1. Introduction

Design decision making is very much a cognitive process. It relies on the ability of a person to reason articulately or autonomously. If the reasoning process fails or the basic information used for reasoning is untrue, then the resulting design decision is likely to be wrong. In software engineering, there is almost no empirical investigation on the design reasoning failures. By design reasoning failures, we mean that either (a) the basic premise of an argument is missing or wrong; (b) the logical reasoning process is unsound or unbelievable; (c) reasoning is incomprehensive.

There are many potential causes of design reasoning failures:

- **Cognitive and Other Biases** – a distortion of judgment in particular situations due to psychological effects and insufficient regards of probability [2]. For example, software designers select inappropriate design solutions because they are more familiar with these design solutions, despite that the solution is ill-suited to solve the problem. A phenomenon we call “I have a hammer, and everything is a nail”.

- **Incomprehensive Reasoning** – a designer does not reason sufficiently before making design judgments.

- **Illogical Reasoning** – a logical reasoning requires that the basic premises of a decision, in our case design concerns and requirements, should be factual and true; and the arguments and inferences to reach a design conclusion should be sound [1]. Quite often software designers make design decisions without regards for whether the premises are true or the conclusions are reasonable. Sometimes the design problems are ill-defined. When asked to justify his decisions, it is not uncommon to see designers make retrospective justifications.

- **Low Quality Premises** – in large software projects in which multiple designers make decisions, failures to represent the premises truly, i.e. inaccurate or inadequate premises, can cause incorrect decisions. For instance, if an assumption is unclear, that could cause a designer to make a decision based on faulty inputs.

In order to make sound design decisions, designers must ensure that the premises are as complete and accurate as possible, and make decisions that are unbiased and logical. In this experiment, we test participants to investigate the causes of design reasoning failures.
2. Theoretical Framework

This experiment is aimed at discovering the ability of participants to reason with software engineering cases. In the reasoning exercises, there are ambiguities and missing premises deliberately built in to the cases. To reach the right conclusion, a designer must work out that there are missing premises, make sound logical inferencing and avoid cognitive biases, or design reasoning failures can occur otherwise. Biases could be introduced by personal beliefs of certain conclusions that is not a result of logical reasoning.

Meyer [3] has studied requirement specification errors and created 7 classes of errors, some of the relevant ones that involve reasoning are:

- noise – irrelevant information in the premise or the argument
- silence – features that have been implemented without specification
- over specification – solution elements already included in the requirements specification
- contradictions – requirements that contradict with each other
- ambiguity – the specification is unclear
- wishful thinking – some goals are not attainable at least in the current circumstances

These are common issues in documented specifications. It may be because it is difficult to articulate requirements precisely with a natural language. We conjecture that some of these issues are caused reasoning issues [4]. There are two basic rules of applying reasoning techniques. First, we observe that reasoning techniques must be used in combination and comprehensive. Secondly, reasoning techniques cannot replace knowledge. They must be used in conjunction with some suitable technical and application domain knowledge to construct premises.

3. Research Questions

There are two goals of this research. Firstly, we want to study how design reasoning works and understand the relationships between reasoning and judgments. Secondly, we want to compare the ability to do design reasoning between two groups of people: (a) novice; (b) experienced designers.
4. Research Design

This experiment is aimed to find out if the subjects can perform software design reasoning based on a common form of documentation, i.e. vignette. In order for a software designer to reason with a design successfully, a designer has to reason with the information and the conclusion. A designer also needs to apply argumentation logically to arrive at the right conclusion. The idea of the question “Do you agree” is to measure how much a designer agrees or disagrees with the conclusion. We can relate the level of agreement with the reasoning.

4.1. Experimental Tool

An online website will be set up for the experiment. Participants will be asked to enter their personal data such as name, years of experience etc. Then a set of 6 vignettes will be given. Each vignette describes a scenario in which participants will have to reason with. Each participant has to state whether s/he agree with the conclusion, in a Likert scale of 1 to 7. The participant has to state the reasons of why s/he disagrees or agrees. We count the number of reasons given by the participants to argue their cases.

A pilot test is conducted to see if there are any ambiguities or issues with the experiment. The subjects will be asked when they start to get tired and whether they comprehend the questions. We have prepared a set of 10 exercises. After the pilot test, we select 6 exercises to be included in the real experiment.
5. Exercises for the Participants

5.1. About the Participant

The following information is collected for each participant.

