Four Cases from Social Sciences and Their Implications to Engineering Design

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Abstract

Four cases from social sciences are collected in this paper to illustrate how social sciences are relevant to engineering design. The first case, which originates from psychology, discusses how the representation of a problem would affect the human's problem-solving skill. This case highlights the need of proper design representation for both innovation and communication. The second case shows how peer pressure would affect a personal judgment on a problem. The result of this case emphasizes the importance of the group environment and human interactions to the performance of a design team. The third and fourth cases are two famous examples respectively taken from two mathematically rigorous theories in economics, namely, game theory and social choice theory. The third case discusses the prisoner's dilemma in game theory, and it illustrates that rational individual decisions do not necessarily lead to a collective rational decision. This case result suggests the development of a mathematical framework for group decision making in team-based engineering design. The fourth case is concerned with the aggregation of individual preferences towards the agreement on a design decision. While the goodness of design can be evaluated from various aspects and subject to different people's judgment, how to aggregate these opinions to form a logical design choice is not entirely obvious. The fourth case suggests the development of a logical foundation for choosing a good design based on individual preferences or selections. The selection of these four cases is intended to illuminate some unobvious research results from social sciences and their relevance to engineering design. In turn, it is encouraged to explore the multidisciplinary nature of engineering design research and education by investigating the efforts from social sciences.

1 Introduction

The purpose of this paper is to explore some interesting results from social sciences and discuss their relevance to engineering design. Particularly, this paper focuses on some specific issues in team-based engineering design. Facing the complexity of modern engineered products, multiple teams with different domain experts are often involved to handle various aspects of the design. Typically, the original design problem is somehow represented so that teams can effectively communicate with each other based on the representation model. Then, different design solutions would be proposed, discussed, and judged by applying their domain knowledge. Also, collaboration among teams is required. Since intensive communication between teams is expensive, teams are usually autonomous in solving their own design issues and share their design results with other teams on a periodical basis. At the end, teams would express their preferences towards the common design, and the preferences of different teams should be properly aggregated to reflect the rational choice of a design solution among different teams.

In this context of team-based engineering design, consider the following intuitions about design:

- ❖ Intuition #1: innovation of engineering design mainly depends on human creativity and contextual information. Besides their correctness and precision, design models (i.e., how the design problem is represented) generally are not significant in the innovation process.
- ❖ Intuition #2: better design judgments can always be expected from a team rather than from an individual since more people can identify and avoid extreme options.
- ❖ Intuition #3: as long as different teams behave rationally for the benefits of common good of the design, their design effort and decisions will always lead to a generally good design.

- ❖ Intuition #4: individual preferences towards different design solutions can be simply and easily aggregated (or *averaged*) to select the most preferential design by all teams.

Yet, this paper has selected four cases from psychology and economics to explain that these intuitions are not necessarily correct. The selection of these cases is intended to illuminate some unobvious research results from social sciences and their relevance to engineering design. In fact, as both social sciences and engineering design rely on contextual information (with less emphasis on universal rules as compared to natural sciences), it is encouraged to explore the multidisciplinary nature of engineering design by investigating the efforts from social sciences. Sections 2 to 5 will introduce and discuss each of the selected cases, as well as their relevance to the above intuitions respectively. Section 6 will provide the closing remarks.

2 Case One: A Card Game

2.1 Description of Case One

This case is based on a card game that has been reported in [1] and [2]. The card game involves 9 cards, each of which is marked with an integer from 1 to 9, respectively. Two people alternatively pick up a card until all cards are picked. All the cards are facing up, and they know what cards have been picked. To win the game, the player needs to strategically collect any three cards which sum is equal to 15. The question is: what is the best strategy to win the game?

At the first glance, it may not be obvious for most people to find the best strategy to play this game. However, if we arrange these number cards according to a magic square (as shown in Figure 1), the best strategy becomes more apparent. First of all, any straight line that joins three numbers in the magic square will lead to the sum of 15. Then, the original card game has been transformed to a tic-tac-toe game. Simon [1] used this case to illustrate the importance of representation in design. In contrast, Norman [2] explained why people perceive the game differently in two representations.

In principle, the complexity of the game has not been changed. The basic strategy of the game is to obtain a set of numbers so that we can pick any two remaining numbers to add up to 15. For instance, after holding numbers 1, 6 and 7 at hands, we can either pick 8 ($8+1+6 = 15$) or 2 ($2+6+7 = 15$) to win the game. Suppose that both numbers 8 and 2 remains unpacked. Since the opponent cannot pick these two numbers at the same time, the player can pick either number 8 or number 2 in the next round to win the

game. Thus, the basic strategy of the game is to avoid such situation that the opponent can pick any two remaining numbers to win the game.

