Affordances and Limitations of Cognitive Bias Reduction in Introductory Digital Design Pedagogy

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Abstract
As digital design rapidly expands the disciplinary knowledge-base of related media, methods, and modes in architecture, cognition-based pedagogical strategies hold unique promise in introductory digital design education to increase knowledge transfer efficiency (i.e. learning) by aligning the learner's natural schema-developmental processes with the inherent affordances of digital tooling methods. Through the employment of cognitive-based instructional strategies that seek to refine the designer's own judgement and decision making processes, can academicians exploit the affordances of digital design technologies to enhance the architectural learning process in ways not possible in an analog age? This paper frames and explores cognitive bias mitigation as a pedagogical strategy that may increase knowledge transfer efficiency in digital design pedagogy by helping novice learners to mitigate common cognitive biases in the iterative design process. The literature that explores decision-making processes in design will be presented first. This foundational introduction will then be followed by an overview of the implications of early-stage design decision making in architectural learning environments. Cognitive biases particularly applicable to architectural design will be introduced with a distinct emphasis placed upon those that may be augmented or compounded in digital design environments. Cognitive limitations to architectural decision-makers such as projection bias, affective forecasting, and the hot/cold model will be explored in detail. Cognition-based pedagogical strategies that seek to refine the designer's own judgement hold promise in the emerging field of digital design as progressive technologies and processes are plagued by missed opportunities for the learner's own decision-making intellectual advancement. Theory and concepts from the decision sciences and digital design in architecture are cross-pollinated in this study.

Keywords: digital design, novice learner, cognitive biases

With or without heuristic usage during the problem solving process, decision making under uncertainty is prone to non-normative behavior, irrationality, and biases

Introduction
Irrational, biased decision-making and non-normative behavior are ubiquitously symptomatic of the human mind. Research related to cognitive biases originated in the field of cognitive psychology but has now expanded into other fields such as economics, management, and decision science. Cognitive biases are sub-conscious, systematic errors or deviations from rationality that are associated with heuristics or the mental shortcuts that people use in decision-making (Kahneman 2003). Decision-makers resort to heuristics when faced with the limitations of cognitive processing capacity within a decision-making environment characterized by complexity, ambiguity, and uncertainty (Hallihan 2012; Keil, Depledge & Rai 2007). Whether it is a consumer deciding which product to

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purchase or an executive making a financially impactful decision, choosing one alternative among many within the face of uncertainty creates the potential for the use of heuristics and the influence of cognitive biases. Hence, in a disciplinary context such as architecture characterized by iterative decision making and the nearly infinite spectrum of potential design artifacts engendered by digital technologies, one must question how heuristics and biases impact the design decision-making process and whether digital tools alleviate or compound prevalent biases in design.

Although architectural design is often stereotypically viewed as an act of 'creative genius' (Beaty, Silvia, Nusbaum, Jauk & Benedek 2014; Dorst & Cross 2001; Goldschmidt 1983) rather than an iterative decision-making process, "the development of an architectural solution demands reasoning as well as inspiration" according to Salama and Wilkinson (2007, 126). Architecture involves creative design solutions that are developed through an iterative process and, like other forms of design, "necessitates the making of decisions in order to fulfill certain objectives" (Hasirci & Demirkan 2007, 260). Replicating professional task performance in architecture, the design studio provides students similar decision-making experiences through course projects. Perhaps the most challenging element of architectural practice and education is the framing and probing of the ill-defined problems of design (Eastman 1969; 2001).

Given that, architecture involves decision-making and "cognitive biases are always present in decision making" (Keil et al. 2007, 395), the question of how the work of students in the design studio may be influenced by cognitive biases seems worthy of consideration by architectural educators. As cognitive psychologists continue to expand upon their understanding of cognitive biases in decision making, those involved in the education of future architects continue to debate the learning ramifications of the movement from analog to digital design. It appears that both "fields are making progress on parallel paths" (Lovett & Greenhouse 2015, 196). This article is an attempt to merge research from cognitive psychology related to cognitive bias with the development of digital design in architectural education to specifically consider how such a development and pedagogical integration may impact the degree to which cognitive biases influence student work.

Although the influence of cognitive bias on architectural design in practice is an established subject of research (Bay 2001), the role that cognitive biases may play in the architectural digital design studio have yet to be explored. The purpose of this paper is to establish the decision-making element of architectural design, describe how cognitive biases influence decision-making, consider which cognitive biases may be most relevant to design studios using digital design, and finally consider how certain cognitive biases may be mitigated or augmented in the digital design environment.

