An Axiomatic Method for Cross Cultural Usability Analysis

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Abstract. Cross cultural influences on usability should be investigated together with human cognition and perception, and the context of use. In practice, to reveal culture similarities is more important than differences. An axiomatic method for cross cultural usability analysis was proposed for tackling these issues. It was argued that usability problems related to human cognition and perception can be identified through the Independence Axiom, whereas the best design can be recognized through the Information Axiom with the domain-specific knowledge.

Keywords: Axiomatic Design, Cross Cultural Usability, Culture Similarities.

1 Introduction

Globalization of markets and applications of information technology have made people around the world able to easily contact with each other and access to a vast of information. As a result, cultural diversity in terms of backgrounds of users and contents of information now becomes more important issue for usability than at any time in the past.

Usability is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use [1]." A product designed for high usability facilitates the completion of relevant tasks in an effective, efficient, error-free, and satisfactory manner. Usability is a key factor for differentiating the products from others. In current merging global markets, thoughtful consideration of regional user needs and desired functionality combined with culturally-sensitive design will greatly increase the chances that we meet our customers' expectations.

Due to its parsimoniousness, the dispositional approach has been widely applied to cross cultural research. Among many studies, the most extensive work has been done by Hofstede [2] on modeling cultural diversity through his five national culture dimensions. A brief description for each dimension is listed below:

High/Low Power Distance: A group in which the degree for the less powerful members to expect and accept that power is distributed unequally is high/low

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Individualism/Collectivism: A group in which the ties between individuals are loose/tight

Masculinity/Femininity: A group in which social gender roles are distinct/overlap

Strong/Weak Uncertainty Avoidance: A group in which the degree for members to feel threatened by uncertain or unknown situations is strong/weak

Long-/Short-term Orientation: A group in which virtues are oriented towards the future/the past and present

Other models with more or less similarity are Trompenaars and Hampden-Tuner's [3] 7D model (i.e., *Universalism/Particularism*, *Individualism/Communitarianism*, *Neutral/Emotional*, *Specific/Diffuse*, *Achievement/Ascription*, *Attitudes to Time*, and *Attitudes to the Environment*) and Victor's [4] LESCANT model (i.e., *Language*, *Environment and Technology*, *Social Organization*, *Contexting*, *Authority Conception*, *Nonverbal Behavior*, and *Temporal Conception*). In addition to these models, Hall [5] observed from different cultural groups and proposed two dimensions of culture differences described as follows:

Monochronic/Polychronic Time: A group in which the things are scheduled one at a time/many in parallel

High/Low Context in Communication: Large/Small amount of stored or unspoken information in a given communication

Research on cross cultural usability has shown that culture differences in term of the index values on these culture dimensions can play an important role in determining the performance of people in many activities, such as the research on air transport crews about their culturally-driven attitudes toward automation and communication [e.g., 6], on jobs of an information system to be matched with users' culturally-specific behavior [e.g., 7], and on international customers' web searching performance [e.g., 8]. Despite its usefulness in capturing the influences of cross cultural differences on usability, this dispositional approach has its drawbacks when applied to the research on cross cultural usability:

- Effects of culture may not sufficient to explain the overall usability of a product. To be more complete and accurate, culture should be studied together with human cognition and perception.
- In practice, to reveal cross cultural similarities is more important than the differences for the design of products. Research should focus more on the similarities than the differences.
- To consider the culture backgrounds of users alone is not sufficient. The context of use should be also taken into account in the research.

Details of these arguments are provided in following sections.

1.1 Study Culture Together with Human Cognition and Perception

From anthropological point of view, culture is defined as the total pattern of human behavior and its products or artifacts that reflect a set of values, norms or standards shared, learned and accepted within a range of variation by members of a particular group of people [9]. Different from human basic physical and psychological

functionality which are inherited and universal to all people, culture is learned and specific to group or category [2]. This distinction corresponds to the difference between the bottom-up processing and the top-down processing in human perception [10]. That is, human cognition and perception are influenced by the human sensory systems as well as the experience and knowledge in mind. A good design has to meet basic ergonomic requirements (e.g., accessibility, free of confusion) first then to consider cultural requirements.

