



---

# Working Paper Proceedings

---

**Engineering Project Organization Conference**

Cle Elum, Washington, USA

June 28-30, 2016

---

## **The Objective Value of Subjective Value in Project Design Negotiations**

**Vivek Sakhrani, Massachusetts Institute of Technology, USA**

### **Proceedings Editors**

Jessica Kaminsky, University of Washington and Vedran Zerjav, University College London



© Copyright belongs to the authors. All rights reserved. Please contact authors for citation details.

## THE OBJECTIVE VALUE OF SUBJECTIVE VAUE IN PROJECT DESIGN NEGOTIATIONS

Vivek Sakhrani<sup>1</sup>

### ABSTRACT

Design in infrastructure Public-Private Partnerships (P3s) involves negotiated decision-making. There is a large and growing body of literature on the optimal and contingent design of P3 arrangements and the organizational and institutional dynamics in such projects, however the individual designer's cognitive and psychosocial experience in P3 design negotiations is relatively uncharted. This research associates the individual's Subjective Value outcomes (psychosocial effects such as trust, rapport) with the Objective Value outcomes (economic payoffs of technical design choices) from project design negotiations. An established theoretical framework from social psychology research called the Subjective Value Inventory is adapted to assess Subjective Value. Engineering designers participated in a collaboration exercise for the conceptual design of a large infrastructure P3 project. The exercise included control and treatment settings to test the effect of two different collaboration mechanisms: communication (dialogue) and common knowledge (reduced information asymmetry). Participants used a real-time tradespace and visualization model to explore and refine designs in support of the negotiated decision-making process. The tradespace model tracked not only every exploratory design iteration, but also every negotiated, i.e. agreed upon design outcome. These design choices generated the Objective Value outcomes of negotiated design. Detailed pre-experiment and post-experiment survey tracked psycho-social and emotive outcomes as well as problem understanding levels using indicator scales. The scores from these instruments generated the Subjective Value outcomes of negotiated design. Participants in the collaboration exercise overwhelmingly reported high Subjective Value scores, which are positively correlated with both their improved understanding of the project's design objectives and their degree of agreement on design choices. Enhanced psychosocial outcomes, i.e. positive emotive effects can be an important relationship foundation for future rounds of engagement between the same actors in long-lived arrangements such as negotiated P3s, especially since P3 participants may not previously have a history of establishing trust and credibility.

**KEYWORDS:** design, negotiation, psychosocial, experiment, infrastructure

### INTRODUCTION

Early stage infrastructure project design involves negotiated decisions. Negotiated design is particularly relevant in the context of public-private partnerships (P3s), which are long-term contractual arrangements. In setting up these contracts, partners must engage each other at the outset to actively make design choices that are likely to accomplish their separate and joint objectives over a long period of time. The partners' preferences may not always align, and so they negotiate to find agreement.

At the same time, the premise of negotiated design in these arrangements is to secure benefits through collaboration. Since each partner may have different roles, expertise, and

---

<sup>1</sup> Senior Consultant, CPCS Transcom Inc., Washington DC, [vsakhrani@cpcstrans.com](mailto:vsakhrani@cpcstrans.com); and Research Affiliate, Massachusetts Institute of Technology, Cambridge, USA, [sakhrani@alum.mit.edu](mailto:sakhrani@alum.mit.edu)

information, collaborative design may enable the partners to capture value above and beyond that available from traditional procurement arrangements such as E-P-C or Design-Build. This research therefore frames early-stage design decisions in infrastructure P3s as *negotiated collaboration*.

Studies of P3 arrangements mostly focus on institutional issues, contracting and incentive structures, and financing and investment arrangements. Project design under the frame of a P3 arrangement is an understudied area. In other words, the question of whether design in P3s is different from, and leads to different outcomes than other procurement approaches is an important question that has not been systematically addressed. Furthermore, there has been very little emphasis on gauging the individual designer's experience in these complex settings, neither cognitively nor psychosocially. This research focuses on the individual's experience in the design process of a P3 infrastructure project, and builds on the literature in design cognition and the social psychology of negotiations.

This paper investigates the outcomes of design negotiations. Specifically, the research associates the psychosocial outcomes with the technical design outcomes of an infrastructure project design negotiation. Psychosocial outcomes are inherently subjective and transient, difficult to measure, and often dismissed by academics and practitioners alike. Yet an individual's psychosocial experience can affect relationships with team members and counterparts and either enhance or undermine rapport, trust, credibility and legitimacy. In contrast, technical outcomes are objective and often easier to measure than subjective outcomes. The two types of outcomes may be linked. This research measures both through the use of a controlled design experiment, and establishes the link, showing that subjective psychosocial dynamics can have objective value in a negotiated design situation.

## **CONCEPTUAL OVERVIEW**

Problem-solving by human actors plays an important role in the conceptual design of systems. Since infrastructure projects are systems, we may extend the argument to projects as well. In complex product design, Hernandez, Shah, and Smith (2007) found that 70 - 80% of product cost is a consequence of design choices made during the conceptual stage of the product design process. While a similar statistic is unavailable for infrastructure projects, it is clear that the conceptual stage of design has cascading implications for the rest of the project design process, and indeed over the project's life. Problem-solving and conceptual design involve human cognition.

### **Problem-Solving and Design Cognition**

Design cognition as a field of research applies cognitive science to design. It takes on questions of how human designers think about a problem, how they find and reason through relevant information, and how they create solutions (Linsey et al., 2010; Dinar et al., 2015). The topics of information processing, shared understanding, collaboration and mental models, information exchange, and communication are relevant to the study of design negotiations.

#### *Information Processing*

Theories and models of information processing describe how humans perform the complex intellectual function of solving problems (Newell and Simon, 1972). Cognitive science has demonstrated that Working Memory (WM) or Short Term Memory (STM) limits the cognitive abilities of human designers. The 7 +/- 2 rule of chunking is a heuristic for deciding

how much human beings can be expected to reasonably retain in WM while solving complex problems (Miller, 1956). Lowering the demands on WM can reduce cognitive cost, for example with the help of devices such as calculators to aid in standard routines, or external memory (EM) aids to store information. The process of learning transfers information or memories from STM to Long-term Memory (LTM). Reasoning helps to embed relevant schemas in LTM over time (Lawson, 2004). Both learning and the use of EM aids free up WM to focus on other intellectual functions such as sense making and communication. In design negotiations, EM aids such as computational simulation models and the repeated use of the models can thus help with cognitive load reduction and to embed learning in LTN.

### *Design Complexity*

The complexity of the design problem affects whether designers are able to develop productive mental models and how they exchange information. Hirschi and Frey (2002) find a geometric relationship between problem solving time and the degree of coupling, i.e. interdependence between design parameters. Flager, Gerber, and Kallman (2014) also look at the effects of coupling for a building design problem although they find that coupling becomes less important as the scale of the problem (number of design variables) increases. Instead, solution quality decreases sharply as scale increases. The design process must account for these effects as designers explore complex problem spaces.

### *Shared Understanding*

For designers to negotiate design choices, they must develop a shared understanding of the design problem (Lawson, 2006). Prior research on team cognition has looked at how interaction and collaboration can lead team members to converge on a single problem-solving outcome (Fiore et al., 2010; Reiter-Palmon, Wigert, and de Vreede, 2012). In these situations, designers adopt a similar view of a technical problem and transform a single or small number of ideas into a creative solution. Mental models are one way to capture and describe designers' shared understanding (Badke-Schaub et al., 2007).

### *Collaborative Design*

Wood et al. (2014) study the effect of team interaction structure, i.e. independent versus collaborative design, on the designers' mental models. Representations of mental models are produced with Latent Semantic Analysis (LSA), essentially an analysis of bodies of text (Dong, 2005). They found that collaborating designers had mental models that were more similar than those of independent designers. Collaboration also decreased fixation, the tendency to focus on a subset of features or ideas, and led designers to think openly about possible solutions. Collaboration can thus increase shared understanding between designers.

When designers possess asymmetric information about the design problem, the mechanism of information exchange becomes critical (Honda et al., 2015). Designers' style or approach towards information exchange can shift system-level design outcomes. Austin-Breneman, Yu, and Yang (2014) show that design practitioners behave strategically while negotiating design trade-offs. They hedge their future needs by representing their view of the problem conservatively and through "worst cases". This biases the collaborators' mental models.

### *Role of Dialogue*

Information exchange and communication (dialogue, more specifically) are two distinct mechanisms of collaboration. Dialogue between designers, i.e. their words and expressions, contains information relevant to the problem they are solving. However, dialogue is neither a necessary nor sufficient means of exchanging relevant information. Written documents such as proposals, graphs and charts, presentations, and other such objects all deliver information without requiring dialogue. Designers may however need to actively engage in dialogue over these objects and seek clarity to truly understand their meaning and importance. On the other hand, too much information can also be burdensome and fail to improve design outcomes (Clevenger, Haymaker, and Ehrich, 2013). Further, designers may intentionally withhold or bias information in some competitive situations when there is no way to reveal facts.

Communication (dialogue) can assist designers in developing a useful mental model of a complex problem when information is limited, biased or asymmetric. Studies have demonstrated the importance of face-to-face communication for distributed design problems, where designers often work separately and meet infrequently. Others have also studied the effects of collocation. When face-to-face meetings and collocation is infeasible, designers may use computer-based collaboration spaces or methods to support one or both of information exchange and communication (Ostergaard et al., 2005).

### **Social Psychology of Negotiations**

Irrespective of the types of decisions, whether design, managerial decisions, or something else, negotiation interactions have a psychological effect on human negotiators. These effects in turn may impact outcomes either in the same or future interactions. The negotiation environment, i.e. the structural conditions of the negotiation, personality, and cognitive biases can all have implications. These aspects of negotiation are sometimes predictors of negotiation outcomes (payoffs), however psychosocial effects are also outcomes, though not strictly economic or technical payoffs.

### *Structural Features of Negotiations*

Early work in the social psychology of negotiation demonstrated that structural features affected outcomes. These structural or situational features include the number of people on each side, their incentives and payoffs, deadlines, and other environmental conditions. Studies of the 1960s and 1970s focused mainly on (i) the individual differences of negotiators and (ii) situational effects (Bazerman, Curhan, et al., 2000). Initially, Rubin and Brown (1975) documented the extensive empirical literature showing that individual differences do not explain much of the variance in negotiators' behavior. Others showed that situational features that define the context of a negotiation easily swamp any effects of individual differences (Thompson, 1998). However, recent work with updated methods and variables has re-established the importance of individual differences (Elfenbein et al., 2008; Sharma, Bottom, and Elfenbein, 2013). This does not take away from the importance of situational features however.

