Conference*, Long Beach, CA, paper no. DETC2005-85017.

Castelfranchi, C (2001) The theory of social functions: challenges for computational social science and multi-agent learning, *Cognitive Systems Research* **2**(1): 5-38.

Casti J (1999) The computer as laboratory: Toward a theory of complex adaptive systems, *Complexity* **4**(5): 12-14.

Chalmers, DJ (2006) Strong and weak emergence, *in* P Davies and P Clayton (eds), *The Re-Emergence of Emergence*, Oxford University Press.

Clancey, WJ (1997) *Situated Cognition: On Human Knowledge and Computer Representations*, Cambridge University Press.

Crilly, N, Good, D, Matravers, D and Clarkson, PJ (2008) Design as communication: Exploring the validity and utility of relating intention to interpretation, *Design Studies* **29**(5): 425-457.

Dewey, J (1896 reprinted in 1981) The reflex arc concept in psychology, *Psychological Review* **3**: 357–370.

Dubberly, H (2008) Toward a model of innovation, *interactions* **XV**(1): 28-36.

Edquist, C (1997) *Systems of Innovation: Technologies, Institutions and Organizations,* Pinter Publishers.
Epstein, JM (2007) *Generative Social Science: Studies in Agent-Based Computational Modeling,* Princeton University Press.
Epstein JM and Axtell R (1996) *Growing Artificial Societies: Social Science from the Bottom Up*, Brookings Institute Press.
Feller, I (2010) Why and where for a science of science and innovation policy, This Volume.
Gero, JS (1990) Design prototypes: a knowledge representation schema for design, *AI Magazine* **11**(4): 26-36.
Gero, JS (1999) Recent design science research: Constructive memory in design thinking, *Architectural Science Review* **42**: 3-5
Gero, JS (2008) *Towards the Foundations of a Model of Design Thinking,* DARPA Project BAA07-21.
Gero, JS and Gomez, A (2009) Exploring knowledge transfer in a society of designers, *in* Noell Bergendahl, M, Grimheden, M, Leifer, L, Skogstad, P and Badke-Schaub, P (eds), *Design Information and Knowledge,* Design Society, pp. 8:99-110.
Gero, JS and Kannengiesser, U (2004) The situated Function-Behaviour-Structure framework, *Design Studies* **25**(4): 373-391.
Gero, JS and Kannengiesser, U (2009) Understanding innovation as a change of value systems, *in* R Tan, G Gao and N Leon (eds), *Growth and Development of Computer-Aided Innovation,* Springer, pp. 249-257.
Gero, JS and Maher, ML (eds) (1993) *Modeling Creativity and Knowledge-Based Design,* Lawrence Erlbaum.
Gilbert, GN and Conte, R (1995) *Artificial Societies: The Computer Simulation of Social Life*, UCL Press.
Gilbert, GN and Doran, J (1994) *Simulating Societies: The Computer Simulation of Social Phenomena*, UCL Press.
Gombrich, E (1966) *Studies in the Art of the Renaissance.* Phaidon.
Hegselmann, R, Mueller, U and Troitzsch, KG (1996) *Modelling and Simulation in the Social Sciences from the Philosophy of Science Point of View*, Kluwer Academic Publishers.
Holland, JR (1999) *Emergence*, Basic Books.
Llerena, P and Mireille M (eds) (2005) *Innovation Policy in a Knowledge-Based Economy: Theory and Practice*, Springer.
Macy, MW and Willer, R (2002) From factors to actors: Computational sociology and agent-based modeling, *Annual Review of Sociology* **28**: 143-166.
Miller HJ and Page ES (2007) *Complex Adaptive Systems: An Introduction to Computational Models of Social Life.* Princeton University Press.
Redström, J (2008) Re: Definitions of use, *Design Studies* **29**(4): 410-423.
Roozenburg, NFM. and Eekels, J (1995) *Product Design: Fundamentals and Methods*, Wiley.
Runco, MA (2006) *Creativity: Theories and Themes: Research, Development and Practice,* Academic Press.
Sawyer, MK (2006) *Explaining Creativity: The Science of Human Innovation,* Oxford University Press.
Schön, DA (1983) *The Reflective Practitioner: How Professionals Think in Action,* Harper Collins.
Schön, DA and Bennett, J (1996) *Reflective Conversation with Materials: Bringing Design to Software,* ACM.
Schumpeter, JA (1942) *Capitalism, Socialism and Democracy,* Harper.
Smith, G and Gero, JS (2005) What does an agent mean by being "situated"? *Design Studies* **26**: 535-561.
Simon, HA (1969) *Sciences of the Artificial,* MIT Press.

Sosa, R and Gero, JS (2004) Diffusion of creative design: Gatekeeping effects, *International Journal of Architectural Computing* **2**(4): 518-53.
Sosa, R and Gero, JS (2005) Innovation in design: Computational simulations, *in* A Samuel and W Lewis (eds), *ICED'05: Engineering Design and The Global Economy,* Institution of Engineers Australia, CD Paper 529.61.
Sosa, R and Gero, JS (2007) Computational explorations of compatibility and innovation, *in* N Leon-Rovira (ed), *Trends in Computer Aided Innovation,* Springer, pp. 13-22.
Sosa, R and Gero, JS (2008a) Creative social systems, *in* D Ventura, ML Maher and S Colton (eds), *Creative Intelligent Systems,* AAAI Spring Symposium, AAAI Press, pp. 90-94.
Sosa, R and Gero, JS (2008b) Social structures that promote change in a complex world: The complementary roles of strangers and acquaintances in innovation, *Futures* **40**(6): 577-585.
Thomas, J (2010) A vision of data and analytics for the science of science policy, This Volume.
Sternberg, RJ (1998) *The Handbook of Creativity,* Cambridge University Press.

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Gero, JS (2011) A situated cognition view of innovation with implications for innovation policy, *in* K Husbands-Fealing, J Lane, J Marburger, S Shipp and B Valdez (eds), *The Science of Science Policy: A Handbook*, Stanford University Press, pp. 104-119.