Participatory Design of Warning Symbols Using Distributed Interactive Evolutionary Computation

by

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Abstract

Safety warnings play an important role in communicating risk via product labels and environmental signs. With the diversification of cultures and languages in the United States, and with the increasing globalization of most industries, emphasis on the communication of this risk through symbols and other non-written forms has increased. Both ANSI and ISO have developed voluntary standards for the production and evaluation of warning symbols, but many symbols currently in use have been found deficient with respect to the comprehension and effectiveness guidelines found in these standards. In other cases, commonly used symbols have not undergone effectiveness evaluation at all. Thus, there remains a need to produce warning symbols shown to be effective in communicating risk to a multicultural, multilingual, global society.

Though the ANSI and ISO standards fail to specify a technique for developing symbol designs, three techniques were identified from the literature. Of these three, the focus group method was claimed by its developers to be the most effective in producing high quality symbol designs because it involves realistic users of the symbols in more aspects of the design process than either of the other techniques. The focus group method requires human participants to sort and filter many designs into a single proposed symbol. This type of search task is well suited to machine computation, and this research will model the focus group method of human design generation and consolidation as a distributed interactive genetic algorithm which will evaluate and generate designs using

simple simultaneous feedback from a group of human users. The literature revealed a similar interactive evolutionary computation algorithm used to design safety symbols in a prior study, although that algorithm used a single participant and still required human designers to evaluate many symbols by hand to determine the best design. The proposed distributed interactive genetic algorithm will remove the designer's input at this stage of the design process by allowing the users and the algorithm to determine a final design for the group without designer interference.

First, a survey was administered to 145 university students and safety professionals to determine an ordered list of safety messages (or referents) sorted by their perceived difficulty to convert into symbols. From this list, two referents were chosen for the study, one easy ("Hot Exhaust") and one difficult ("Do Not Touch with Wet Hands"). Seventy American university students, 35 born in the U.S. and 35 born in India, were recruited to sketch symbol designs for each of the two referents. These designs were evaluated by a panel of safety professionals to identify the graphical attributes contained in each drawing, and the presences or absence of each identified attribute in a given symbol created a binary attribute matrix for each referent. These matrices were summed and clustered using a K-means clustering algorithm to determine the centroid values of each cluster of symbol drawings. Thirty-five attributes were identified by the panel among the "Hot Exhaust" drawings, and the clustering revealed that only three of them were present among the centroid values of each of the five identified clusters. Likewise, 28 attributes were identified for the "Do Not Touch with Wet Hands" drawings, but only five were present in the centroid values of the four clusters identified for this referent.

From these centroidal attributes, a version of the distributed interactive genetic algorithm was created for each referent. Forty-six participants, divided into four groups of 10-12 by country of origin, designed symbols using the algorithm, and the symbol most representative of each group was compared by 401 participants from around the globe to symbols generated using a traditional method and to symbols in use currently. The results indicated that for the easier referent, “Hot Exhaust”, the algorithm produced symbols that performed as well or better than symbols produced by other means, including the symbol currently in use. However, for the more difficult referent, “Do Not Touch with Wet Hands”, other symbols performed better than those produced by the algorithm. Additionally, the algorithm generally converged in 20 generations or less, which falls within the recommended limitations of such algorithms within the literature. However, the algorithm converged faster for U.S. and multinational groups than for groups of participants from other single nations.

In summary, the distributed interactive genetic algorithm technique showed promise as a design tool for developing symbols that perform as well or better than current design methods. Furthermore, the algorithm’s performance may vary depending on the difficulty level of the referent tested as well as on the composition of the participant groups used in the design process. Further research is needed to confirm and characterize these relationships.