With a move towards cognitive issues in the 1980s and 1990s, behavioral decision research (BDR) then began to focus on the interaction of structure and behavior. This body of work focused (descriptively) on how negotiators actually make decisions, so that it could prescribe negotiation strategies (Raiffa, 1982; Bazerman and Neale, 1992; Bazerman and Moore, 2012). It tackled questions left unaddressed by the mathematical game theory perspective of decision science.

### *Psychological Biases*

Behavioral decision research pinpointed the many biases that can lead negotiators to deviate from normative prescriptions and rational behavior. Of the many systematic biases in two-party negotiations (Bazerman, Curhan, et al., 2000; Tsay and Bazerman, 2009), three in particular are very relevant to design-related negotiations:

- (i) **Bounded Awareness:** Negotiators are drawn more towards readily available information even if it is unimportant. They are often unable to make use of less noticeable salient information (Pinkley, Griffith, and Northcraft, 1995). They may fail to focus (Bazerman and Chugh, 2005; Chugh and Bazerman, 2007).
- (ii) **Egocentrism:** Negotiators may ignore the perspective of other parties (Valley, Moag, and Bazerman, 1998) and overlook valuable available information by failing to consider the opponent's cognitive perspective (Bazerman and Carroll, 1987). Often the egocentric view arises because a negotiator believes that the other party is overstating its case (Tsay and Bazerman, 2009).
- (iii) **The "Fixed Pie" effect:** Negotiators may falsely assume that the available payoffs from negotiation are constant sum - the size of the so-called "pie" is fixed (Bazerman, Magliozzi, and Neale, 1985; Gimpel, 2008). They miss opportunities for mutually beneficial trade-offs that increase the size of the pie (Fukuno and Ohbuchi, 1997).

These cognitive biases often surface in design interactions. They are important to consider because they affect the negotiating designers' mental models and understanding. The literature on mental models in negotiation is parallel to that in design cognition, and rarely do the two acknowledge each other.

### *Mental Models*

Studies of negotiation define a mental model as a cognitive representation of the expected negotiation (Bazerman, Curhan, et al., 2000). This literature shows that cognition and the negotiation structure are reciprocally intertwined - structure influences mental models and cognitive perception shapes structure and behavior.

Mental models of the negotiation situation, the other parties in the negotiation, and the self affect negotiator behavior and outcomes. Thompson and Hastie (1990) suggested that some negotiators modified their 'fixed pie' perception early in the negotiation to account for the bias; and for those who didn't the bias persisted throughout. Studies on attribution and interpersonal perception (Gilbert, 1994) have demonstrated how negotiators often overestimate the ideological difference or incompatibility of interests of others (Keltner and Robinson, 1997).

Even though individual negotiators may start out with different or contradictory perceptions, asymmetric mental models do not persist over the course of the negotiation interaction. Negotiators eventually create a shared understanding of the situation, their perception of other negotiators, and the rules of engagement (Messick, 1999). This phenomenon is precisely what we are looking to leverage in developing shared understandings of design problems in collaborative processes.

### *Role Theory*

Role theory addresses mental models of the self (Montgomery, 1998), showing that in negotiation situations with the same economic structure, individuals behave differently depending on the meta-rules of their roles. The same individual may also modify behavior depending on how they perceive their role changing in different situations. How negotiators understand and define the game for themselves can thus be a critical determinant of how they engage.

### *Negotiation Outcomes*

Negotiations have two types of outcomes: economic and psychosocial. The first type, economic outcomes, are the terms of the agreement struck by the negotiating parties. The bulk of the organizational and behavioral science literature over the last quarter century has focused on economic outcomes, treating them as objective or tangible terms of exchange (Raiffa, 1982; Bazerman and Lewicki, 1983; Raiffa, Richardson, and Metcalfe, 2002). For example, Neale and Bazerman (1985) studied the effect of framing and overconfidence in simulated negotiations. Their factorial design framed outcomes in terms of gains and losses between managers and unions, however these outcomes were economic.

The second type of negotiated outcomes, social psychological outcomes, is the attitudes, perceptions and emotions of the negotiators (Thompson and Hastie, 1990; Thompson, 1998). These subjective outcomes are squarely within the psychological and emotional realm. They receive little to no attention as the performance dimensions of negotiation studies because they are transient and fleeting, and perceived as hard to assess. Only in the last decade have researchers formalized the study of social psychological factors as outcome measures, instead of predictors of economic outcomes (Walsh, Weber, and Margolis, 2003; Curhan, Elfenbein, and Xu, 2006; Bendersky and McGinn, 2010).

Recent work suggests that the Subjective Value (SV) of social psychological outcomes of negotiation is just as, if not more important than the Objective Value (OV) of economic outcomes. Curhan, Elfenbein, and Xu (2006) developed the construct of SV, which they define as the "social, perceptual, and emotional consequences of a negotiation."

### *Subjective Value in Negotiated Design*

Subjective Value in negotiated agreements for design is important for at least four reasons. First, negotiators often place high value on the degree of respect or favorable relationships, sometimes even more than the value they attribute to economic payoffs. Social psychological outcomes thus have intrinsic value. For example, when given the choice, negotiators often describe the negotiation objective with frames that signify fairness and respect even if they may secure lower monetary outcomes (Blount and Larrick, 2000). This imbalance may be conscious or unconscious. Second, individuals or entities may be sought out as good counterparts based on the strength of the relationship and credible reputation (Curhan, Elfenbein, and Xu, 2006; Curhan, Elfenbein, and Eisenkraft, 2010). The desire to deal with partners who have established rapport may serve to further enhance SV (Tinsley, O'Connor, and Sullivan, 2002). Third, securing high SV in the first round of a negotiation may lead to both higher SV and OV in subsequent rounds (Drolet and Morris, 2000; Curhan, Elfenbein, and Eisenkraft, 2010). This reinforces the intuition of the two reasons above. Finally, enhanced Subjective Value can serve as a means of commitment to honor the terms of the agreement, when outcomes are not self-enforcing or easily monitored (Curhan, Elfenbein, and Kilduff, 2009; Ferguson, Moye, and

Friedman, 2008). Curhan and Brown (2011) call this the "insurance policy" function of SV. For the reasons described here, the relational view of negotiation (Gelfand et al., 2006) may sometimes take precedence over the rational view (Bazerman and Neale, 1992).

### **Summary of Concepts**

Negotiation is inherent in the collaborative design process, as the design cognition literature shows. After exploring many possible design solutions, designers must make decisions jointly to ensure that the chosen design will meet their competing objectives. As designers negotiate choices, they rely on information exchange and communication. Klein et al. (2003) suggest that interdependent designers exhibit tendencies such as "hill climbing" (securing a local maximum) or "annealing" (temporarily accepting lower payoffs to continue the search process). The engineering literature has emphasized the mathematical formulation of strategies and game design to secure desired system-level outcomes (Honda et al., 2015). When human designers engage with each other in real time however, emotional and social psychological effects affect negotiation dynamics (Simon, 1987).

Subjective Value of negotiation thus has implications for the collaborative design processes addressed in this study. The relational phenomenon is observed in contract settings between government agencies and private firms, where a perceived lack of respect or perceived opportunism may contribute to the adversarial nature of the relationship (Edkins and Smyth, 2006). Many authors point to trust as a key element of negotiated decisions in this space (Smyth and Edkins, 2007; Smyth and Pryke, 2009). Relational approaches to contracting therefore emphasize a longer-term view of bargaining with an emphasis on collaborative mechanisms for securing outcomes (Rahman and Kumaraswamy, 2004; Osipova, 2014; Suprpto et al., 2014).

The dual nature of value in negotiated decisions implies that neither should be considered in isolation. Curhan and Brown (2011) make the case that the very prescriptions and methods that negotiators apply to enhance OV may undermine SV, detracting from the overall organizational objective. For this reason, the research described here tracks both the Objective Value and Subjective Value of negotiation outcomes.

## **THEORETICAL FRAMEWORK AND CONCEPTUAL DEFINITIONS**

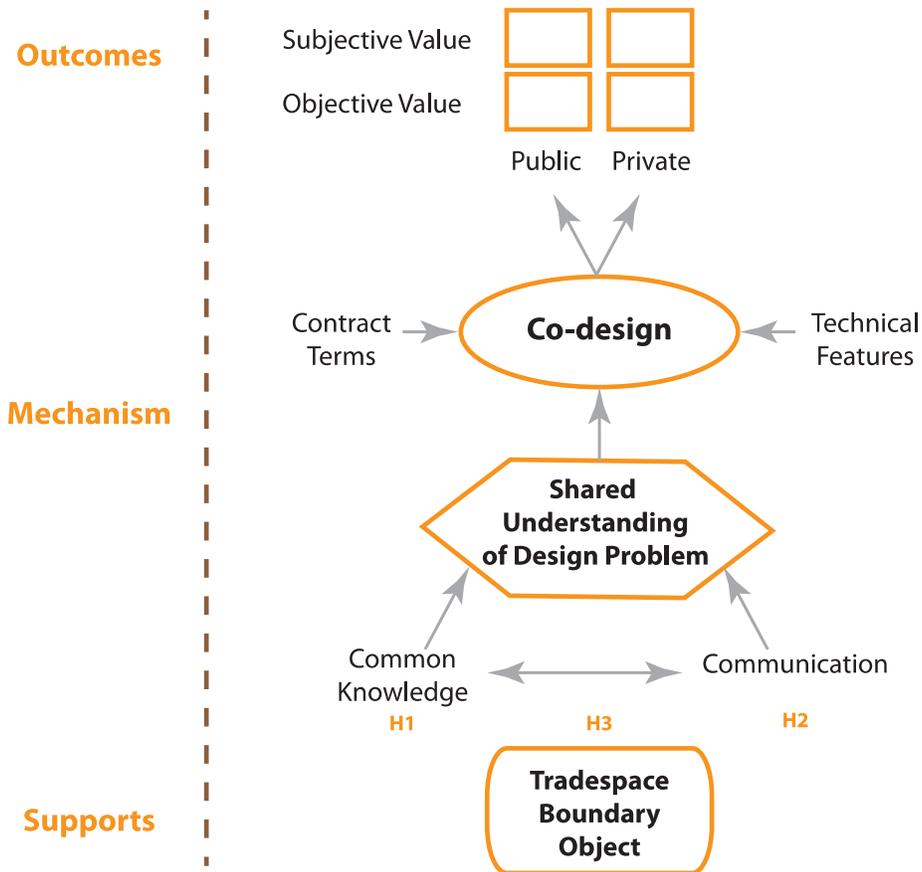
Early-stage design in infrastructure P3s is based on the premise that the partners will both collaborate and negotiate over design choices so that they can increase the likelihood of outcomes that accomplish their possibly competing objectives. We thus define *negotiated collaboration* as a process in which project actors with competing objectives and asymmetric information co-create a solution to balance design trade-offs through communication and knowledge exchange. Figure 1 presents a theoretical framework which links negotiated outcomes with mechanisms of collaboration.