1. Name: ________________________________ (for student participants)

2. Age: ______

3. No of years working in the software industry (please put zero if you have not worked in the software industry before): ______________________

4. Highest Academic Qualification (e.g. Bachelor/Master/PhD): __________________

5. Gender: Male / Female:

6. Languages Spoken: (a) Native ____________________; (b) Other ______________________

7. Study Program or Specialization: ____________________________________________
5.2 Design Cases

Instructions to participants: There are 6 software design cases in this exercise. You are the designer of the systems described below. Your job is to check if the conclusion is reasonable. You can assume that the statements about the cases are all true statements. You are asked to assess each case and state whether you agree with the conclusion or not, and state the reasons why you disagree and agree with the conclusion. Please note how long (in minutes) you spend on each case.

Case 1

In a car wholesale system, some customer records are updated daily. All updated customer records require a reconciliation process at the end of each week. A reconciliation process is a process that checks that the sum of all invoices is equal to the total sales recorded in the customer record. At the end of each month, a report is created to show any reconciled transactions.

Conclusion: So at the end of each month, the sales manager would have up-to-date reconciliation figures of all her customers. Do you agree? Please indicate your level of agreement below.

Complete disagree 1 2 3 4 5 6 7 Complete agree

Please give reasons for any disagreements:

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If you agree, please summarize your reasoning:

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1 All 10 cases are listed here for pilot testing, only 6 cases were used in the experiment. See Section 5.3 for these cases.
A new type of electricity meter called interval meter is introduced. The interval meter measures electricity usage once every 30 minutes. It replaces the old meter which is read once every 3 months. The power consumption data measured by the interval meter is sent to the power distribution company via a modem at 17:00h each day. The collected data is to be processed and settlement information is prepared for the power generating company at 18:00h. Settlement is a computation to determine which company has to pay and which company is owed money.

Conclusion: The only programs we need to design for the server are the data collection programs running at 17:00h and the settlement process data running at 18:00h. Do you agree? Please indicate your level of agreement below.

Completely disagree  1  2  3  4  5  6  7  Completely agree

Please give reasons for any disagreements:
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If you agree, please summarize your reasoning:
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A new Ambulance Scheduling System is designed to service medical emergency calls. The goal of this system is to accurately estimate ambulance arrival time to within 15% of the scheduled arrival time. Ambulances have in-vehicle GPS systems. Each ambulance transmits its location to the system once every 5 minutes. Using this data, the Ambulance Scheduling System can predict how long it will take an ambulance to reach its destination.

Conclusion: The Ambulance Scheduling System can compute when an ambulance can arrive at the desired location within 15% error margin. Do you agree? Please indicate your level of agreement below.

Completely disagree 1 2 3 4 5 6 7 Completely agree

Please give reasons for any disagreements:

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If you agree, please summarize your reasoning:

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A new system is designed to dynamically coordinate flight paths of commercial aircrafts. The goal of the system is to automate air-traffic control and reduce the number of air-traffic controller staff. A single communication device is installed on each plane to enable such coordination. It communicates with a ground-based system to carry out flight-path coordination. Based on the current position of each flight, the ground-based system computes flight-paths. It instructs the pilot of a chosen flight path. If the automated-coordination works, there is no need for air-traffic controller to intervene.

Conclusion: The system should produce a satisfactory result. Do you agree? Please indicate your level of agreement below.

Completely disagree   1  2  3  4  5  6  7   Completely agree

Please give reasons for any disagreements:

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If you agree, please summarize your reasoning:

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A new contactless smart-card system is designed to be used in the public transport in Pakistan. Each traveler would need to pay a deposit to obtain a personalized smart-card. Each card costs US$4.50. With the smart-card, a passenger can travel on all public transport systems such as bus, train and mini-bus throughout the country. The smart-card can be reloaded at ATM machines or over the counter at a bank. This system will replace all cash tickets in 18 months.

Conclusion: It is viable to implement this system in Pakistan. Do you agree? Please indicate your level of agreement below.

Completely disagree  1  2  3  4  5  6  7  Completely agree

Please give reasons for any disagreements:

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If you agree, please summarize your reasoning:

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A new system is to be created to simplify government election process. There are 10 million eligible voters in the country. Each voter would be issued a smart-card. A smart-card is authenticated by password and a finger-print. Voters can vote through the Internet. It is expected that many voters would vote online. The number of voting booths and the number of employees required for vote counting can be reduced significantly.

Conclusion: The savings of an election would be significant. Do you agree? Please indicate your level of agreement below.

Completely disagree  1  2  3  4  5  6  7  Completely agree

Please give reasons for any disagreements:

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If you agree, please summarize your reasoning:

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A traffic control system is to be designed to reduce vehicles entering the central business district (CBD) of Paris, La Défense. The goal is to reduce traffic jam in the CBD. Any vehicle entering the CBD will be charged a fee during work days. Cameras would be installed at all entries to the CBD. Based on the photos, number plate recognition software would identify vehicles and issue charges.