In the following seven sections, cognitive biases and irrationality will be explored relative to the novice learner and the media, modes, and methodologies of digital design. The order of the research will be organized as follows: (1) introduce decision making in design and the architectural learning environment; (2) acknowledge the projection-based irrationalities in design underpinned by the comparison between analog and digital design's ideational developmental processes; (3) introduce projection bias and its impact on the process of progressive decision making in architecture; (4) utilize affective forecasting and temporal correction as analytic lenses to explore the regressive decision-making tendencies of novice learners in design; (5) establish a background and introduce accountability shifting – a key procedural avenue for projection bias mitigation – relative to the digitally-mediating potential of digital tooling methods in architectural design; (6) explore hot/cold biases in relation to inter-temporal choice, design thinking, stimuli-influenced choice, and novice learning. In furtherance of these seven steps, limitations and future research possibilities are then presented.

Decision making in design

Judgements under uncertainty

Decision making is a crucial component of the iterative design process in architecture. From the initial outset of the design problem until the design or building is completed, architects are required to make an extensive number of decisions that affect virtually every component of the final design artifact or design product (Schön 1983). Design problems in academia as well as practice are difficult to solve due to “incomplete information, limited time and human mental resources” (Bay 2001, 51). It is not possible, due to the aforementioned constraints, to search through all “alternative solutions, multiple contingencies, and multiple conflicting demands” (Bay 2001, 51) that affect the design situation. “Donald Schön (1983, 49-50) referred to this condition as practice with ‘uncertainty, instability, uniqueness and value conflict’, where the architect managed his design work by using his experience, intuitive and human feel, rules-of-thumb and previous examples, developed through the years of education and practice” (Bay 2001, 51). Schön (1983) and Tversky and Kahneman (1982) have referred to these experiential and intuitive rapid judgements, or cognitive shortcuts, as heuristics. Heuristics, as described by Tversky and Kahneman (1975), reduce the complexity of assessing probabilities and predicting values and preferences to more simple judgmental cognitive operations based upon the brain’s limited processing capacity. These simplified judgmental operations, however, may lead to “severe and systematic errors” (Tversky & Kahneman 1975, 1124). With or without heuristic usage during the problem solving process, decision making under uncertainty is prone to non-normative behavior, irrationality, and biases (Kahneman 2011; Kahneman & Tversky 1973; 1979; Tversky & Kahneman 1975; 1985; Stanovich & West 1998; Nikander & Liikkanen 2014). In an iterative decision making process such as the design-development method commonly employed in architectural design, biases and irrationality can be compounded or mitigated through the iterative design process. The reasons why compounding and/or mitigation of biases and irrationalities are particularly delicate aspects of the design process will be explained next.

Implications of early-stage design decisions

Architectural decision making is a particularly high-stakes form of design decision making due to the high level of material and financial resource investment and the expected lifespan of the design product. Socio-cultural and technological changes that occur during the lifespan of the design product make this form of design decision making particularly challenging as future requirements and uses may or may not be known during the design development process. Concept design, or early-stage design, is particularly critical for the design development process due to the divergent-convergent method of ideational development, a process in which an initial spectrum of various design alternatives are considered and then “evaluated and eliminated in order to select the best concept or concepts for further development” (Nikander & Liikkanen 2014, 474).

As stated by Nikander and Liikkanen (2014), the early-stage divergent-convergent method of ideational development is particularly critical for the success of a project as large decisions that impact scale, quality, cost, and desirability of the end product are typically made rapidly and the “consequences of a poor choice may be disastrous at worst” (Nikander & Liikkanen 2014, 473; Asiedu & Gu 1998 cited in Nikander & Liikkanen 2014). Thus, the importance of the divergent-convergent process of ideational development beacons instructors to consider how biases with regressive tendencies such as the projection bias, and relatedly affecting forecasting, may be mitigated in architectural design environments.

As previously stated, digital design is fundamentally discrete, diverse, and dynamically evolved while analog design has been linked to the relatively static historical design-development logics of industrial modernism. As such, pedagogical strategies that align the innate characteristics of digital design ideational development with the novice learner's conceptual design process may help to alleviate some regressive tendencies associated with projection bias and affective forecasting. A key aspect of digital design is that it positions the designer in novel relationships with design media, though as in analog design the designer still assumes a key role in design schema (Becker 2015). The introduction of novel relationships with design media, a rapidly expanding field of digital design specializations, and varying degrees and nature of interactivity between the designer and material representational medium each increase the possible processes by which conceptual design development may occur.