### **Value Outcomes**

Negotiation outcomes have value implications for the partners. These value outcomes are positioned at the top of the schematic, because they emerge from the design process. The value outcomes are arranged along two dimensions (2 x 2) with the project actors' roles along the horizontal axis and type of outcome value along the vertical.

*Outcomes by Role Type*

Along the horizontal, ‘Public’ and ‘Private’ indicates the project actors playing two key design roles, the principal and the agent respectively. In a real project, the principal is a public authority that must ensure the delivery of an infrastructure service. The agent is a private firm (or consortium) that contracts with the authority to deliver this service, under a concession framework.



**Figure 1. The Co-Design framework for linking the mechanisms of collaboration with the outcomes of negotiation, i.e. both SV- and OV-type outcomes**

*Outcomes by Value Type*

Along the vertical, value outcomes are of two types. The first type, Objective Value (OV), represents the economic and technical payoffs to the principal and agent in the project. Profits are an example of economic payoffs to the firm; for the public authority, this type of payoff could imply service contract payments. Service or system reliability is a technical payoff, and both public and private actors experience it. The bulk of the design and negotiation literature has focused on outcomes in terms of Objective Value. On the other hand, Subjective Value (SV) has received less attention. SV denotes the project actors’ psychosocial outcomes. These are of an emotional and relational variety. The SV type captures phenomena such as sense of self, rapport, trust, and satisfaction from the engagement process.

## **Design and Collaboration Mechanisms**

The middle, intermediate area of the schematic shows the concept of *co-design*. Co-design is defined as the simultaneous design of both the terms of the concession as well as some high-level technical features of the project. Contract price (\$/unit) and payment levels are important parameters for the design of the concession design. Technical design features could include technology type, output production capacity of the project, number of production phases, etc. Co-design thus involves simultaneous decision-making about the values of these parameters in the early design stage. While technical choices and contractual terms interact to deliver Objective Value outcomes for the actors, the dynamics of negotiation influence Subjective Value outcomes.

For project actors to reach agreement in the collaboration process, they must develop a *shared understanding* of the design problem, defined as an understanding of both own and the others' objectives, and a comprehension of the relationships between design choice and expected outcomes. Developing a shared understanding requires actors to reconcile their own interests with those of the negotiation counter-party. In other words, designers' mental models must become similar over time. A designer's individual understanding develops through searching for relevant information, and learning by observing the effect of choices on outcomes. Additional cognitive mechanisms are necessary for shared understanding to develop. After this, collaborators make a number of moves and counter-moves to propose design choices until they approach agreement.

The framework posits three mechanisms of collaboration that can contribute to shared understanding. These mechanisms could be enacted in the design process to influence the OV- and SV-type outcomes, according to the following hypotheses:

*H1 – Common Knowledge: Common knowledge enables collaborators to achieve a shared understanding of the design problem by making explicit the relationship between negotiated choices and the designers' expected outcomes.*

Common knowledge is the converse of information asymmetry. The more knowledge the designers have about each others interests, objectives and expected outcomes, the lower the degree of information asymmetry. When common knowledge is low (i.e. information asymmetry is high), designers must find a way to exchange information with each other to develop a shared understanding. Documents, graphics, and other visual artifacts can all support information exchange. In this sense, these boundary objects are factual. The story is in the data, and collaborators must connect the dots to tell the story.

*H2 – Communication: Communication enables collaborators to achieve a shared understanding of the design problem through a process of discussion and reasoning in which they selectively pass information to alter other designers' mental models.*

Communication is an interactive and iterative process in which designers use language laden with facts to convey meaning through dialogue. Dialogue can be written or verbal. It is characterized by high frequency exchanges composed of individual messages. In other words, communication occurs in real time or over short time spans. Designers propose and evaluate offers and choices iteratively. Communication biases information in that it always represents one party's version of the design story. The bias can be unconscious, or it can be intentional strategic posturing.

*H3 – Knowledge/Communication Interaction: Common knowledge and communication interactively enable collaborators to achieve a shared understanding of the design problem by enhancing the sense-making process.*

Common knowledge provides broader factual representations of the collaborator's selective narrative that the recipient can use to question, verify and validate the altering mental model. Common knowledge may reinforce the effect of communication, whereas communication can amplify the effect of common knowledge by identifying salient information.

### **Collaboration Supports**

Supports for information exchange are at the bottom of the framework schematic in Figure 1. While collaborators can rely on their language and previous training for sense-making and problem-solving, formal artifacts such for information exchange can serve as External Memory (EM) aids to reduce cognitive burden. Computer models that relate design choices to expected performance outcomes for each collaborator are an important form of EM that enable information exchange.

This study uses a design tradespace to visualize the effect of design choices on expected outcomes. A tradespace model links the changes in design to relative changes in value outcomes along multiple dimensions. Since choosing a design entails making trade-offs when the dimensions are not interdependent, a tradespace model summarizes and visualizes the tradeoffs among different design choices.

A common tradespace model can serve as a boundary object (Iorio and Taylor, 2014) when tradeoffs are denoted in terms of payoffs to both project actors in the design negotiation. In other words, the tradespace boundary object is a common calculator that shows outcomes not only in terms of a partner's own OV outcomes but also those of the counterparty, thereby reducing information asymmetry and increasing common knowledge.

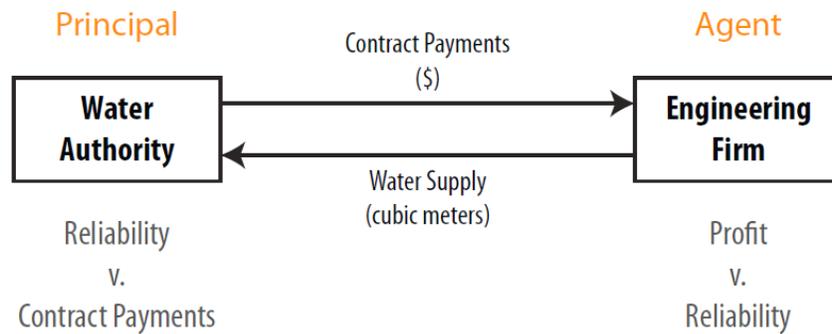
The theoretical framework for this research thus captures a process in which collaborators make design choices through co-design. To negotiate choices effectively, they must develop a shared understanding of the design problem by arriving at similar mental models. Computer models of the co-design problem can support the mechanisms of information exchange and communication in collaboration. The dynamics of negotiation and design choices result in multi-dimensional value outcomes both in terms of the roles of project actors as well as the nature of the payoffs, whether economic or psychosocial.

### **RESEARCH DESIGN**

Executing this research involved developing a stylized design problem for an infrastructure P3 project, with roles for the public and private actor who are linked to each other through a concession agreement. To assess the relationships between design choices, collaboration mechanisms, and value outcomes, a controlled collaborative design exercise was developed. Human designers played the roles of the public and private actors in multiple rounds of design, including negotiation rounds. The designers used a tradespace computer model to explore design choices. Data were collected through design trials, analysis of communication transcripts, and pre- and post-experiment surveys.

### Design Setting

The P3 project is a large desalination facility. A Water Authority contracts with an engineering Firm through a Water Purchase Agreement. The Firm is the agent in this problem; it designs, manages and supplies water to the Authority, who is the principal. The Authority wants reliable water supply and makes contract payments to the Firm in return for this service. Figure 2 depicts the roles and interests of the project actors and the terms of exchange in the concession agreement.



**Figure 2. A stylized design setting for a desalination infrastructure P3**

Each of these actors has different objectives and perceives the value of designs accordingly. The principal wants to ensure the public interest. As a Water Authority, it desires reliable water supply and is willing to make contractual payments in return. It trades off payments for reliability. On the other hand, the agent’s objective is profit. It is willing to deliver a reliable water supply for profit. The Firm trades off reliability for profit. There are thus three ways to express value in these problem, in the three dimensions of contractual payments (Water Authority’s view of the problem), profit (Firm’s view of the problem), and reliability which trades off the other two and links the outcomes to both the principal and the agent.

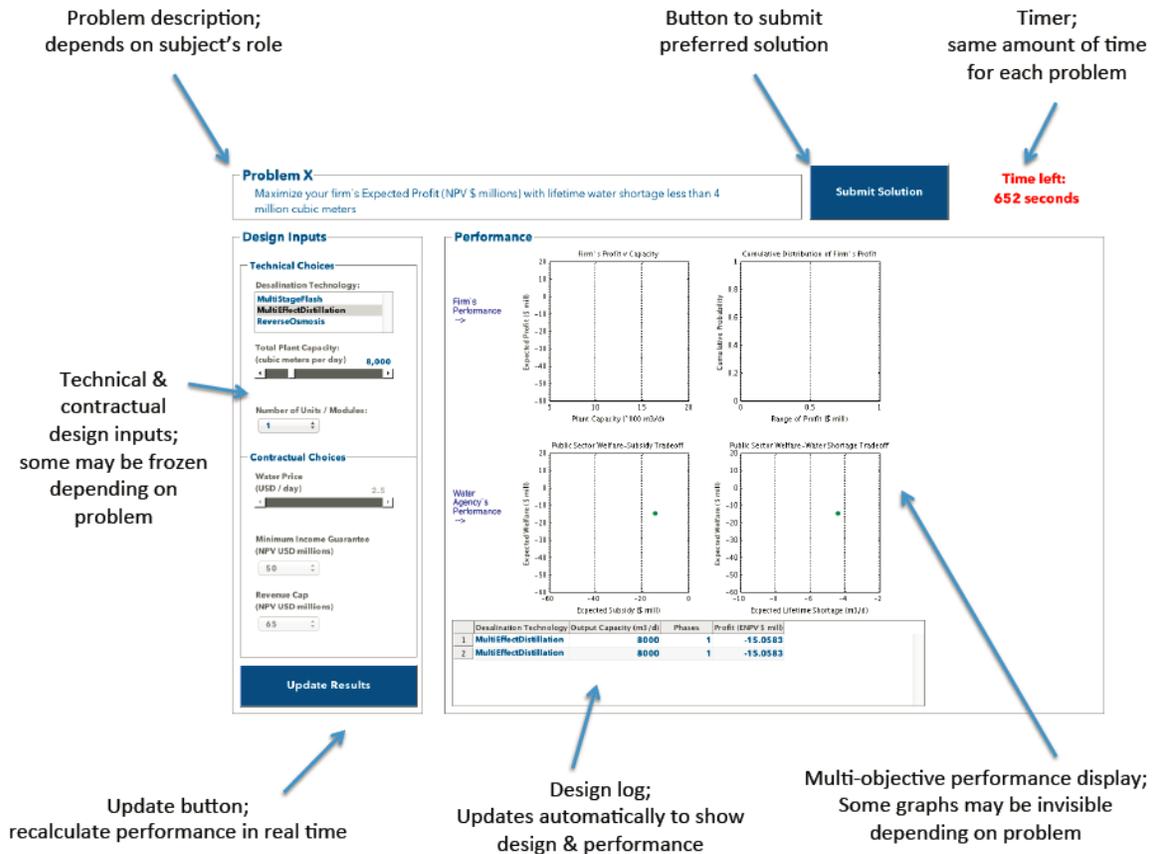
The technical configuration of the facility affects how the project creates value. The desalination facility uses energy to transform saline water into potable water. Since water is valuable to society, the Water Authority (as a proxy for society) benefits from water supply. Under conditions of demand uncertainty, the reliability of the project is defined as its ability to deliver water as and when demand arises over time. Some design configurations may be more reliable in meeting demand than others, and at different cost and profit conditions, which leads to tradeoffs in design.