The above strategy for the card game has not changed due to different representations. However, from human perception, since the card game can be re-represented into a different structure (i.e., the magic square), we can make use of the symmetric and pictorial patterns to learn and memorize the good strategy for playing this game [2]. Besides, since the tic-tac-toe game is very common, it is likely that we have already learned the good strategy to win this game in the past. This experience can help us to play the *re-represented* card game. In this view, making use of patterns and our experience in similar situations can help us to solve problems.

4	9	2
3	5	7
8	1	6

Figure 1. Nine cards arranged in a magic square

2.2 Implications of Case One

In literature, the topic of design representation has been discussed, from the representation of the design process to the representation of the design artifact [3], as well as architectural design [4]. One perspective to look at this topic is the formalization or codification of design information so that computers can be used effectively in the design process. This perspective can lead to research and education in computer-aided design (e.g., spatial representation) and computer-aided manufacturing (e.g., process modeling and control).

Besides the aspect of computer applications, the illustrated card game essentially corresponds to the above Intuition #1 by highlighting the importance of representation for human perception in design. Particularly, as innovative design ideas are often generated in a human brain, how to represent a design problem for better human perception and problem solving is important in design research and education. Since creativity and innovation can be affected by different ways to look at the same problem, poor design representation can implicitly make the design problems more challenging than they should be.

Also, communicating rough and conceptual ideas appears to be challenging and time consuming tasks in team design, particularly during brainstorming sections. It is thus encouraged to educate some (soft) skills (i.e., hand-sketching) to enhance effective communication of immature ideas at the early design stage [5].

Apparently, design representation has already been one important topic in both engineering design research and education. Representation of design process leads to a systematic procedure for engineering design, which becomes more tractable and teachable. Representation of design artifact supports the application of computers in product design and development. Yet, this case is intended to point out that design representation will also affect human's ability to resolve design problems as well as the effectiveness of communicating immature design ideas. At this point, studies from psychology on human perception and understanding will enrich the representation aspect in engineering design.

3 Case Two: The Asch Experiment

3.1 Description of Case Two

This experiment was documented in [6] and [7] to illustrate the negative effect of group conformity. In the experiment, three lines, labelled A, B and C, are presented to the subjects as shown in Figure 2. Then, the subjects are asked to identify the line that matches the same length of the test line. When the subjects answered the question on their own in an isolated environment, 99% of them would get the answer right (i.e., 1% error rate). However, suppose that the subjects line up to answer the question and they are able to hear the answers before them. When one subject gives the wrong answer, the subject who comes right after will have 3% error rate in the answer. If there are two and three people giving the wrong answer in the same setting, the error rates can go up to 13% and 33%, respectively. However, when there are six people giving the wrong answer and one giving the right answer, the error rate will drop to 6%. This experiment is a classical case in studying group problem solving (especially in psychology). Researchers are interested in how a person's judgment and opinion can be influenced in a group environment. Accordingly, some advice and practice are suggested to promote effectiveness in group problem solving [7].

Figure 2. Test line and line candidates in the Asch experiment

3.2 Implications of Case Two

This case corresponds to the Intuition #2, which implies that the team environment can routinely avoid extreme and poor options. In industrial practice, team design is almost unavoidable, and various types of experts are required to tackle and manage the complexity of the design process. Due to this reason, engineering design education also emphasizes the design process in a team environment (such as team design projects). The conventional wisdom often tells that “two” is better than “one”, and we can always combine different opinions to come up with a solution better than that of a sole designer. However, the result of the Asch experiment implies that a group environment may alter an individual's better judgment. Note that the judgment required in the experiment is very straightforward. Facing a more complicated situation, the similar “groupthink” effect can even more dramatically take place to influence the performance of the design team.

In design education, I think it is appropriate to introduce some groupthink effects that can occur in a team design environment. Then, we can let students discuss how to avoid such effects. Some engineering design textbooks have suggested some good practice in team design (e.g., [8]). However, most students in a team often think that a good team member is equivalent to a “nice guy” (e.g., accommodating different opinions, complete the assigned tasks on time, etc...). In contrast, leadership roles and nurturing the environment for different opinions (remember, one right answer among six wrong answers can still dramatically improve the error rate in the experiment) are important to the effectiveness of team design. At the end, the key point is not to compromise different opinion to come up with an “average” solution. Rather, team members should rationally analyze different design solutions with

critical thinking. The good design does not necessarily go with the majority.