Conclusion: The system will be able to accurately issue charges for the vehicles entering the CBD. Do you agree? Please indicate your level of agreement below.

Completely disagree  1  2  3  4  5  6  7  Completely agree

Please give reasons for any disagreements:

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If you agree, please summarize your reasoning:

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Case 8

A government is to launch an electronic health monitoring service to all citizens over the age of 75 living alone and in need of support, such as serious heart and diabetes conditions. Each person who participates will receive a monitoring device. The intelligent device is an adaptation of an Apple iPhone. The intelligent device would communicate the location of the aged person to the medical center once an hour. If the location does not change for an extended period, the person will be contacted. If there is no response from the aged person, then aid will be dispatched to check on the aged person.

Conclusion: This service should save many old people’s lives. Do you agree? Please indicate your level of agreement below.

Completely disagree  1  2  3  4  5  6  7  Completely agree

Please give reasons for any disagreements:

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If you agree, please summarize your reasoning:

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An online complaint system is required to register citizen complaints of any government services. All government department complaints can be made via this system. Authenticity of a complaint is important. Citizens would be asked to provide names and resident number. Non-citizens would be asked to provide passport identification and address. The authenticity of a complaint is checked by the respective government department. An online form will be provided to fill in the complaints. On this form, users will need to identify the government department which the complaint is directed to and to write about their complaints. The user can, optionally, leave a contact address, email address and phone number for future correspondence. The system would send the complaint form to the appropriate department.

Conclusion: This online form should capture the preliminary information of a complaint. Do you agree? Please indicate your level of agreement below.

Completely disagree  1  2  3  4  5  6  7  Completely agree

Please give reasons for any disagreements:

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If you agree, please summarize your reasoning:

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Case 10

A company is migrating all the database records from an old system to a new system. No data transformation is required in the migration. The old system has been operating for over 10 years. The migration process involves an export of data from the old system into files stored on mirrored disks, followed by an import from the files into the new system. A trial migration was tested last week. The migration process would take approximately 1 hour, 20 minutes to export 100MB of data and 40 minutes to import that data. A special disk area has been allocated for this purpose. The system is non-critical and can be out of service during the weekend.

Conclusion: The migration process should be satisfactory. Do you agree? Please indicate your level of agreement below.

Completely disagree  1  2  3  4  5  6  7  Completely agree

Please give reasons for any disagreements:

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If you agree, please summarize your reasoning:

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5.3. Scenarios and Normative Reasons

Scenario 1. Scenario: In a car wholesale system, some customer records are updated daily. All updated customer records require a reconciliation process at the end of each week. A reconciliation process is a process that checks that the sum of all invoices is equal to the total sales recorded in the customer record. At the end of each month, a report is created to show any reconciled transactions. Conclusion: So at the end of each month, the sales manager would have up-to-date reconciliation figures of all her customers.

Identified Reasons. Issue 1: Which customer records are updated, i.e. some versus all. Some records are updated daily but some can be updated once every 10 days for example. Issue 2: The weekly updates may not align with the monthly reconciliation. If these two periods are not aligned, then some records cannot be seen in the reconciliation till next month. This requires deduction based on the given facts.

Scenario 5. Scenario: A new contactless smart-card system is designed to be used in the public transport in Pakistan. Each traveller would need to pay a deposit to obtain a personalized smart-card. Each card costs US$4.50. With the smart-card, a passenger can travel on all public transport systems such as bus, train and mini-bus throughout the country. The smart-card can be reloaded at ATM machines or over the counter at a bank. This system will replace all cash tickets in 18 months. Conclusion: It is viable to implement this system in Pakistan.

Identified Reasons. Issue 1: Can the citizen afford to pay US$4.50? Issue 2: Is it possible to build an infrastructure of card readers in the public transport system to capture usage? Issue 3: Do people really need such a ticketing system in villages, intercity travels and local transport etc? Issue 4: The cost of implementation and the return on investment is not justified. Issue 5: Can people adopt such a technology with the assumption that everyone has bank accounts? Issue 6: Currently there is not enough infrastructure to charge the card; do the people have access to bank accounts & ATMs etc? Issue 7: The system must cater for anonymised passengers such as tourists. Issue 8: The system must cater for cash transaction as well. Issue 9: The issue of not being able to align charging schemes of the different modes of transport across Pakistan. Is it possible to have one system cater for all that? Issue 10: The issue of not being able to use this system and the new devices in all transport systems. Transport companies may not be able to afford the cost and all the practical issues. Issue 11: The system security and privacy issues are risky to the public in Pakistan. Issue 12: The viability of implementation in 18 months for a country is too short. For-Analogy 1: Unified ticketing system for convenience. For-Analogy 2: Similar systems already operating successfully elsewhere. Against-Analogy 1: Similar systems in operation that have significant issues.
Scenario 6. Scenario: A new system is to be created to simplify the government election process. There are 10 million eligible voters in the country. Each voter would be issued a smart-card. A smart-card is authenticated by password and a fingerprint. Voters can vote through the Internet. It is expected that many voters would vote online. The number of voting booths and the number of employees required for vote counting can be reduced significantly. Conclusion: The savings of an election would be significant.