The long-term concession agreement creates a mechanism for the exchange of value. It provides the project with a structure to link the decisions of the two project actors. It also governs how risk affects the principal and the agent. For example, the contractual price terms and other provisions determine the payments that the water authority makes to firm. The contract may also include risk allocation mechanisms such as minimum income guarantee provision in a take-or-pay structure to mitigate the demand risk to which the project is exposed.

### Tradespace Model

Desalination is a useful case for illustrating co-design, i.e. simultaneous technical and contractual design because most desalination projects are stand-alone dedicated facilities. Desalination projects are not networked, in the manner that power plants are networked into a grid. This allows designers to focus on the concept of the individual facility and how their





**Figure 4. The user interface for the DesalDesign tradespace model, the support for the collaboration exercise**

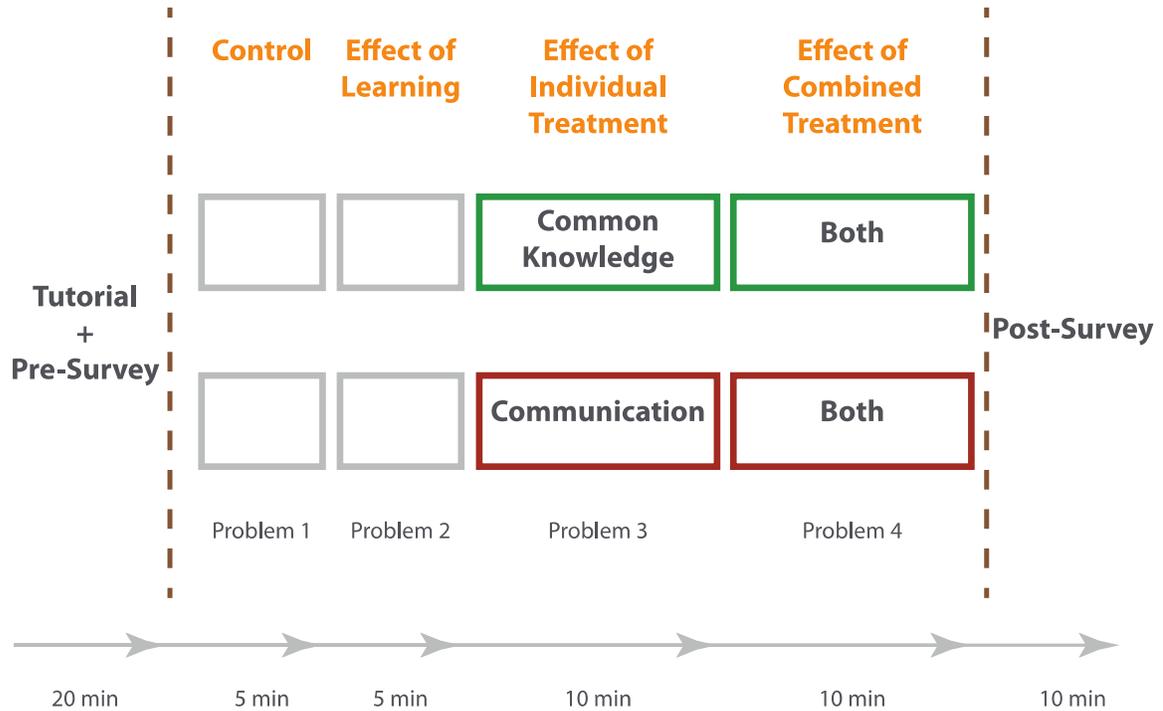
### Collaboration Exercise

A large number of engineering designers were invited to participate in the collaboration exercise, following Institutional Review Board procedures. The original sample size of designers who agreed to participate was N=140. After attrition and accounting for logistical issues, about 112 participants fully completed the exercise, and data for 92 individuals was captured reliably. The average age of participants was 32 years. They had on average ten (10) years of experience in sectors such as mechanical and aerospace engineering (product/system design, manufacturing, procurement and contracting); information technology (software, services and enterprise systems). About 90 subjects participated “onsite” on MIT’s campus, and 50 participated using a remote virtual connection. The exercise contained multiple design rounds structured as treatment and control rounds, as shown in Figure 5.

#### *Tutorial and Pre-Exercise Survey*

At the start of the design session, the administrator simultaneously gave all participants a ten-minute tutorial on the essential elements of the design problem and setting. The tutorial consisted of a pre-recorded movie clip, with embedded presentation slides and a voice recording. The tutorial included an example of a desalination plant, and the long-term concession contract approach for procuring such facilities. The presentation slides and verbal description covered the

principal- agent nature of the procurement with each party’s objective functions, constraints and the design variables that affected them. The presentation also included an overview of the DesalDesign software with an introduction to the interface, problem description readouts, and key input and output indicators. By the end of the tutorial, participants had thus had a full overview of the general design problem, and also the workings of the software tool they were about to use.



**Figure 5. Structure of the collaborative design exercise to assess the effects of collaboration mechanisms on OV and SV outcomes.**

In addition to the tutorial, participants also received a one-page role sheet that summarized the information from the tutorial, in a way that emphasized their role. This served as a reinforcement of the information and as an easy resource and reminder. With the recorded movie clip and printed role information, participants received the information using three media to support a number of differential learning styles.

The participants completed a pre-exercise survey immediately after the tutorial. Some questions addressed factual details covered in the tutorial and printed role sheet. These were designed to capture participant’s understanding of the facts of the design problem. Participants were also asked to explicitly rank how well they thought they understood the design task and objectives. The first subset of questions had ‘correct’ responses with binary scoring (correct: 1, incorrect: 0) and total scores could range from 0 to 20. The rest of the questions were marked on seven-point Likert scales with a 1: ‘Not at all’, to a 4: ‘Moderately’, and 7: ‘Extremely’. These scores were used to populate the measures of Objective Understanding (*ObjU*) and Subjective Understanding (*SubjU*) respectively.

### *Treatments and Controls*

Prior to the exercise, participants were grouped in pairs through stratification and random selection, where each pair included one Water Authority role player and the other played the role of the Firm. Pairs were also randomly assigned to two groups called ‘*communication first*’ and ‘*information first*’, their meanings are described further below. Pairs in both groups had to solve the same design problem four times. The design problem was identical in each round for both groups. This provides a natural control in the experiment since the structure of the task does not change.

For the first two problems, the control round and test of learning round, participants were told to design independently. One aspect of ‘*independent design*’ is that there was no communication between collaborators. This implied that each person in a design pair would work individually on the design problem on their computer device, without interacting with their pre-assigned counterparty in any way. The second aspect of ‘*independent design*’ is that participants would only see performance results that affected their performance objective. In other words, the Firm would see the trade-off of profits versus reliability, whereas the Water Authority would see the trade-off of contract payments with reliability. In Problem 3, two different treatments were applied, one to the ‘*communication first*’ group and the other to the ‘*information first*’ group:

- ‘*Communication*’ treatment: Under this treatment, participants were asked to communicate with their pre-assigned collaborator (the counterparty) to complete the design problem. Pairs of co-designers communicated using a private chat room created specifically for their dyad. The chat room recorded a transcript of their communication. The group that received Communication as the only individual treatment in Problem round 3 is labeled the ‘*communication first*’ treatment group.
- ‘*Common Knowledge*’ treatment: In this treatment, participants saw information about both their own value outcomes as well as their collaborating counterparty’s outcomes on their computer screen. Participants now had access to both their own results as well as the counterparty’s results. The information asymmetry in performance between the two thus vanished. The group that received Common Knowledge as the treatment in Problem 3 is the ‘*information first*’ treatment group.

These two treatments are independent. A group of participant pairs could have Communication, Common Knowledge or both. All participants received both treatments in the final round, Problem 4. Thus both groups received both treatments, albeit in different orders (order switching). This allows us to isolate the effects of the two treatments in some parts of the analysis.

### *Post-Exercise Survey*

Participants responded to a post-experiment survey after all four problems. Some questions elicited their perceived experience of the treatments. Specifically, participants stated whether completing the exercise resulted in an Improvement (*Im*) in their understanding. They also stated how much they attributed any improvement to the ability to communicate. The survey also asked about whether seeing additional information about the counterparty led to confusion, thereby detracting from their understanding.

### *Measuring Subjective Value*

Subjective Value is measured with the Subjective Value Inventory (SVI), a measurement scale developed by Curhan, Elfenbein, and Xu (2006). The SVI scale is an umbrella device and has four sub-dimensions or subscales, described below (Curhan, Elfenbein, and Eisenkraft, 2010).