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Table of Contents

List of Tables

List of Figures

CHAPTER 1

INTRODUCTION

Hazard warnings communicate safety information, often in the vicinity of the hazard, through a variety of modalities. Classical warnings, such as the light house and fog horn, have been used for centuries to aid those exposed to hazards to which they might have been unaware (Egilman & Bohme, 2006). Common warnings in modern American society include flashing lights and bell alarms for railroad crossings, printed pharmaceutical information about potential side effects and interactions, and traffic signs alerting drivers to the risk of deer crossing the highway. One of the most common forms of hazard warnings is the static visual warning, which may include written messages, graphical symbols, color coding schemes, or all of these (ANSI, 2007a, 2007b; ISO, 2003, 2006). These kinds of warnings are found in a variety of locations, such as on product labels, in written manuals, on industrial signage and in places used by the public.

Graphical symbols have been suggested to improve comprehension of visual warnings as well as to attract attention to them (Boersema & Zwaga, 1989; Davies, Haines, Norris, & Wilson, 1998). Unfortunately, the process of producing effective graphical symbols for static visual warnings can be a tedious and time consuming task involving iteration after iteration of research participant input, designer evaluation and field trials (Goldsworthy & Kaplan, 2006; Green, 1993; Young & Wogalter, 2001). For this reason, many designers borrow or modify existing designs rather than attempt to create their own from scratch (Edworthy & Adams, 1996). However, using older symbols that were designed prior to the publication of current guidelines may mean that the borrowed symbols have not been evaluated for their effectiveness (Deppa, 2006) or that they were not designed with a global, diverse population in mind (Huer, 2000; Laughery, 2006). While more and more symbols are being designed and tested, at least in part, to address the former concern, the latter concern continues to grow more problematic as global trade and immigration diversify the user populations of nearly every product or piece of equipment.

The use of participatory design, or the development and evaluation of design concepts using potential users of the system or product, is believed to improve the quality of the final designs (Schuler & Namioka, 1993). This technique has been used, to varying degrees, in the design of graphical warning symbols for years (Green, 1993; Macbeth, Moroney, & Biers, 2000; Pettendorfer & Mont'alvao, 2006). Furthermore, recent advances in computational methods have led to the addition of technology to assist in the participatory design process (Carnahan & Dorris, 2004; Carnahan, Dorris, & Kuntz, 2005; Dorris, 2004; Dorris, Carnahan, Orsini, & Kuntz, 2004; Dozier, Carnahan, Seals, Kuntz, & Fu, 2005b; Parmee, Abraham, & Machwe, 2008). This has proved to be a promising development in the attempt to involve more diverse participants in the design process because the technological innovation allows communication of design information with less interference from the barriers of language, culture and geography.

Research Objectives

The literature, reported in Chapter 2 of this dissertation, reveals a gap in the incorporation of innovative computational technology in the participatory design process of producing graphical safety symbols. While computational technology has been used to assist symbol designers before, it has yet to be incorporated into the methods that are the most participatory in nature (Macbeth et al., 2000; Pettendorfer & Mont'alvao, 2006). Furthermore, the literature clearly reports the missing component of cultural and first-language diversity among the participants recruited to design and develop these symbols (Huer, 2000; Lesch, Rau, Zhao, & Liu, 2009; Russo & Boor, 1993). Thus, the objective of this research is to bridge the gap between participatory design and computational technology by using advanced computational techniques to replace a traditional symbol design focus group with a group of design participants interacting through a computer network. In this way, users of various cultures, language proficiencies and even geographic locations can interact and share ideas meaningfully and simultaneously in the symbol design process.