1.2 Focus More on Culture Similarities Than Differences

Culture-related issues are usually addressed through the processes of internationalization and localization. While the process of internationalization is to develop a general or culture-neutral base for localization, the process of localization is to meet the language or cultural requirements from specified target markets or locales [11, 12]. In practice, localization is usually an expensive and inefficient process [13]. Developing culturally neutral products may not only reduce the cost of production but also enhance the share in markets. There has been an attempt in search of internationalized operator interface displays in process control, and resulted a great cross cultural similarities among several Asian culture groups [14].

1.3 Study Culture Together with the Context of Use

The dispositional approach defines culture groups by their most probable values, norms or standards. The variation within a culture is treated as random errors. Fig. 1 demonstrated the distribution for a specific culture group against a culture dimension could approximately be a normal distribution [3].

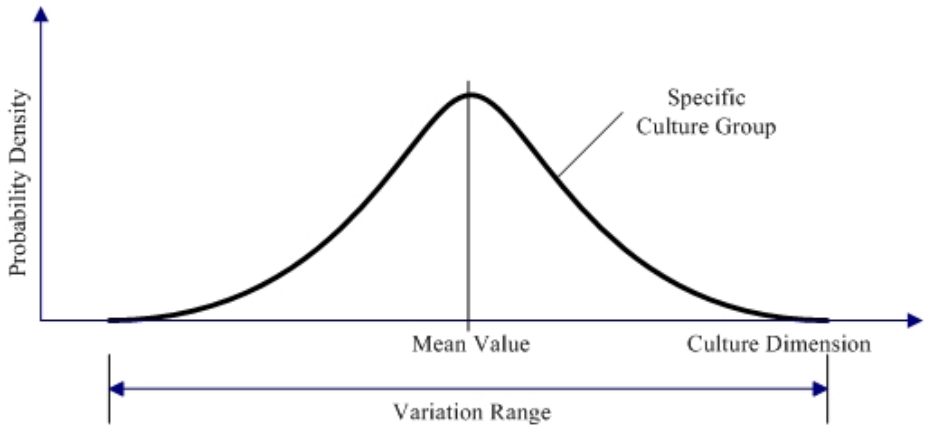

Fig. 1. Distribution for a specific culture group against a culture dimension

In most cross cultural research, within-culture variations are much greater than between culture differences [15]. Thus, to treat the within-culture variations as just errors in the data and ignore them may not be appropriate. Research showed that

significant part of within-culture variations could be explained by the context of use [16, 17]. That is, users from the same culture group may behave differently in different contexts of use. The context of use includes users, equipment, tasks and goals, and environment. In the checklists of ISO 9241-11:- Guidance on Usability [18], social/cultural environment is one of usability criteria in the category of environments, together with the usability criteria in the categories of users, equipment, and tasks. A domain-specific knowledge and a understanding of regional culture are necessary for designs with sound usability.

A new promising usability analysis method is under development [19], and it seems capable to deal with the cross cultural usability issues mentioned above. This method is based on the Axiomatic Design (AD) theory [20]. The AD theory is introduced below followed by a case study to demonstrate its application procedures.

2 Axiomatic Design

Axiomatic Design (AD) approach [21, 22] is a tool for designers to construct and understand design problems, as well as to find possible solutions. AD has been widely applied in the designs of software applications, consumer products, manufacturing systems, and decision support systems [23]. AD views the design process as a series of mappings between four domains: the customer domain, functional domain, physical domain, and process domain. The objective of the AD is to establish a scientific foundation for design activities by two axioms [20]:

Axiom 1: *The Independence Axiom*: Maintain the independence of functional requirements.

Axiom 2: *The Information Axiom*: Minimize the information content in design.

The most applied mappings are the mappings between Functional Requirements (FRs) in the functional domain and Design Parameters (DPs) in the physical domain. The independence axiom claims that each FR should be satisfied by the mappings between FRs and DPs without affecting other FRs, that is, the independence of FRs. Relevant to the information theory [24], the information axiom indicates that the best design is the design with minimum information content. In statistical terms, the best design has a set of DPs to fulfil their associated FRs with the highest probability of success. The mappings between FRs and DPs can be defined as below:

$$\{FR_n\} = [A]_{nm} \bullet \{DP_m\} \tag{1}$$

Where $\{FR_n\}$ is the n-vector of FRs in the functional domain, $\{DP_m\}$ is the m-vector of DPs in the physical domain, and $[A]_{nm}$ is called a design matrix of $\{FR_n\}$ and $\{DP_m\}$. The binary values of elements in the design matrix represent the mapping relationship between $\{FR_n\}$ and $\{DP_m\}$. While the value of 0 denotes no relationship between associated FR and DP, the value of 1 stands for the full relationship between them.