1. Instrumental SV: this sub-scale records the subjective perception that the economic or Objective Value of outcomes in the design negotiations were balanced between the parties' objectives, and in line with negotiators' normative expectations of legitimacy. Negotiators' responses to four questions about satisfaction, balance, loss, and legitimacy populate the scores of this sub-scale.
2. Self SV: the second sub-scale indicates the perception of feeling competent during the session and not "losing face." This is relevant because the economic outcomes of some negotiations are not immediately revealed or clear, and negotiators resort to their own perceptions to find closure about the "deal".
3. Process SV: Perceptions of fairness in process, being heard or feeling listened to while expressing arguments, and perception of the counterpart adequately considering the self's viewpoint are captured by this sub-scale.
4. Relationship SV: this sub-scale captures impressions about the positivity of the exchange between negotiators, beliefs about trust, and the extent to which counterparties perceive a good foundation for future exchanges, if they were to transact again.

These four sub-dimensions of Subjective Value taken together comprise the global SVI measure. The post-survey at the end of the collaboration exercise asked participants a series of questions that have been standardized in the Subjective Value Inventory.

## RESULTS

### Pre-Exercise Variable Construction

#### *Understanding*

Two types of scores were calculated from responses to the pre-exercise survey to capture the construct of understanding, Objective Understanding (*ObjU*) and Subjective Understanding (*SubjU*). *ObjU* records the degree to which participants absorbed factual knowledge about the design problem and related phenomena based on information provided in the tutorial and role sheets. *SubjU* records a participant's perception about how well they understood the design problem and tasks at that moment in time. A number of two-sided differences in means tests of sample bias (role, treatment group, gender, location, education) did not show much support for a bias in understanding based on these participant attributes. In other words, there was insufficient evidence to reject the null hypothesis that means of *ObjU* in the stratified sub-samples (and separately of *SubjU*) were different.

#### *Mood*

Participants' instantaneous disposition going into the collaboration exercise may affect the quality of their interactions. Mood (*M*) is a latent variable and difficult to measure directly, so the pre-exercise survey asked participants a number of questions related to this construct. Participants scored how motivated, how nervous, and how confident they were about the upcoming exercise on scales from a minimum of 1: "Not at all", 4: "Moderately" to 7: "Extremely". Both the validity and the reliability of the proposed Mood (*M*) scale were analyzed. Broadly, validity of a tool is a statement about whether it measures what it is supposed to measure. Reliability is about the consistency of the tool's measurements across time, situations,

and evaluators (Juni, 2007). A final reliable Mood ( $M$ ) scale ( $\alpha = 0.65$ ) with items recording participants' motivation and confidence was retained. Further tests of differences in means did not provide evidence that the sub-samples were biased in the  $M$  measurements, supporting the notion that the different participant groups were similar before the start of the collaboration exercise.

*Relationship between Understanding (ObjU, SubjU) and Mood (M)*

We would expect  $ObjU$  and  $SubjU$  to be related by construction, and the results showed a significant positive correlation (Pearson's  $r$  product-moment correlation,  $r = 0.4$ ,  $p < 0.001$ ) for continuous variables as well as Spearman's rank-order relationship  $\rho$  for ordinal variables,  $\rho = 0.32$ ,  $p = 0.002$ ). Similar tests of correlation show a weak positive relationship between  $ObjU$  and  $M$  ( $r = 0.22$ ,  $p < 0.05$ ;  $\rho = 0.20$ ,  $p = 0.06$ ). In comparison, there is a strong positive relationship between  $M$  and  $SubjU$  ( $r = 0.57$ ,  $p < 0.001$ ;  $\rho = 0.56$ ,  $p < 0.001$ ).

The correlations permit us to formulate the hypothesis that Subjective Understanding can be explained in relationship to Objective Understanding as well as Mood. This hypothesis is plausible because participants' belief about their level of understanding may be influenced by their "true" understanding of the facts, and also their instantaneous disposition. We can test this hypothesis with a standard OLS regression, and formally state it as:

H0: Subjective Understanding is independent of Objective Understanding and Mood, such that  $\beta_0 = \beta_1 = \dots = \beta_i = 0$

Table 1 shows the results of four different models analyzed to test this hypothesis. The first two regress  $SubjU$  individually on  $ObjU$  and  $M$  respectively. The third represents the two independent variables additively ( $ObjU + M$ ) and the final also includes their multiplicative interaction term ( $ObjU : M$ ).

**Table 1. OLS regression results for Subjective Understanding as a function of Objective Understanding and Mood. Model (3) is the best fit.**

	Dependent variable:			
	SubjU			
	(1)	(2)	(3)	(4)
$\beta_{SubjU}$	4.130*** (0.112)	4.130*** (0.101)	4.130*** (0.095)	4.132*** (0.098)
$ObjU$	0.468*** (0.113)		0.340*** (0.098)	0.337*** (0.105)
$M$		0.667*** (0.101)	0.593*** (0.098)	0.592*** (0.099)
$ObjU : M$				-0.009 (0.110)
Observations	92	92	92	92
R <sup>2</sup>	0.160	0.325	0.405	0.405
Adjusted R <sup>2</sup>	0.151	0.317	0.392	0.385
Residual Std. Error	1.078 (df = 90)	0.966 (df = 90)	0.912 (df = 89)	0.917 (df = 88)
F Statistic	17.157*** (df = 1; 90)	43.326*** (df = 1; 90)	30.332*** (df = 2; 89)	19.998*** (df = 3; 88)

Note: \*p<0.1; \*\*p<0.05; \*\*\*p<0.01

The OLS procedure requires *means shifting* so that the intercept of the regression results can be interpreted appropriately. The common intercept value for all the models indicates the mean of *SubjU*. Of the four models, Model (3) which represents *SubjU* as an additive function of *ObjU* and *M* is the best fit. It best explains the variation in *SubjU* (adj.  $R^2 = 0.39$ ), has the lowest standard error of residuals, and a robust *F* statistic. (30.3; df 2, 89;  $p < 0.01$ ). We thus reject the null hypothesis; *SubjU* can be statistically modeled as a function of *ObjU* and *M*. In other words, Objective Understanding and Mood predict the level of a participant’s Subjective Understanding of the design problem prior to the collaboration exercise.

*SubjU* is more sensitive to variation in *M* than in *ObjU*. A unit change in the *M* score shifts *SubjU* from its mean value of  $\mu_{SubjU} = 4.13$  by approximately 0.6, almost twice the effect of *ObjU*. After controlling for the effect of a participant’s factual understanding (*ObjU*) of the design problem, an individual’s perception of their level of understanding is highly dependent on their disposition at that moment in time.

**Post-Exercise Variables**

Participants answered a series of questions in the post-exercise survey that provided the scores to populate the SVI inventory. The survey also asked the participants a number of questions about whether their understanding improved after collaboration (Improvement, *Im*), whether communication with their collaborator increased their understanding (Communication factor, *Cm*), and whether seeing extra information about their collaborator’s performance results confused them or detracted from understanding (Confusion factor, *Cf*). *Im*, *Cm* and *Cf* are thus self-reported measures. The results in this section links\ the three to each other and to Subjective Understanding, *SubjU*.

*Reliability of the SVI Measurements*

A series of reliability tests on the SVI scores from the post-survey establish that the SVI instrument provided reliable scores that are consistent with each other and can be used for further analysis. The results for three different estimates of reliability (Cronbach’s  $\alpha$ , standardized  $\alpha$ , and G6) are summarized in Table 2, suggesting that Instrument (I) and Self (S) SV estimates are reliable, however they are slightly lower than the prescribed threshold of 0.7 for ordinal measurement scales. These sub-scales should therefore not be used independently. On the other hand, Process (P) and Relationship (R) are highly reliable. We can confidently combine the latter two into the Rapport SV scale ( $\alpha = 0.85$ ). High  $\alpha$  reliability estimates [0.7, 0.9] imply that the aggregated Rapport and Global SV scores may be confidently used to indicate Subjective Value in further analysis.

**Table 2. Reliability tests for SV outcomes along the sub-scales and global SVI scale. The scales used to calculate SV are highly reliable.**

Sub-scale	Cronbach’s $\alpha$	Std $\alpha$	G6(sm)	avg <i>r</i>	S/N	ase	mean	sd
Instrument (I)	0.617	0.622	0.615	0.291	1.642	0.100	4.873	1.046
Self (S)	0.640	0.687	0.690	0.305	2.199	0.087	4.871	0.780
Process (P)	0.896	0.897	0.880	0.686	8.737	0.060	4.861	1.446
Relationship (R)	0.928	0.933	0.919	0.776	13.871	0.054	4.759	1.355
Rapport SV (P+R)	0.852	0.853	0.743	0.743	5.783	0.132	4.778	1.323
Global SV (I+S+P+R)	0.710	0.701	0.700	0.370	2.346	0.085	4.809	0.872

*Improvement in Understanding (Im)*

The variable Improvement (*Im*) measures how a participant's understanding changed over the course of the collaboration exercise, after receiving the Communication and Common Knowledge treatments. *Im* is reported by participants, and is thus the perceived change in *SubjU*. Participants' mental models and understanding will have evolved in both treatment groups as they coursed through the exercise, so we can expect both treatment groups to report an Improvement. A formal Analysis of Variance (ANOVA) hypothesis test for whether one treatment group reported a systematically higher *Im* score showed that the *communication first* group (mean = 4.97, var = 1.92) reported higher *Im* with a lower spread than the *information first* group (mean = 4.51, var = 2.22), although the difference was not statistically significant ( $p=0.13$ ).

*Effect of Communication (Cm)*

Participants were asked how much of their improvement in understanding related to the ability to communicate (*Cm*) with their counterparty. Reported *Im* was found to correlate well with *Cm* ( $r = 0.45$ ,  $p < 0.001$ ;  $\rho = 0.35$ ,  $p < 0.001$ ). One hypothesis is that more of the *communication first* group's improvement in understanding came from the process of discussion with their collaborator. This group has a higher mean with much lower variance than the *information first* group. Specifically, the difference in means  $\mu$  from a Welch test with unequal variance is 0.71 ( $p < 0.05$ , 95% ci: [0.02, 1.4]). Overall, these results imply that while both treatment groups reported Improvement (*Im*) in understanding, the *communication first* group attributed more of that improvement to communication.

*Effect of Confusion (Cf)*

The final question regarding Improvement in the post-exercise survey was whether participants experienced confusion (*Cf*) when presented with the counterparty's performance results in the Common Knowledge condition. The variable Confusion (*Cf*) was included in the survey to assess whether the additional information in this condition detracted from the otherwise overall improvement in understanding as a consequence of completing the exercise. As expected, *Cf* is negatively correlated with *Im* ( $r = -0.2$ ,  $p = 0.06$ ;  $\rho = -0.20$ ,  $p = 0.05$ ).