Identified Reasons. Issue 1: Who is to pay for this device? How much does this device cost? How many elections are required to get a return on investment of the device? Issue 2: What is the fingerprint registration process and system? Issue 3: Some people may opt not to use technologies, e.g. aged people. Issue 4: What is the density of population and the location of booths? Issue 5: What is the cost and ROI? Issue 6: Number of people having online access. Issue 7: The cost of educating voters. Issue 8: This system requires a fingerprint reader. Issue 9: The system requires a fingerprint DB to be set up for 10 million people. Issue 10: Government is able to obtain fingerprint and backup policies. Issue 11: Is there any privacy issue with the fingerprint registration? Issue 12: Do we know that people would be willing to vote online? How many amongst the 10 million people would be required to make a saving? Issue 13: The security risks, such as in collecting and maintaining personal data and fingerprints; and detection of fraud or hacking activities.

Scenario 7. Scenario: A traffic control system is to be designed to reduce vehicles entering the central business district (CBD) of Paris, La Défense. The goal is to reduce traffic jams in the CBD. Any vehicle entering the CBD will be charged a fee during workdays. Cameras would be installed at all entries to the CBD. Based on the photos, number plate recognition software would identify vehicles and issue charges. Conclusion: The system will be able to accurately issue charges for the vehicles entering the CBD.

Identified Reasons. Issue 1: Assume that the accuracy of camera and number plate recognition software is large enough? Issue 2: Assume that the system caters for the residence in the area and regular users? Issue 3: Accuracy of the recording of exiting vehicle for charging. Issue 4: The environmental conditions such as weather and light allow accurate imaging. Issue 5: The charge is per period of time a car is within the CBD. Issue 6: Access to number plate and owner information. Issue 7: The system can only recognize French vehicles but has no access to vehicles registered elsewhere. Issue 8: System cannot recognize fake or stolen number plates. Issue 9: How many non-French vehicles, as opposed to French vehicles, would travel to the CBD? Issue 10: Not capturing number plate info accurately due to different reasons. Issue 11: Privacy issue. For-Analogy 1: Workable because similar system is already operational somewhere else.
Scenario 9. Scenario: An online complaint system is required to register citizen complaints of any government services. All government department complaints can be made via this system. Authenticity of a complaint is important. Citizens would be asked to provide names and resident number. Non-citizens would be asked to provide passport identification and address. The authenticity of a complaint is checked by the respective government department. An online form will be provided to fill in the complaints. On this form, users will need to identify the government department which the complaint is directed to and to write about their complaints. The user can, optionally, leave a contact address, email address and phone number for future correspondence. The system would send the complaint form to the appropriate department. Conclusion: This online form should capture the preliminary information of a complaint.

Identified Reasons. Issue 1: Complainant has access to computer and internet. Issue 2: Offline (e.g. phone) system should be available as alternative to lodge complaint. Issue 3: System does not provide acknowledgement or feedback on receipt of complaint. Issue 4: Complainant cannot remain anonymous. Issue 5: System can only capture textual description of complaint. Additional documents, images, etc cannot be captured. Issue 6: Privacy issue. Issue 7: False information including fraudulent use of someone's identity, or authenticity of complaint. Issue 8: Insufficient details of complaint provided (e.g. responsible department unknown) or no contact details for follow up clarifications. For-Analogy 1: Workable because similar system is already operational somewhere else.

Scenario 10. Scenario: A company is migrating all the database records from an old system to a new system. No data transformation is required in the migration. The old system has been operating for over 10 years. The migration process involves an export of data from the old system into files stored on mirrored disks, followed by an import from the files into the new system. A trial migration was tested last week. The migration process would take approximately 1 hour, 20 minutes to export 100MB of data and 40 minutes to import that data. A special disk area has been allocated for this purpose. The system is non-critical and can be out of service during the weekend. Conclusion: The migration process should be satisfactory.

6. References