Architectural learning environments

Architects have traditionally utilized material-representational media to engage in the experimental, 'reflective conversations' with the materials of the design situation that lead to a design solution (Schön & Wiggins 1992). Through the design process, architects draw, model, sketch, and through additional means, seek to accurately represent the design idea. As Schön (1983) has described in his foundational texts on the design-learning process, the architect sees what design ideas have been represented and reflects upon the physical manifestations of the aforementioned design ideas, thus informing further design concepts. This process of representing, 'seeing', reflecting, and retranslating forms the foundation of modern, analog architectural design in both practice and academia. Architectural education, as in other related design fields, is based upon professional-task-performance replication (Oxman 1999). As such, students of architecture also face the cognitively demanding task of making iterative sets of decisions. This method of education typically includes students from across the curricular spectrum, from novice learners in foundation courses to 'experts' at the thesis level. As various researchers have articulated, traditional architectural pedagogy to a great extent is still based on the Ecole des Beaux Arts educational model including the aforementioned cross-curricular example (Cuff 1991 cited in Oxman 1999). In addition to professional-task-performance similarities, Beaux-Arts-based studios are also organized in the standard problem-exploration-solution sequence capped by a final review of the design product. As alluded to by Oxman (1999), this studio model contains a plethora of missed opportunities for the student's intellectual development. In addition to an overemphasis on the final design artifact at the expense of process, instructors may also miss, one, important opportunities to stimulate cognitive development via digital tooling methods, and two, the utilization of digital media as a bias-mitigating decoupling-agent between designer and material representational medium.

Projection bias

As an introduction to the affordances and limitations of projection bias reduction in studio based learning environments, a general chronology of the typological-to-dynamic ideational shift in design will be presented. While digitally mediated design creates increased opportunities for cognition-based pedagogy in architecture, the integration of digital media, modes, and methodologies into studio-based learning environments also challenges educators to consider not only the curated selection of material to be integrated but also the varying cognitive expertise levels to be achieved by the student. "These cognitive demands for the learner also create critical pedagogical challenges for educators" as they in turn consider how to implement instructional strategies for effective knowledge transfer (Becker 2015, 1). Cognitive biases play a key role in the knowledge-transfer process, yet they have neither been studied relative to the transformative, digital age in architecture nor to novice learners in creative fields, thus justifying the relevance and novelty of this study.

Analog developmental processes

Through the framing, structuring, and articulation of digital design as a methodologically unique form of design, an inverse articulation has emerged which further assists in the understanding of analog design. As differentiated from the digital, analog design and developmental processes can be understood as fundamentally typological and self-referential in nature, thus engendering a typologically-based discourse and the emergence of typologically-based critique (Oxman 2006). This can be partially attributed to historical practices of iterative ideational development via non-intelligent representational media (i.e. paper, wood, glue, etc.), but perhaps also due to historical disciplinary practices that derived symbolic value through formal and spatial attribution. Thought processes that were primarily based on formal and socio-cultural precedent drove design development and alternate logics based upon an alternative to the relatively static concepts of architectural development had not yet gained influence. William Mitchell (2005) has described the static, analog logics of architectural development as normative, standard, and repetitive in nature, while emphasizing that historical and cultural conceptions helped to propagate these sets of ideas comprising what is generally termed ‘industrial modernism.’ (Mitchell 2005 cited in Oxman 2006).

Digital differentiation

For a section concerning projection bias reduction and its potential implications in studio-based design environments, the typological methods and ideological frameworks aforementioned are essential to understand as a counterpoint to the striking shift in media, modes, and methodologies introduced by the development and evolution of digital design. Rather than a typologically based logic, fundamentally modular in nature, digital design promulgates the development of design artifacts that are systemically derived, discrete, diverse, differentiated, and dynamically evolved (Oxman 2006). This seminal shift from the static and singular in nature to dynamic and systemic can primarily be attributed to the complexity of the digital era spurred by a plethora of digitally-mediated design software applications and related tooling methods (Oxman 2006). While digitally-mediated design is commonly understood to be capable of producing exceptional geometric complexity, it is important to note that perhaps the most distinguishing characteristic between digitally-mediated design as a methodologically unique form of design and analog design is the digital’s ability to propose “meaningful alternatives” to the aforementioned industrial-modernist logic of modularity and repetition.