**Main Result on Improvement in Understanding through Collaboration**

The effects *Cm* and *Cf* were uncorrelated with each other, and both were included in an OLS regression model along with *SubjU* as independent predictor variables. Table 3 shows some OLS specifications with *Im* as the dependent variable that include both the main and interaction effects of *SubjU*, *Cm*, and *Cf*. The intercept is the mean value of *Im*, as all the scores were mean-shifted to make the intercept meaningful. All the models tested control for the treatment group. Model (3) is obtained by including main effects for *SubjU*, *Cm*, *Cf* and the interaction terms of *SubjU*, dropping the last possible *Cm* : *Cf* interaction term. This model is the best in terms of goodness of fit, amount of variation explained and low standard error of the residuals.

The interpretation of Model (3) is that participants who reported an improvement in understanding by the end of the collaboration exercise attributed much of this improvement to the ability communicate ('Communication' treatment) with each other. The additional information received (through the 'Common Knowledge') treatment had the potential to confuse participants. The degree of improvement in understanding (*Im*) also depended on the

participant’s own initial perception (*SubjU*) of how well they understood the problem at the start of the exercise. Even participants who thought they initially understood it well could find that their understanding improved further. If their initial perceived understanding was high, then communication still helped but to a lower degree than for the participant’s with a low perceived understanding initially.

**Table 3. OLS regression results for Improvement in Understanding (*Im*) after the collaboration exercise as a function of Subjective Understanding (*SubjU*) prior to the exercise, the ability to communicate (*Com*) and the degree of confusion (*Cf*)**

	<i>Dependent variable:</i>			
	<i>Im</i>			
	(4)	(5)	(6)	(7)
Intercept	4.981*** (0.198)	4.957*** (0.192)	5.006*** (0.192)	5.006*** (0.193)
<i>SubjU</i>	0.309** (0.130)	0.266** (0.127)	0.288** (0.127)	0.287** (0.127)
<i>Com</i>	0.468*** (0.133)	0.503*** (0.130)	0.497*** (0.129)	0.493*** (0.131)
<i>Cf</i>		-0.315** (0.124)	-0.258** (0.127)	-0.263** (0.130)
Group ‘Info first’	-0.342 (0.262)	-0.294 (0.255)	-0.331 (0.253)	-0.327 (0.255)
<i>SubjU</i> : <i>Com</i>	-0.441*** (0.124)	-0.458*** (0.121)	-0.492*** (0.121)	-0.492*** (0.122)
<i>SubjU</i> : <i>Cf</i>			0.223* (0.131)	0.226* (0.133)
<i>Com</i> : <i>Cf</i>				-0.023 (0.121)
Observations	92	92	92	92
R <sup>2</sup>	0.352	0.397	0.417	0.417
Adjusted R <sup>2</sup>	0.322	0.362	0.376	0.369
Residual Std. Error	1.199 (df = 87)	1.164 (df = 86)	1.151 (df = 85)	1.157 (df = 84)
F Statistic	11.799*** (df = 4; 87)	11.323*** (df = 5; 86)	10.128*** (df = 6; 85)	8.588*** (df = 7; 84)

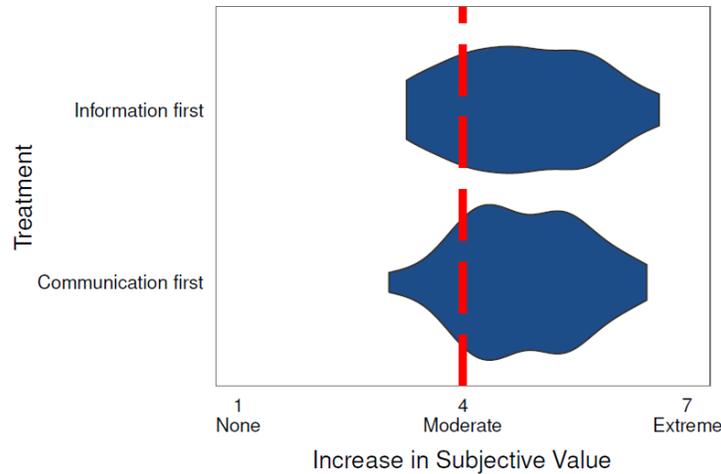
Note: \*p<0.1; \*\*p<0.05; \*\*\*p<0.01

### Main Results on Subjective Value Outcomes

#### Overall Increase in SV

Most participants reported a large increase in Subjective Value after participating in the collaboration exercise. The SV outcomes were analyzed in a number of ways to substantiate this result. Subjective Value outcomes by treatment group show that both groups (*communication first* and *information first*) experienced a large increase in SV, as shown in the violin plots in Figure 6. The aggregate SVI scale for ‘Increase in Subjective Value’ is on the horizontal axis and ranges from 1: None to 7:Extreme. The red dashed line marks the scale mid-point. The ends of the colored areas indicate the range of the observations for each group. The relative density of

observations at each level of the scale is given by the width of the shaded area at each level of the scale. We can see that most of the shaded area is well to the right of the scale mid-point of ‘Moderate’ increase in SV. The difference in the means of the two groups is not statistically significant.



**Figure 6. Overall SV results by treatment group across the sample of exercise participants with both the range and the density of observations shown.**

#### *Increase in SV by Role Type*

The conclusion from an analysis of SV by Role is similar. Participants in both the Water Authority’s and the Firm’s role reported that their SV increased after collaboration. Although the increase in SV on the whole was large, the difference in the means of the two Role groups is not statistically significant.

#### *Effect of Sample Attributes on SV*

Elfenbein et al. (2008) find that some demographic attributes correlate with SV outcomes. Correlation tests of ‘Gender’, ‘Age’, ‘Education’, and ‘Location’ of participation, are charted in Table 4. The four sub-scales comprising the Global SV measure are positively correlated with each other, by construction and from the reliability tests above. Another relationship of note is the negative correlation between the Relationship (R) sub-scale measure and Gender [Female=1, Male =2]. The interpretation is that women ascribe higher SV outcomes along the Relationship dimension. This observation is explored further below. SV outcomes do not co-vary much with the other demographic attributes tested.

The relationship between Gender and Relationship SV is consistent with observations in the literature, but not sufficiently compelling based on a test of correlation alone. Two different tests of means comparison - Welch’s t-test ( $t=2.24$ ,  $p<0.05$ ,  $\mu$ : [0.07,1.37]) and a non-parametric Wilcoxon rank sum test ( $W=985.5$ ,  $p<0.05$ ) both reject the null hypothesis that gender has no effect on Relationship SV outcomes. The evidence thus supports the finding that women did indeed experience higher Subjective Value along the Relationship sub-dimension, with a difference in means of slightly more than 0.7 points on the scale. Many women reported very high absolute increases of 6 or 7 on the Relationship sub-dimension. Tests of the dimensions of Subjective Value other than Relationship SV for correlation, means differences and dependence on either experimental Role or Treatment condition did not produce statistically significant results.

**Table 4. Correlations of Sample Attributes, Treatment and Role Types, and SVI scale sub-dimensions.**

	Gender	Age	Education	Location	Role	Treatment	Instrument (I)	Self (S)	Process (P)	Relationship (R)	Rapport SV (P+R)
Gender	0.28**										
Age	-0.17	-0.02									
Education	0.28*	0.14	-0.02								
Location	-0.01	-0.04	0.18	0.02							
Role	-0.08	0.06	-0.04	-0.04	-0.01						
Treatment (I)	0.07	-0.03	-0.11	-0.09	0.11	0.11	0.21				
Self (S)	-0.06	0.13	0.02	-0.03	0.01	-0.05	0.27*	0.28*			
Process (P)	-0.16	-0.10	-0.06	-0.04	-0.08	0.12	0.27*	0.44***	0.75***		
Relationship (R)	-0.22*	-0.09	0.08	-0.10	-0.07	-0.08	0.28**	0.38***	0.94***	0.93***	
Rapport SV (P+R)	-0.20	-0.10	0.01	-0.07	-0.08	0.03	0.28**	0.58***	0.85***	0.88***	0.93***
Global SV (I+S+P+R)	-0.14	-0.06	-0.02	-0.09	-0.09	0.04	0.57***	0.58***	0.85***	0.88***	0.93***

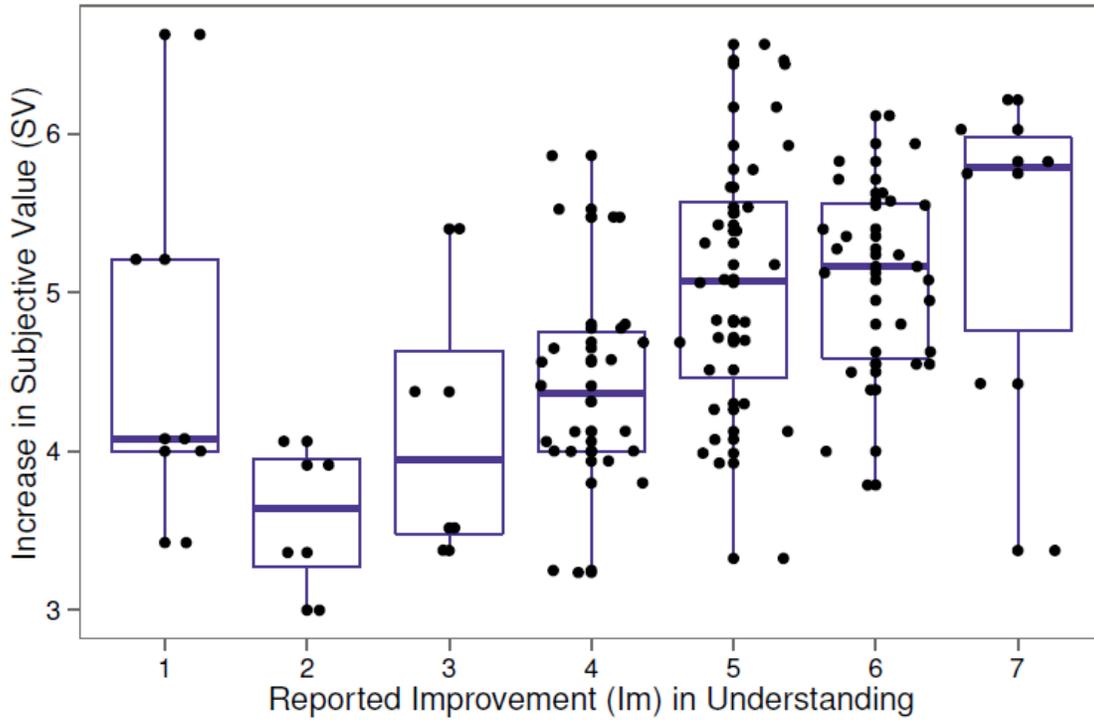


Figure 7a. Variation in the increase in SV through collaboration, controlling for the level of Improvement in understanding