Some management and design textbooks have provided solid guidance for an appropriate group decision process. Oftentimes, students will see such guidance as obvious and trivial without deeply appreciating the human nature behind when designing such guidance. In this context, introducing some classical cases and even historical cases (failure of group processes) will help students aware of the nontrivial part of the group process.

4 Case Three: The Prisoner's Dilemma

4.1 Description of Case Three

The prisoner's dilemma was originated by two RAND (a global policy think tank in US) scientists, Merrill Flood and Melvin Dresher, to characterize a nonzero-sum game in 1950. Albert W. Tucker then coined this game the prisoner's dilemma [9]. This game starts in a situation that two suspects are arrested by the police. While these two suspects (say, A and B) are separated in two different rooms and cannot communicate with one another, they are asked whether to admit the crime or not. Since the police do not have sufficient evidence for a conviction, the suspects are essentially subject to two choices: betray or stay silent. Figure 3 has summarized four different consequences based on their choices. If they both remain silent, each of them will receive a light one-year sentence. If they both betray each other, each of them will receive a two-year sentence. If one suspect betrays and another suspect remains silent, the one who betray will be freely released, and the other one will receive a heavy three-year sentence. In this game situation, what and how would the suspect choose?

The analysis and application of the prisoner's dilemma have been found in a wide range of domains, such as economics (e.g., analyzing the competitive market), psychology (e.g., understanding the cooperative behaviour), and political science (e.g., analyzing military strategies) [9]. The analysis of the prisoner's dilemma can be greatly varied according to the research contexts. This paper focuses on the analysis of decentralized decisions in team design.

Based on Figure 3, let us assume the rationality of suspect A that suspect A will make a choice that will minimize his/her own period of sentence and do not really care how long suspect B will stay in jail. Notably, it is NOT a zero-sum game that suspect A does not need to do "bad things" to suspect B for its own benefit. The major challenge for suspect A now is that suspect A do not know which choice suspect B

will pick. Then, by logical and rational thinking, suspect A can analyze two situations:

- ❖ Case 1: suppose that suspect B stays silent. Then, suspect A will definitely choose to betray as this choice will let suspect A free to go. (Remember, the consequence of suspect B is not in the consideration of suspect A's analysis.)
- ❖ Case 2: suppose that suspect B betrays. Then suspect A will also choose to betray in order to avoid the heavy three-year sentence.

Based on the above two situations, the rational choice of suspect A is to betray because this choice will give suspect A a better consequence no matter which choice suspect B will pick. The same analysis can also apply to suspect B, who should also choose to betray. Consequently, both suspects will receive two-year sentences. However, this result is definitely worse than the result if they both stay silent. The major puzzle in this case is that individual rational decisions do not necessarily lead to a collective (overall) rational solution (i.e., Pareto optimal solution).

	Suspect B stays silent.	Suspect B betrays.
Suspect A stays silent.	Each serves one year.	Suspect A serves three years. Suspect B is freely released.
Suspect A betrays.	Suspect A is freely released. Suspect B serves three years.	Each serves two years.

Figure 3. Matrix of the prisoner's dilemma

4.2 Implications of Case Three

This case corresponds to the Intuition #3. In the collaborative design environment, different teams often consider different aspects of a product. For instance, to design a car, the manufacturing team focuses on the manufacturing cost, while the engine team focuses on the fuel efficiency. This characterizes a multi-criteria design environment. In principle, it is satisfactory to have design solutions that produce either "cheap and low fuel-efficient" cars or "expensive and high fuel-efficient" cars. Those designs essentially form the set of Pareto optimal solutions, in which more information is required to finally decide on a car design (e.g., assigning a weight for each criterion). However, it is irrational to choose the non-Pareto optimal solution that produces more expensive and lower fuel-efficient cars as compared to another design solution.

By analogy, two criteria are also involved in the prisoner's dilemma: the prison periods for suspects A and B. As both suspects (decision makers) behave rationally based on their available information, their decisions can eventually lead to an irrational solution from the standpoints of all stakeholders. It could be argued that the prisoner's dilemma assumes the "selfishness" of the players in the game, and it is not the case in the collaborative design environment. However, it can be shown that even when teams are motivated to accomplish a common goal, an isolated design environment can lead to a poor design solution [10].

The prisoner's dilemma has a strong implication to the research of collaborative engineering design. The key message is that individual goodwill and rational mind do not guarantee rational design as a whole. Communications can help the situation. However, in collaborative design, seamless communications between teams are often expensive (if not impossible). For design research, topics such as the formulation of team-based decision models and the decentralized decision-making process are intended to investigate this issue. For design education, since the prisoner's dilemma is simple and illuminating, it can stimulate students to think about the importance of cooperation and rational decision-making in team-based design.