Due to the fundamental shift in the systems of design from the analog to digital, would it not be logical to assume that by designing with an industrial-modernist logic rather than the digital’s associative discrete, diverse logic that one would partially overlook or altogether miss both novel design opportunities and design solutions engendered by digitally-mediated design? While the following paragraphs introduce and unpack projection bias relative to introductory digital design, the underlying presumption is that projection bias in introductory learners may limit or result in a failure of the designer to exploit the myriad of novel interactions, possibilities, and opportunities for design development in digital environments. The complementing presumption is that this “projection of a decision-maker’s past into attempts to imagine a new future impedes the development of novel ideas as well as accurate assessment of their likelihood of success” (Liedtka 2015, 6).

Rationality and decision making

As discussed in earlier sections, designing is iterative decision making and designers like all others are susceptible to irrationality. Projection bias, as described by Loewenstein, O'Donoghue, and Rabin (2000), is defined as an exaggeration of "the degree to which [the subject's] future tastes will resemble their current tastes" (Loewenstein, O'Donoghue & Rabin 2000, 1209). If one was able to accurately predict future preferences relative to current preferences without being cognitively compromised, the initial decision could then be deemed rational. In order for optimal decision making to occur, one must able to predict future preferences in an uncompromised state. However, depending upon social, cultural, environmental, and personal changes, future preferences may change considerably from current preferences due to various stimuli and physiological development and/or maturation; thus the likelihood that one's cognitive state is not impacted to some degree over time is unlikely (Wertenbroch 2001). Generally, "people tend to understand qualitatively the directions in which their tastes will change, but systematically underestimate the magnitude of these changes" (Loewenstein, et al. 2000, 1210), a common example being an excessive purchasing of food while shopping when hungry. As stated by White and Poldrack (2014), biases in decision making provide valuable information about cognition in general, thus the study of biases in architectural design may open new avenues for the study of existing challenges in architectural thought.

Limited ideational development in architectural design

In architectural design, the projection bias may be limiting to progressive decision-making and in relatively extreme scenarios may stifle the entire iterative design process by contributing to a common condition known as 'stuckness' (Sachs 1999). Due to the novice learner's relative lack of design-based knowledge structures, structures that are understood to be composed of both precedent knowledge and problem and solution space knowledge (Cross 1982, 2004), the novice learner may be more inclined to succumb to projection bias through the over reliance on initial design concepts and limited pursuit of iterative development. Described as the inability to see beyond themselves, or in other words escape the confines of past experience, designers impacted by projection bias will tend to become overly attached to initial design concepts due to a limited perspective on future possibilities (Novemsky & Kahneman 2005). Thus, the student's design decisions tend to be regressive with an overemphasis on the present. The following sections will present a cognitive action termed affective forecasting, a similar concept to projection bias yet one that through the recognition of mental images holds promise to mitigate regressive tendencies via temporal correction.

Affective forecasting in design

A related approach to Loewenstein's definition of projection bias is what Gilbert, Gil, and Wilson have described as affective forecasting, a prediction of future preferences or interests based upon mental proxies for actual or previously experienced events (Gilbert, Gill & Wilson 2002). With affective forecasting come two primary problems, one being that current preferences can be contaminated by current circumstances and, two, that "mental images often fail to specify the temporal location of events they are meant to represent" (Gilbert, et al. 2002, 431). These problematic factors could have a particularly strong impact in disciplines such as architecture that make frequent use of precedents and that are artistic in nature, thereby being impacted upon to some degree by an inspiration. For novice learners with reduced knowledge-structure clarity and relatively limited experiences with the ill-defined problems of design, a greater reliance on the projection of past experiences to future situations may occur more frequently than with experts who can draw upon their more developed and relevant knowledge structures to the related design problem or challenge. Without developed knowledge structures relative to the problem and solution spaces of design (Cross 1982, 2004), novices may have to draw from more disparate mental images that are then projected onto future design solutions, thereby increasing the likelihood that misalignments and irrational associations will form from mental images in unrelated temporal locations.

Affective forecasting and temporal correction in design

In architectural design, for example, the aforementioned problematic factors of affective forecasting could be influential for a student who has just read about Zumthor’s Therme Vals baths in Switzerland and predicts that the building design that they will develop next semester will include many types of baths, hot and cold, deep and shallow like the Therme Vals. The student may have enjoyed swimming as a child and has many fond memories of their local pool, so they predict that guests in the building that they will design will enjoy the excellent quality of the baths. It is likely that the student has imagined some aspects of their future design and predicts a pleasant future experience for the swimmers. A complicating factor in this projective process is not only that this projection was made under the influence of a circumstantial excitement stimuli by having just read about the Therme Vals, but also that the student’s prediction may not have included a cognitive assessment of the temporal locations of their mental images, a process known as temporal correction (Gilbert, et al. 2002). In other words, the student may not have realized that by combining positive mental images of swimming from childhood, a precedent project, and a projection of an enjoyable thermal bath experience for guests of a future building that there may be misalignments and irrational decision making due to unrelated, disparate associations.