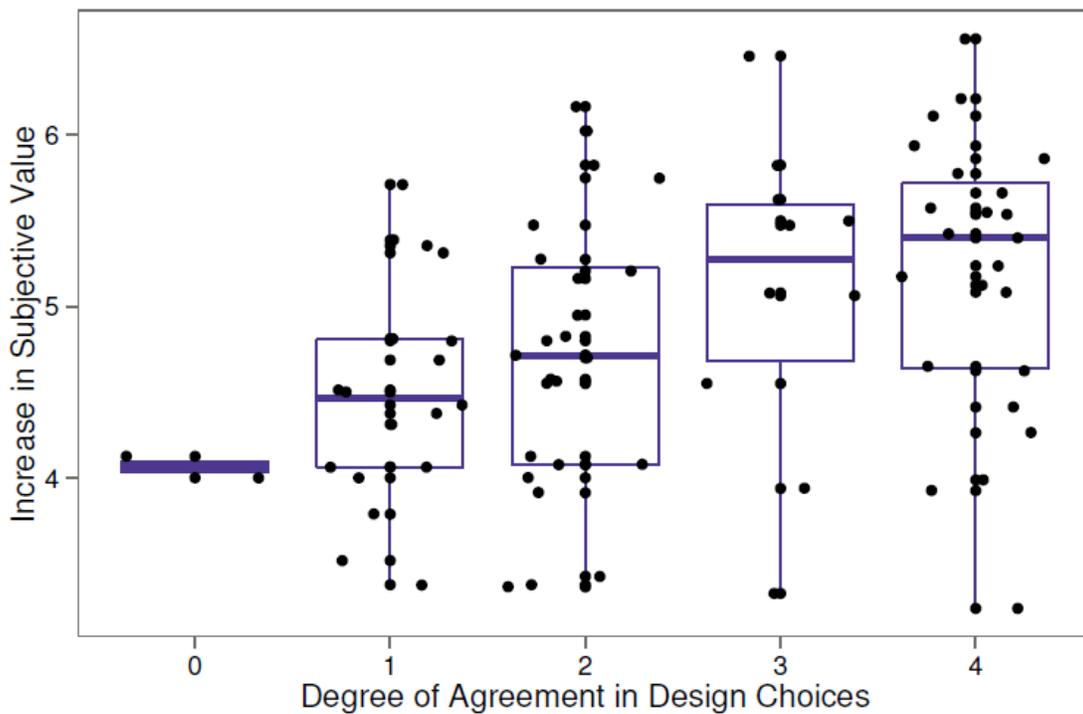


Figure 7b. Variation in the increase in SV through collaboration, controlling for the degree of agreement in design choices (proxy for Objective Value outcomes)

### *Relationship between SV and Improvement in Understanding*

The analysis summarized in Figure 7 gives a sense of the relationship between the increase in aggregate SV scores and *Im*. The figure uses boxplots for SV to illustrate both the mean and the variation in outcomes, while controlling for *Im* on the horizontal axis. Except for the lowest level of *Im*, the distribution of aggregate SV score shifts upward on the SVI scale as *Im* increases. Even at the lowest *Im* ('no improvement' in understanding), a few participants reported a high increase in SV. Tests of correlation do in fact show that SV and *Im* are positively correlated ( $r = 0.37$ ,  $\rho = 0.41$ ,  $p < 0.001$ ). We conclude that there is a positive relationship between how much participants felt their understanding improved after collaboration and the Subjective Value they ascribed to their experience.

### *Relationship between SV and Agreement (Ag) in Design Choices*

The degree of agreement, Agreement (*Ag*) in design choices, is one representation of Objective Value outcomes, and can be linked to aggregate SV outcomes. The variable *Ag* is a suitable proxy for OV outcomes because, to balance value trade-offs between reliability of meeting demand, profit, and contract payments, the collaborators had to agree on the independent dimensions of design. Hence we can hypothesize that if collaborators agreed more on designs, they may have experienced higher SV outcomes.

The distribution of aggregate SV scores suggests a positive relationship between SV and *Ag*, while controlling for the degree of agreement *Ag* (Figure 7b). As the degree of agreement across participants increases, the mean level of increase in SV rises. However, the variation in SV scores also increases. It becomes clear that collaborators who did not agree on designs reported low increases in SV as a result of collaboration. There are also many participants with both high *Ag* and SV scores. The resulting correlation between SV and *Ag* is significantly positive ( $r = 0.36$ ,  $\rho = 0.36$ ,  $p = 0.001$ ).

An important observation is that many participants who did agree on a high number of design dimensions experienced low Subjective Value change after the exercise. This supports the idea that negotiated agreements do not always result in high Subjective Value outcomes, for example, when collaborators feel that they are forced to agree because of some external enforcing mechanism. Since the collaboration mechanism had no enforcing mechanism, the low SV scores are likely due to the negotiating dynamics in collaborating pairs interacting with their attributes (Subjective Understanding, Mood, etc.)

### **Summary of Main Results**

The SV assessment finds that collaborators on the whole experienced a large increase in Subjective Value, their psychosocial outcomes, from collaborative design. The large increase was observed across both treatment groups in the exercise, as well as across the design roles. Women in particular ascribed higher increases in Subjective Value to its relationship aspects, compared to men. These increases were associated with other aspects of the collaboration. Participants who believed that their understanding of the design issues improved significantly through collaboration also exhibited high increases in Subjective Value. In a similar manner, if collaborators agreed on design choices, they tended to report higher Subjective Value increases on average.

## **DISCUSSION**

A collaborator's degree of understanding can help or hinder the objective of approaching agreement on design choices. The analysis demonstrated that a participant's Subjective Understanding is predicted by not only their understanding of the facts and structure of the problem, but also by their disposition at the time of the exercise. Further, participants who reported an improvement in understanding by the end of the collaboration exercise attributed much of this improvement to the ability communicate with each other. The additional information received through common knowledge had the potential to confuse participants. The degree of improvement in understanding also depended on the participant's own initial perception of how well they understood the problem at the start of the exercise. Even participants who thought they initially understood it well could find that their understanding improved further. If their initial perceived understanding was high, then communication still helped but to a lower degree than for the participant's with a low perceived understanding initially.

Subjective Value represents the psychosocial type of outcomes experienced in negotiations. It is also based on perceptions and has the potential to influence the quality of future design sessions with the same partners, and even the conclusions a participant reaches about the results after a single design session. Collaborators on the whole experienced a large increase in Subjective Value from negotiating agreement over designs. The large increase was observed across both treatment groups in the exercise, as well as across the design roles. Women in particular ascribed higher increases in Subjective Value to its relationship aspects, compared to men. Participants who believed that their understanding of the design issues improved significantly through collaboration also exhibited high increases in Subjective Value. In a similar manner, if collaborators agreed on design choices, they tended to report higher Subjective Value increases on average.

An exception is that many collaborators who demonstrated high agreement often reported low increases in Subjective Value. Even though a collaboration process results in agreement over designs, the manner in which this agreement is obtained can detract from collaborators psychosocial experience. If agreement is forced through some external mechanism, the negotiating collaborators may be more likely find the experience negative, for example. In this exercise however, there were no forcing mechanisms. This supports the rationale for considering not only the techno-economic or Objective Value outcomes of negotiated collaboration, but also the Subjective Value outcomes.

## **CONCLUSION**

Constructs such as Subjective Understanding and Subjective Value, based on the underlying notions of understanding and psychosocial effects are often left untreated in many design and negotiation studies because they are transient and difficult to measure. A relatively recent formalization of the Subjective Value (Curhan, Elfenbein, and Xu, 2006) outcomes of negotiations provides a more robust theoretical framework for assessing these effects in negotiated collaboration. Linking these subjective notions with analysis of technical design outcomes provides a more holistic view of the nature of negotiated design. Studying the social psychology of project actors also rounds out the understanding of dynamics over and above the insights provided by the fields of relational contracting and project organizations.

The insights about understanding and the social psychological outcomes of collaboration tell us more about the "lived" subjective experience of individual project actors than just the design and value outcomes from observing the design of a project at a distance. Retaining a

focus on the subjective aspects of negotiated collaboration can create a better foundation for future interactions between collaborators, and help them better balance trade-offs to meet each others design objectives. This has important implications for P3 projects because such projects are long-lived, making it unlikely that the same partners will be able to complete multiple partnerships. As a result, trust and credibility through rapport early on in the relationship are important for shaping the project.

## REFERENCES

- Austin-Breneman, J., Yu, B., and Yang, M. (2014). “Biased Information Passing Between Subsystems Over Time in Complex System Design”. *ASME 2014 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. American Society of Mechanical Engineers, V007T07A023–V007T07A023.
- Badke-Schaub, P., Neumann, A., Lauche, K., and Mohammed, S. (2007). “Mental models in design teams: a valid approach to performance in design collaboration?” *CoDesign*, 3(1), pp. 5–20.
- Bazerman, M., and Carroll, J., (1987). “Negotiator cognition”. *Research in Organizational Behavior*.
- Bazerman, M., and Chugh, D. (2005). “Bounded awareness: Focusing failures in negotiation”. *Frontiers of social psychology: Negotiation*, pp. 7–26.
- Bazerman, M. and Moore, D. (2012). *Judgment in Managerial Decision Making*. 8th edition. Wiley & Sons.
- Bazerman, M., Magliozzi, T., Neale, M. (1985). “Integrative bargaining in a competitive market”. *Organizational behavior and human Decision Processes*, 35(3), pp. 294–313.
- Bazerman, M., and Neale, M. (1992). *Negotiating rationally*. New York: Free Press.
- Bazerman, M., Curhan, J., Moore, D., and Valley, K. (2000). “Negotiation”. *Annual Review of Psychology*, 51(1), pp. 279–314.
- Bazerman, M., and Lewicki, R. (1983). *Negotiating in organizations*. Sage Beverley Hills, CA.
- Bendersky, C., and McGinn, K. (2010). “Perspective—Open to Negotiation: Phenomenological Assumptions and Knowledge Dissemination”. *Organization Science*, 21(3), pp. 781–797.
- Blount, S. and Larrick, R. (2000). “Framing the Game: Examining Frame Choice in Bargaining”. *Organizational Behavior and Human Decision Processes* 81(1), pp. 43–71.
- Chugh, D., and Bazerman, M. (2007). “Bounded awareness: What you fail to see can hurt you”. *Mind & Society*, 6(1), pp. 1–18.
- Clevenger, C., Haymaker, J., and Ehrich, A. (2013). “Design exploration assessment methodology: testing the guidance of design processes”. *Journal of Engineering Design*, 24(3), pp. 165–184. “Empirical Studies of Designer Thinking: Past, Present, and Future”. *Journal of Mechanical Design*, 137(2).
- Curhan, J., and Brown, A. (2011). “Parallel and divergent predictors of objective and subjective value in negotiation.” ed. by Cameron, K. and Spreitzer, G., *The Oxford handbook of positive organizational scholarship*. Oxford University Press.
- Curhan, J., Elfenbein, H., and Kilduff, G., (2009). “Getting off on the right foot: subjective value versus economic value in predicting longitudinal job outcomes from job offer negotiations.” *Journal of Applied Psychology*, 94(2), p. 524.
- Curhan, J., Elfenbein, H., and Eisenkraft, N. (2010). “The Objective Value of Subjective Value: A Multi-Round Negotiation Study”. *Journal of Applied Social Psychology*, 40(3), pp. 690–709.