5 Case Four: Paradox of Voting

5.1 Description of Case Four

This example is obtained from [11]. Suppose that there are 60 individuals voting for three different alternatives (say, alternatives a , b , and c). These individuals have clearly articulated their preferences by ordering these alternatives. The preference results are listed below, in which the symbol $\succ$ means "is preferred to".

- ❖ 23 individuals have the preference order of $a \succ c \succ b$.
- ❖ 19 individuals have the preference order of $b \succ c \succ a$.
- ❖ 16 individuals have the preference order of $c \succ b \succ a$.
- ❖ 2 individuals have the preference order of $c \succ a \succ b$.

Then, which alternative should be chosen based on the preference information above? It sounds like an obvious question. However, different voting rules will lead to different results. Let us examine three voting rules as follows.

- ❖ Plurality rule: voters only choose one alternative out of three. Based on this rule, alternative a

receives 23 votes, b 19 votes, and c 18 votes. Then, alternative a will be chosen.

- ❖ Majority rule: voters first choose one alternative. If the winner does not receive the majority votes (i.e., over 50% of the total votes), the one who receives the least number of votes will be eliminated, and a second round of voting will take place. This process continues until a winner gets the majority votes. Based on this rule, alternative a does not receive the majority votes. Since alternative c has the least number of votes, it will be eliminated. In the second round of voting, alternative b receives more votes (35 votes) than a does (25 votes) according to the existing preference information. Thus, alternative b will be chosen based on the majority rule.
- ❖ Borda rule: the alternative that receives the first-place vote will get two points, the second-place will receive one point, and the third-place will receive no point. Then, the alternative that receives most points will be the winner. Based on this rule, alternative a will receive $(23 \times 2) + (2 \times 1) = 48$ points, alternative b will receive $(19 \times 2) + (16 \times 1) = 54$ points, and alternative c will receive $(23 \times 1) + (19 \times 1) + (16 \times 2) + (2 \times 2) = 78$ points. Thus, alternative c will be chosen.

Though these voting rules are intuitively reasonable to apply, the result of voting could depend on the choice of the voting rules. This "paradox of voting" is actually related to an important research issue about how to aggregate individual preferences to reflect a rational choice for a society as a whole. According to the Arrow's Impossible Theorem [12], there does not exist a method that aggregates individual preferences without violating some of reasonable conditions. This result has essentially motivated abundant research in social choice theory with relevant applications in welfare economics [13].

5.2 Implications of Case Four

This case corresponds to the Intuition #4. The relevance of social choice theory to engineering design has been discussed in [14] [15] [16]. As commented in these papers, some design tools have implicitly involved aggregation of individual values towards a selection problem, and these tools are not flawless from the standpoint of social choice theory. As engineering design unavoidably involves preferences (or options) among different development teams as well as customers, how to properly handle this preference information is a fundamental and important question. As compared with the efforts in economics and political science, it is expected that similar efforts should be pursued in engineering design.

Besides the research aspect, the example of “paradox of voting” can be used to illustrate the counterintuitive result of the aggregation of individual preferences. It helps students to realize the notion of “unique fair voting system” does not really exist. Depending on the design context, some conditions need to be defined to articulate the notions of fairness and appropriateness in the team design situation.

6 Closing Remarks

Engineering design has once been considered “not-so-teachable” as compared to other engineering subjects based on natural sciences since it lacks for generally accepted fundamental theories. Some researchers argue that engineering design is undergoing the “pre-paradigmatic” stage of the development, which many subjects of natural sciences have gone through [17]. When critical mass of knowledge in engineering design has been acquired, fundamental theories will emerge. In fact, such theoretical efforts have contributed significantly to our understanding of engineering design [1] [5] [18]. In this context, this paper is intended to provide another perspective about the possible links of social sciences to engineering design by introducing four interesting cases from psychology and economics. One common ground of social sciences and engineering design lie in the handling of contextual information, which natural sciences do not concern that much. Accordingly, it is argued that the multidisciplinary nature of engineering design should include the efforts from social sciences in both research and education.

In fact, the subjects of social sciences have gone through (or are still undergoing) a big argument about developing fundamental theories like what being done for natural sciences [19]. However, as Flyvbjerg [20] has pointed out, the subject matters in social sciences are often context-dependent, and contextual information is hard (if not impossible) to be exactly formulated in a model for prediction purpose. In comparison, the theoretical development of engineering design also shares similar kind of difficulty. Engineering design requires contextual information. From this perspective, it is not surprising or arbitrary to link the research and education efforts of engineering design to social sciences.

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