The relationship between a set of FRs and a set of DPs is categorized into three types of design: uncouple design, decouple design, and coupled design. A 3×3 design matrix is used as an example to illustrate these three design types:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \tag{2}$$

Where FR_1, FR_2, and FR_3 are three FRs in the functional domain. DP_1, DP_2, and DP_3 are three DPs in the physical domain. a_{ij} (i, j = 1, 2, or 3) is the element of the design matrix.

When $a_{ij} = 1$ for all i = j, and $a_{ij} = 0$ otherwise, the design is an uncoupled design illustrated as Eq. 3.

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \tag{3}$$

When $a_{ij} = 1$ for all i ≥ j, and $a_{ij} = 0$ otherwise, the design is a decoupled design illustrated as Eq. 4.

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 1 & 1 & 0 \\ 1 & 1 & 1 \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \tag{4}$$

If a design is neither an uncoupled design nor a decoupled design, then it is a coupled design. An example of a coupled design is illustrated as Eq. 5.

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 0 \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \tag{5}$$

Note that only the uncoupled design satisfies the Independence Axiom. That is, one-to-one mappings between FRs and DPs.

In the Information Axiom, the information content is measured by its information amount. The information amount is defined as the probability of satisfying a certain FR. For example, if the probability of satisfying the FR_i is P_i, then its information content, I_i, is defined as Eq. 6 as below:

$$I_i = \log_2 \frac{1}{P_i} = -\log_2 P_i \tag{6}$$

From Eq. 6, if $P_i = 1$, then $I_i = 0$, which means the FR_i is satisfied in one hundred percent. When the value of P_i approaches to 0, the value of I_i approaches to infinity, which means the FR_i is almost impossible to be satisfied.

These two design axioms can be applied to the new design of products, manufacturing processes, or systems, as well as to the evaluation and improvement of existed designs. The procedure is first to eliminate any decoupled or coupled design by

applying the Independence Axiom. If there still have more than two alternatives remained, the second step is to select the design with minimum information content by applying the Information Axiom.

3 Case Study: Alarm Icon Design

From a previous study [25], a set of icons used in a DCS product for ASEAN market was reviewed and used as an example to show how the axiomatic method can be applied as a systematic framework for the design of icons in the alarm summary operator interfaces.

An alarm is generated whenever an abnormal condition occurs. By clicking the "Alarm Summary" button on the tool bar of the system home page, the "Alarm Summary" page would be shown on the screen. Typically, 12 alarms could be displayed simultaneously on a single screen. The information for each alarm was listed horizontally on the "Alarm Summary" screen with the associated icon shown on the left side of each alarm. On the "Alarm Summary" screen, there were four icons in the legend to represent four different conditions of alarm:

- Acknowledged and in Alarm
- Unacknowledged and in Alarm
- Unacknowledged and Disabled
- Unacknowledged and Returned to Normal

The first step of applying axiomatic method is to define a set of independent referents, i.e., the FRs. After the analysis on the intended meanings of four alarm conditions, the alarms were classified by two sets of independent FRs. The first set was in terms of Alarm Acknowledgement with two FRs:

FR_1: Acknowledged
FR_2: Unacknowledged

The second set was in terms of Alarm Status with three FRs:

FR_1: In Alarm
FR_2: Disabled
FR_3: Returned to Normal

The second step of applying axiomatic method is to design the icons from a set of visual features, or to review the features used in current design.

The blink was used for the current alarm icon design to distinguish the acknowledged alarms and unacknowledged alarms. However, the distinctiveness among the conditions of "In Alarm", "Disabled" and "Returned to Normal" were not clear. Alarm icons represented these different conditions shared the same color (e.g., red) and shapes (e.g., square and asterisk) that might confuse users. Current design is shown in Table 1.