- Curhan, J., Elfenbein, H., and Xu, H. (2006). “What do people value when they negotiate? Mapping the domain of subjective value in negotiation.” *Journal of personality and social psychology*, 91(3), p. 493.
- Dinar, M., Shah, J., Cagan, J., Leifer, L., Linsey, J., Smith, S. and Hernandez, N. (2015).
- Dong, Andy (2005). “The latent semantic approach to studying design team communication”. *Design Studies*, 26(5), pp. 445–461.
- Drolet, A., and Morris, M. (2000). “Rapport in conflict resolution: Accounting for how face-to-face contact fosters mutual cooperation in mixed-motive conflicts”. *Journal of Experimental Social Psychology*, 36(1), pp. 26–50.
- Elfenbein, H., Curhan, J., Eisenkraft, N., Shirako, A., and Baccaro, L.(2008). “Are some negotiators better than others? Individual differences in bargaining outcomes”. *Journal of Research in Personality*, 42(6), pp. 1463–1475.
- Ferguson, M., Moye, N., and Friedman, R. (2008). “The Lingering Effects of the Recruitment Experience on the Long-Term Employment Relationship”. *Negotiation and Conflict Management Research*, 1(3), pp. 246–262.
- Fiore, S., Smith-Jentsch, K., Salas, E., Warner, N., and Letsky, M. (2010). “Towards an understanding of macrocognition in teams: developing and defining complex collaborative processes and products”. *Theoretical Issues in Ergonomics Science*, 11(4), pp. 250–271.
- Flager, F., Gerber, D. and Kallman, B. (2014). “Measuring the impact of scale and coupling on solution quality for building design problems”. *Design Studies*, 35(2), pp. 180–199.
- Fukuno, M., and Ohbuchi, K. (1997). “Cognitive biases in negotiation: the determinants of fixed-pie assumption and fairness bias”, 13(1), pp. 43–52.
- Gelfand, M., Major, V., Raver, J., Nishii, L. and O’Brien, K. (2006). “Negotiating Relationally: The Dynamics of the Relational Self in Negotiations”. *Academy of Management Review*, 31(2), pp. 427–451.
- Gilbert, D. (1994). “Attribution and Interpersonal Perception”. ed. by Tesser, A., *Advanced Social Psychology*, McGraw-Hill., pp. 99–147.
- Gimpel, H. (2008). “Negotiation, Auctions, and Market Engineering.” Ed. by Gimpel, H. Jennings, N., Kersten, G. *Cognitive Biases in Negotiation Processes*
- Hernandez, N., Shah, J., and Smith, S. (2007). “Cognitive Models of Design Ideation”. *ASME 2007 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. American Society of Mechanical Engineers, pp. 135–144.
- Hirschi, N., and Frey, D. (2002). “Cognition and complexity: An experiment on the effect of coupling in parameter design”. *Research in Engineering Design*, 13(3), pp. 123–131.
- Honda, T., Ciucci, F., Lewis, K., and Yang, M. (2015). “Comparison of Information Passing Strategies in System-Level Modeling”. *AIAA Journal*, 53(5), pp. 1121–1133.
- Iorio, J., and Taylor, J. (2014). “Boundary object efficacy: The mediating role of boundary objects on task conflict in global virtual project networks”. *International Journal of Project Management*, 32(1), pp. 7–17.
- Keltner, D. and Robinson, R. (1997). “Defending the status quo: Power and bias in social conflict”. *Personality and Social Psychology Bulletin*, 23(10), pp. 1066–1077.
- Klein, M., Sayama, H., Faratin, P., and Bar-Yam, Y. (2003). “The dynamics of collaborative design: insights from complex systems and negotiation research”. *Concurrent Engineering*, 11(3), pp. 201–209.

- Lawson, B. (2004). “Schemata, gambits and precedent: some factors in design expertise”. *Design Studies*, 25(5), pp 443–457.
- Lawson, B. (2006). *How designers think: the design process demystified*. 4<sup>th</sup> ed. Oxford, UK: Architectural Press.
- Linsey, J., Tseng, I., Fu, K., Cagan, J., Wood, K. and Schunn, C. (2010). “A study of design fixation, its mitigation and perception in engineering design faculty”. *Journal of Mechanical Design*, 132(4).
- Messick, D. (1999). “Alternative logics for decision making in social settings”. *Journal of Economic Behavior and Organization*, 39(1), pp. 11–28.
- Montgomery, J. (1998). “Toward a Role-Theoretic Conception of Embeddedness”. *American Journal of Sociology*, 104(1), pp. 92–125.
- Miller, G. (1956). “The magical number seven, plus or minus two: some limits on our capacity for processing information”. *Psychological Review*, 63(2), pp 81.
- Neale, M., and Bazerman, M. (1985). “The effects of framing and negotiator overconfidence on bargaining behaviors and outcomes”. *Academy of Management Journal*, 28(1), pp. 34–49.
- Neale, M., and Bazerman, M. (1992). “Negotiating rationally: the power and impact of the negotiator’s frame”. *The Executive*, 6(3), pp. 42–51.
- Newell, A, and Simon, H. (1972). *Human problem solving*. Prentice-Hall.
- Osipova, E. (2014). “Establishing Cooperative Relationships and Joint Risk Management in Construction Projects: Agency Theory Perspective”. *Journal of Management in Engineering*.
- Ostergaard, K., Wetmore III, W., Divekar, A., Vitali, H., and Summers, J.(2005). “An experimental methodology for investigating communication in collaborative design review meetings”. *CoDesign*, 1(3), pp. 169–185.
- Pinkley, R., Griffith, T., and Northcraft, G. (1995). “‘Fixed Pie’ a la Mode: Information Availability, Information Processing, and the Negotiation of Suboptimal Agreements”. *Organizational Behavior and Human Decision Processes*, 62(1), pp. 101–112.
- Raiffa, H. (1982). *The art and science of negotiation*. Cambridge, Mass.: Belknap Press of Harvard University Press.
- Raiffa, H., Richardson, J., and Metcalfe, D. (2002). *Negotiation analysis: the science and art of collaborative decision making*. Cambridge, USA: Belknap Press of Harvard University Press.
- Rahman, M. and Kumaraswamy, M. (2004). “Potential for Implementing Relational Contracting and Joint Risk Management”. *Journal of Management in Engineering*, 20(4), pp. 178–189.
- Reiter-Palmon, R, Wigert, B., and de Vreede, T. (2012). “Team creativity and innovation: The effect of group composition, social processes, and cognition.” in *Handbook of organizational creativity*. ed. by M. D. Mumford, New York: Academic Press, pp. 295–326.
- Rubin, J., and Brown, B. (1975). *The social psychology of bargaining and negotiation*. New York: Academic Press.
- Sharma, S., Bottom, W., and Elfenbein, H. (2013). “On the role of personality, cognitive ability, and emotional intelligence in predicting negotiation outcomes: A meta-analysis”. *Organizational Psychology Review*, 3(4), pp. 293–336.
- Simon, H. (1987). “Making Management Decisions: The Role of Intuition and Emotion”. *The Academy of Management Executive* (1987-1989) 1(1).
- Smyth, H. and S. Pryke (2009). *Collaborative Relationships in Construction: Developing Frameworks and Networks*

- Smyth, H. and Edkins, A. (2007). “Relationship management in the management of PFI/PPP projects in the UK”. *International Journal of Project Management*, 25(3), pp. 232–240.
- Suprpto, M., Bakker, H., Mooi, H., and Moree, W. (2014). “Sorting out the essence of owner–contractor collaboration in capital project delivery”. *International Journal of Project Management*.
- Thompson, L. (1990). “Negotiation behavior and outcomes: Empirical evidence and theoretical issues.” *Psychological Bulletin*, 108(3), p. 515.
- Thompson, L. and Hastie, R. (1990). “Social perception in negotiation”. *Organizational Behavior and Human Decision Processes*, 47(1), pp. 98–123.
- Thompson, L. (1998). *The mind and heart of the negotiator*. Upper Saddle River, NJ: Prentice Hall.
- Tinsley, C., O’Connor, K., and Sullivan, B. (2002). “Tough guys finish last: The perils of a distributive reputation”. *Organizational Behavior and Human Decision Processes*, 88(2), pp. 621–642.
- Tsay, C., and Bazerman, M. (2009). “A Decision-Making Perspective to Negotiation: A Review of the Past and a Look to the Future”. *Negotiation Journal*, 25(4), pp. 467–480.
- Valley, K., Moag, J. and Bazerman, M. (1998). “‘A matter of trust’: Effects of communication on the efficiency and distribution of outcomes”. *Journal of Economic Behavior & Organization*, 34(2), pp. 211–238.
- Walsh, J., Weber, K., and Margolis, J. (2003). “Social issues and management: Our lost cause found”. *Journal of Management*, 29(6), pp. 859–881.
- Wood, M., Chen, P., Fu, K., Cagan, J. and Kotovsky, K. (2014). “The Role of Design Team Interaction Structure on Individual and Shared Mental Models”. In: ed. by Gero, J., *Design Computing and Cognition*, Dordrecht: Springer, pp. 209–226.