If the student was aware of the possibility that their current assessment of future design preference could be irrational, they may realize that next semester they should be much more careful when designing, perhaps including more quantitative factors in the conceptual design process in addition to the factors drawn from personal experience. The student’s positive memories of swimming and a widely-regarded belief that Zumthor’s baths in Switzerland are architecturally successful have little to no bearing on the potential for success in a completely novel design scenario.

To help alleviate the irrational, regressive tendencies to combine disparate mental images and utilize past experiences to form future preferences, digital tooling methods hold the possibility to materialize a plethora of differentiated, diverse design artifacts based upon the designer's input criteria. Perhaps most importantly for irrational decision making as spurred by affective forecasting, digital design technologies *offer the designer a choice* of highly differentiated artifacts stemming from singular or multiple initial concepts. Higher-order generative logics can be initiated with or without editing by the designer, arguably a complication of digital flexibility but also an opportunity to expand the ideational process of the learner beyond past-to-future affective forecasting tendencies. Affordances of digital design technologies relative to design pedagogy also involve a mediation of the relationship between designer to design artifacts as will be introduced next.

‘Accountability shifting’ via digital mediation

In contrast to analog design in which conceptual design is limited by the medium’s compositional and formal nature via material-based developmental constraints, digital design affords the possibility of highly-diversified processes, relationships, and outcomes through the diversity of digitally-mediated designer-to-design-artifact interactions. For example, rather than designing and producing a series of ten different concept models for a two-story, mixed-use housing project in paper or cardboard, the student can exploit the rapid-production affordances of digital design tools to produce any number of design artifacts, each at a variety of complexity-levels relative to the student’s digital skill level. Basic box modeling could be employed, or for greater ranges of complexity and interactivity, highly-diversified generative processes such as evolutionary modeling, morphogenetic modeling, parametric modeling, and others could be employed (Becker 2015). Each of these unique procedural vehicles for digital design employ a process of bidirectional information transfer that could be utilized as a means to generate multiple concepts and design artifacts from a singular initial concept (Becker 2015; Oxman 2006 cited in Becker 2015). Additionally, high levels of complexity in digital design enable a “more sensitive and inflected response to the exigencies of contextual aspects such as site, program, and expressive intention than was generally possible within the framework of industrial modernism” (Mitchell 2005 cited in Oxman 2006), a personal and professional context from which designers may source ideational projections.

Through the process of digitally-mediating the interaction between designer and material-representational medium, a key strategic avenue for projection bias mitigation is born. This novel avenue is referred to by the author as ‘accountability-shifting’. A problematic aspect of projection bias in design thinking is the tendency of the designer to overestimate the similarity between the experience or importance of a future event or entity to the current or past experience of an event/entity. The projection of one’s past as a means to imagine a new future is particularly limiting for novice learners, a process that stunts the development of novel ideas and solutions (Liedka 2015). That said, as a form of media, which supports affordances unavailable in analog design environments, digital media offers the unique possibility for accountability-shifting, a method that may de-personalize past-to-future design logics by disrupting the direct designer to material-representational-media relationship. Through the decoupling of the direct designer-to-design-artifact connection via a digital logic, interface, product, or other means, digital technologies, through their diversity and degrees of interactivity, afford increased possibilities for design development in a context methodologically unique from analog processes and existing artifact production systems, thereby to some degree shifting accountability for future designs drawn from past experience to digitally-enabled, dynamic, discrete, and differentiated digital developmental processes. Digital media, methods, and modes could serve as a proxy for the designer themselves, the degree dependent upon the level of control shifted from the designer to the related digital technology (Oxman 2006). Through digital design’s inherent decoupling of the designer's direct relationship to the associative material-representational media, the impact of the projection bias on novice learner’s decision making processes may be mitigated via accountability shifting.

Hot/cold model

Intertemporal choice
A majority of the choices that one makes are intertemporal. In fact, intertemporal choice is such a broad domain within the fields of psychology and economics that one would be hard-pressed to find a consequential choice that is not intertemporal (Loewenstein, Read & Baumeister 2003). Defined as the type of choices we make when determining the trade-offs between costs and benefits occurring at different points in time, intertemporal choice could include whether we prepare for a lecture now or after our morning coffee to the order and difficulty of assignments that are given to students throughout the semester. Chosen from among a number of foci in psychology and economics, two primary fields with a rich history in the study of intertemporal choice, the situational determinants of impulsivity, hot and cold systems in particular, may be beneficial to consider in relation to digital design pedagogy.