Table 1. Current design of icons

Intended Meaning	Current Design	Description
Acknowledged & in Alarm		Red asterisk
Unacknowledged & in Alarm	 *blink*	Blinking red asterisk
Unacknowledged & Disabled	 *blink*	Blinking red square with a white dash inside
Unacknowledged & Returned to Normal	 *blink*	Blinking red square with a white asterisk inside

The visual features of current design and their further decompositions are listed as below:

DP_1: Animation
- DP_{11}: No Blink
- DP_{12}: Blink

DP_2: Symbol
- DP_{21}: Asterisk
- DP_{22}: Dash
- DP_{23}: Square

DP_3: Color
- DP_{31}: Red
- DP_{32}: White

Now we could apply the Independence Axiom for the current design:

$$\begin{Bmatrix} \text{Acknowledged} \\ \text{Unacknowledged} \end{Bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{Bmatrix} \text{No Blink} \\ \text{Blink} \end{Bmatrix} \tag{7}$$

$$\begin{Bmatrix} \text{In Alarm} \\ \text{Disabled} \\ \text{Return to Normal} \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 1 \\ 1 & 0 & 1 \end{bmatrix} \begin{Bmatrix} \text{Asterisk} \\ \text{Dash} \\ \text{Square} \end{Bmatrix} \tag{8}$$

$$\begin{Bmatrix} \text{In Alarm} \\ \text{Disabled} \\ \text{Return to Normal} \end{Bmatrix} = \begin{bmatrix} 1 & 0 \\ 1 & 1 \\ 1 & 1 \end{bmatrix} \begin{Bmatrix} \text{Red} \\ \text{White} \end{Bmatrix} \tag{9}$$

The results showed that only Eq. 7 was uncoupled design. Both Eq. 8 and 9 were coupled design. This analysis revealed that the usability problem of the set of icons was due to the confusion, the failure to discriminate similar stimuli that represent different concepts [10]. It was a universal problem across all culture groups. Once this problem has been solved, the next step is to apply the Information Axiom to find out

the best set of icons. Since users may be interfered or facilitated by their cultural background and the context of use for interpreting the icons, a user survey or testing is an effective tool for designers to gain their domain-specific knowledge. It is suggested here that the information content, I_i, can be measured through the probability of successful associations between to-be-used visual features and their referent concepts. The best design then can be selected according to the Information Axiom. For example, in Fig. 2, through a user survey or testing, there are several options (i.e., Shape 1-5) can be chosen as possible design solutions for representing a referent, but there may be only one option with the largest success percentage of representation as the best choice since it is with the least information content (i.e., Shape 3 in Fig 2). Cross cultural similarities or differences can also be examined via checking how similar or different the profile of the success percentage does by comparison with the one from other culture group.

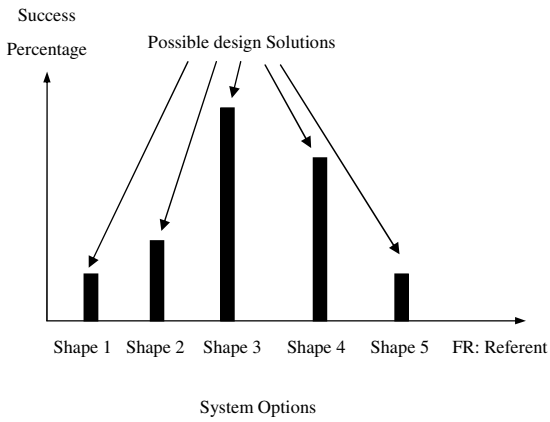

Fig. 2. System options, possible design solutions, and the best solution

4 Conclusion

Cross cultural design is more complex than is always apparent. Variations in the degree to which preferences and values are held within any single culture. Beliefs and values can be dynamic, shifting over time due to social change. Cultures and the context of use frequently interact with unexpected results. All of these factors conspire to make it more difficult to predict consistent behavioral effects of cultures. Most of the research and practice has focused on cross cultural differences and applied a dispositional approach. In contrast, cross cultural similarities have less been researched and the context of use has been less emphasized. The axiomatic method in this paper is a first attempt in this endeavor to highlight the human cognition and perception, and the context of use should be considered together with culture in the cross cultural usability research.

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