The design process in architecture is typified by iterative, exploratory decision-making processes comprised of intertemporal choices. Due to a building’s long lifespan, material transformations – due to moisture, temperature, light, etc. – and various other factors impact the building over time. Thus, architects must make many choices relative to trade-offs between present and future states. Are the higher costs of energy-efficient windows justified by the potential energy savings later? Can a more attractive, expensive stone be justified by the improved building aesthetic and greater durability over time? Both questions are examples of common intertemporal choices. However, the latter also hints at an intricate, complicating aspect of the intertemporal decision-making process in design, the interplay of 'hot' emotional to 'cool' cognitive choice illustrated by the prior example's aesthetic preference factor.

As described by Metcalfe and Mischel (1999) in their influential research on the dynamics of willpower, the interplay between the two-system hot/cold model of cognition is crucial to the way people self-regulate their decision-making, thereby limiting or succumbing to impulsive responses and, associatively, irrational choice (Metcalfe & Mischel 1999). The hot/cold model is also commonly referred to as hot/cool cognition, hot/cold gap, or hot/cool framework. Considering that design is decision-making (Hasirci & Demirkan 2007) and is influenced by excitement stimuli (i.e. novelty, artistic inspiration, etc.), the exploration of hot and cold cognition becomes particularly relevant as design processes in architecture diversify in a digital era. By first exploring the cognitive research that links the hot/cold model to its effects on self-regulative decision-making, an identity for stimuli-influenced-choice can then be more effectively correlated to the opportunities and challenges of rational decision-making in digital design environments. Affordances and limitations of digital design environments will then be considered relative to the cognitive challenges faced by novice learners in stimuli-rich, digital contexts.

'Know' or 'go' decision-making

The hot/cold or hot/cool framework originally proposed by Metcalfe and Mischel (1999) is a theoretical framework through which one can understand and justify how humans who are driven by impulsivity are able to overcome the powerful reactions instigated by environmental stimuli and exert self-control strategies in decision-making processes (Metcalfe & Mischel 1999). Unlike past theories of self-regulation linked to the strength of personal willpower, the hot/cool theory differentiates between "a cool, cognitive 'know' system and a hot 'emotional' go system" (Metcalfe & Mischel 1999). The cool system has been described as "cognitive, emotionally neutral, contemplative … slow, and strategic" while the hot system is "the basis of emotionality, fears as well as passions – impulsive and reflexive – initially controlled by innate releasing stimuli" (Metcalfe & Mischel 1999). The hot/cold model conceptualization is metaphorically based upon connectionist systems where concepts are represented as nodes that are interrelated through links, a link being a connection between two nodes (Mischel, Ayduk & Mendoza-Denton 2003). Designated as either excitatory or inhibitory, "information processing works through spreading activation – that is, activation at each initial concept spreads through the links to the other related concepts" in a metaphorically ripple-like manner (Mischel, et al. 2003, 180). Determining whether it is the 'know' or 'go' system that is primarily activated in decision-making is not of utmost importance; rather it is the interaction of these two cognitive systems that is the essential factor behind purposive volition and self-regulation (Metcalfe & Mischel 1999).

'Hot/cold' overlap

As presented by Mischel, Ayduk, and Mendoza-Denton (2003) in their book, *Time and Decision*, the hot/cold model builds upon a lengthy history of research on the interplay between cognition and emotion. Various cognitive models have suggested that emotion precedes its cognitive interpretation which is dependent on context. Another related model includes an initial state of arousal as a forerunner to emotion and cognitive interpretation. Nonetheless, the emotion-cognition interplay is relevant throughout prior models in a similar way to the hot/cold model. An aspect that is unique, however, is the direct, overlapping relationship between the hot and cold system to the degree that the same environmental referents are utilized with each opposing response. Cold or cool 'know' nodes can activate hot 'go' nodes just as 'go' nodes can be 'cooled' by the contemplative, slow, and strategic 'cool' nodes. According to the hot/cold model, self-control is dependent upon the 'cool' nodes direct access to 'hot' nodes, an aspect of self-regulation that develops over time due to environmental influence (Mischel, et al. 2003). It is important to mention that the effect of stress on decision making extends beyond the scope of this paper; however it is ultimately a crucial factor in the hot-cool decision making process. "The hot-cool model provides a heuristic framework for understanding intertemporal choice, as the 'hot' system works on a here-and-now principal relying mostly on biologically significant active triggers", whereas the compensating 'cool' system is emotionally neutral and strategic (Mischel, et al. 2003, 182). If design pedagogy strives to improve stimuli-influenced-choice, then an understanding of the hot-cold interplay is important to understand as the structured development of robust 'cool' systems for novice learners is intimately related to 'hot' predispositions.

'Hot' thinking in design

Focusing on one system in particular could be beneficial relative to the discipline-specific objectives of this perspective research due to the stimuli-laden environments of design. While the 'cool' system is understood to develop later in children than the 'hot' system, between 4 years and infant respectively, it is the hot system that is most rapidly triggered by environmental stimuli (Mischel, et al. 2003). Linked to an "almond-shaped region in the forebrain thought to enable flight or fight" (Mischel, et al. 2003, 181) reactions (Gray 1982; 1987; 1990) (Ledoux 1996), the 'hot' system is influenced by experiential learning particularly related to significant environmental triggers, significance being determined by prior experience and biological disposition among other factors. The impact of the aforementioned 'triggers' can include, but are not limited to, nodal activation levels, speed of response, and probability of nodal transition or evolution. The specification of environmental stimuli and their related impacts on nodal behavior are important due to the possibility of 'hot' reactions being 'cooled' and new 'hotspots' or 'hot regions' being created over time. Depending upon the situation and cognitive development of the individual, this suggests that 'hot' reactions need to be actively managed as they evolve and spread over time, perhaps via properly adapted 'cool' systems. In a correlative manner, the aforementioned point also suggests that novice students in digital design, or those students with less developed knowledge structures relative to digital design and digital tooling methods, may be impacted by different stimuli than expert learners with digital media. If novice learners in digital design contexts are impacted by different stimuli than expert learners, thus leading to 'hot', biased reactions, how can digital design pedagogy limit these stimuli and create a learning environment that helps novice learners build cognitive 'cool' systems to offset misleading 'hot' reactions? The application of knowledge relative to the interactions between 'hot' and 'cool' systems may be particularly useful for applicable pedagogy (Mcalpine, 2004).

'Hot' thinking and the misuse of advanced digital technology

Digital design is a methodologically unique form of design and thus contains novel mis-uses and missed-opportunities via contemporary technologies along with the promise of increased design capabilities and novel design artifacts, processes, and conceptualizations. Following the establishment of a cognitive, research-based background to stimuli-influenced decision-making, an exploration of digital design's misuses and missed opportunities will be undertaken relative to hot/cold cognition. As introduced by Becker (2015) in *Design Cognition: Optimizing knowledge transfer in digital design pedagogy*, "the misuse of advanced technology is a common plague in introductory digital design education as affordances of advanced technology are exploited. For example, the user-defined associative compositions or frameworks that control parametric operations offer opportunities for explicit knowledge transfer and formative assessment in digital design education, but such affordances are also two-faced with opportunities for enhanced knowledge-transfer being abused for quick results via ease of transference and formal complexities that mask a lack of intellectual rigor" (Becker 2015, 9).

In the prior example, the user-defined associative compositions or frameworks such as Grasshopper or Rhinoceros 3D scripts are particularly relevant to hot-cool/cold biases due to their novelty, capabilities, ease of transference, and ubiquity within contemporary pedagogical discourse in architecture. Unique to digital design media, user-defined associative compositions or frameworks are arguably the foremost exemplification of the ease and speed of geometric production via digital tools. Scripts, one of multiple generative framework examples, can be easily downloaded, imported into the relevant software, and implemented by a student to quickly create geometric complexity and higher-order associative logics, often without requiring the student to understand the higher-order digital facility themselves. If the utmost objective is to develop robust, flexible knowledge structures of digital tooling methods and processes, the ease of script implementation is worrisome. Not only does the aforementioned example of user-defined associative compositions exhibit a generally problematic lack of intellectual rigor, but the novelty of rapid complexity and ease of form generation may compound pre-existing biases relative to design artifact production, a problem spurred by digital tools that affects novice learners to a greater degree.

The 'hot' effect on novice learners

Higher-order generative frameworks and geometric complexity are characteristic of higher-order didactic, or technical, per this particular example, cognitive facility. Due to the "increased exposure of novice learners to digital design media and materialization technologies" (Becker 2015, 9), biases that may be exhibited by expert learners to a limited degree may become more widespread and intensified via higher-order digital media being exploited by inexperienced or novice learners. Visually seductive geometric complexity that would normally be produced only by expert learners in analog contexts can now be produced relatively easily via digital methods by novice learners. While the production of complex geometry and associative logics may support greater design possibilities for novice learners, design artifact production via digital media also runs the risk of being intellectually shallow yet highly stimulating to inexperienced learners, thereby functioning as an environmental stimuli and triggering 'hot' biases due to visual complexity and novelty.

Hot/cold influence upon design artifact production

Design faults in introductory digital design in architecture commonly tend to involve an infatuation with the capabilities of geometric production and formal complexity that privileges seductive formalism over more intellectually robust design artifacts that may have simpler geometries. Visual/tactile environmental stimuli such as attractiveness or complexity may impede rational decision-making due to the generation of emotion-laden 'hot' states such as excitement or intrigue relative to the student's production of a design artifact. Hence, the primary determination then becomes whether being "emotion-laden (hot) or not (cold) unduly influences their assessment of the potential value of an idea, leading them to either under or overvalue ideas" (Loewenstein & Angner 2003 cited in Liedtka 2015, 7). The decision-makers rationality can be so heavily influenced by emotion laden 'hot' states that not only can they vastly mis-assess how others will react to the relevant entity, but also how they themselves will react when not in a 'hot' state. Designs that solely rely on the exploitation of readily-available digital capabilities that may generate excitement and intrigue through complexity, particularly complexity that masks intellectual rigor, can quickly change from objects of excitement and potential to shallow objects with little relevancy through the eyes of the creator. In introductory digital design learning environments in particular, there may exist an enhanced tendency for students to become infatuated with the capabilities of geometric and formal acrobatics. Design capabilities that involve higher-order knowledge are now accessible to introductory learners, a challenge for design instructors as students seek to exhibit higher-order digital facility without proper, well-developed technical knowledge. Simply because the student can produce geometric complexity does not mean higher-order digital facility or design knowledge exists.

Discussion and limitations

The complexity and differentiation present in digital design media is directly correlated to the diversity of affordances and challenges for cognitive-based pedagogy in digital design environments. The propositions and explorations listed here are mere starting points as digital design methodologies continue to evolve in parallel to developments in cognitive psychology and the decision sciences. Despite the affordances of digital technologies for bias mitigation, a failure to recognize the diversity of interactions and possibilities novel digital environments engender may threaten the utility of digital tooling as mediating element in the decision making process.

Thus, a series of questions are raised that further probe the propositions aforementioned in this research. Are ‘hot’ decisions necessarily bad decisions? Should the development of more robust ‘cool’ systems be supported? “Arkes wrote that knowing one has a problem with biases does not help him avoid the effects of biases” (Arkes 1981 cited in Bay 2001, 10). Therefore, what relevance do self-initiated mitigation strategies have when other concepts such as ‘accountability shifting’ are inherent in the design methodology and do not necessarily require a conscious choice for initiation by the student? Besharov (2004) has focused specifically on the correction of cognitive biases, yet his research suggests that there are many complicating factors that limit the possible corrections that can occur. Factors such as multiple, overlapping cognitive biases, the ‘curse of knowledge,’ and the correction of one bias while making others worse all directly impact the study of biases in digital design environments (Besharov 2004). Aligning digital design pedagogy for novice learners with the cognitive sciences does however increase the opportunities for knowledge-transfer enhancement in design fields through the exposing of novel questions and considerations for effective pedagogy.

Conclusion

Design as a decision-making process has been linked with the systematic errors and deviations from rationality associated with heuristics. Unique to the ill-defined problems of design and the vast resource investments associated with the constructed design-artifacts of architecture, learners – particularly those that are novices – are at an increased risk for severe and systematic errors due to biased decision making. This paper attempts to expose and explore projection bias and the hot/cold model in digital design environments as digital media, modes, and methodologies may alleviate or compound the problems of biased decision making.

It is beyond the scope of this paper to quantitatively analyze each aforementioned bias and its impact on digital design pedagogy, however the paper does attempt to raise relevant questions and create multi-disciplinary linkages, thereby raising awareness for future research. A notable gap in digital design literature has thus been exposed through the pairing of decision science and cognitive science with digital design pedagogy. In furtherance, the mediative aspect of digitally-mediated design – a seminal characteristic unique to digital design – is presented as an integral factor for bias mitigation through the development of 'accountability shifting', a concept that exposes the cognitive benefits of decoupling the designer from their material-representational medium. Seeking to refine the designer's own judgement, cognition-based research concerning biases and heuristics hold exceptional promise in design fields as digital design's affordances and limitations are becoming increasingly integrated into architectural pedagogy.

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