Research and Dissertation Organization

The chapters of this dissertation are organized according to the publication format. The dissertation is comprised of six chapter manuscripts. Chapter One is a traditional introduction, and Chapter Six is a traditional conclusion. Chapter Two is a comprehensive literature review of the safety warning symbol development process and the use of interactive evolutionary computation to design risk communication. Each of the remaining chapters is a stand-alone manuscript describing the purpose, methods, results and discussion of an experiment. Because of the special arrangement of this format, a brief survey of the most relevant literature is provided in each of the remaining manuscripts. The experiment in Chapter Three surveys safety professionals to determine the expected difficulty of converting written warning messages to graphical symbols in order to sort those warning messages by difficulty. Chapter Four reports on the production of two pools of symbol proto-designs, with each pool portraying a safety message from a significantly different difficulty level identified in Chapter Three. Each pool of candidates was analyzed for their semantic attributes and grouped into clusters with similar design intent. Software using distributed interactive evolutionary computation was developed with the capability of producing symbols comprised of components from the median symbol of the clusters identified in Chapter Four, the users of which performed the symbol generation and refinement role traditionally performed by safety symbol design focus groups. Chapter Five summarizes the development and performance of the algorithm and reports the results of a comparison of the newly produced symbols to previously published symbols and to symbols generated in an additional experiment following the focus group method of symbol development. The limitations of the study, the study recommendations, and the overall conclusions are discussed in Chapter Six. The appendices contain details outlining the recruitment and participation of human subjects, the specific protocols used for each experiment, summaries of the collected data, and other information which support the results presented in the chapter manuscripts.

CHAPTER 2

A REVIEW OF THE LITERATURE ON THE PRODUCTION AND DEVELOPMENT OF SAFETY WARNING SYMBOLS

Introduction to Warnings

Wogalter (2006) defines a warning as a safety communication "… used to inform people about hazards…" While the last two decades have seen a dramatic increase in the amount of warnings research (Laughery, 2006), warnings have been used by people for millennia (Stanton, 1994). For example, bells were once used to alert villagers of an advancing enemy force, and lighthouses have long warned mariners of reefs or rocky shores. With the industrial age, new hazards arose, and many new warnings were developed. Pedestrians and passengers were alerted to oncoming trains by lamps and whistles, while hand signals and signs used by railroad workers helped ensure that locomotives and people avoided undesirable interactions (Egilman & Bohme, 2006). As industrial production and therefore industrial hazards increased, the development of warnings aimed at industrial workers also increased. Due to both growing concerns for the safety of workers and the emergence of workplace injury litigation citing a "failure to warn," organizations such as the National Safety Council and even the U.S. Congress contributed to the development and use of warnings (Clark, Benysh, & Lehto, 2003; Egilman & Bohme, 2006). Today, both voluntary standards and legal statutes exist that recommend, or in some cases require, the use of safety warnings (ANSI, 2007c; ISO, 2003; OSHA, 1996).

Laughery and Wogalter (2006) list three specific purposes and a fourth general purpose for warnings. Warnings attempt to inform people about hazards, their consequences, and how to avoid them. Warnings purport to influence behavior; specifically, they promote safe behavior. Warnings serve as a reminder of previously learned information, including the nature of hazards and their consequences, how to avoid them, and where and when to be vigilant. Finally, warnings' ultimate purpose is to make the world safer for its human occupants. In this regard, they serve a public safety goal of protecting members of society, and therefore they have received considerable attention from government and standardization organizations. Laughery and Wogalter (2006) present a brief but informative summary of the growth of regulatory interest in warnings in the U.S. during the 20th century.

In practice, warnings may take a variety of forms. Though not exhaustive, Hammer (1989) provides an informative list of warnings targeted to a variety of human senses. Most people have experienced warnings that target the olfactory (odorant added to natural gas to detect leaks), tactile (rumble strips on a highway to warn of upcoming intersections) and gustatory (a bitter chemical added to poisonous products to keep children from consuming them) senses, though examples of these are relatively rare. Warning modalities that utilize the visual and auditory senses are more common (Cohen, Cohen, Mendat, & Wogalter, 2006; Laughery & Wogalter, 2006). Auditory warnings for fire, severe weather and burglary are well known examples among the general public. Industrial safety warnings that use the auditory channel include backup alarms on vehicles, atmospheric contaminant alarms and the voice of an attendant guarding a confined space (Hammer, 1989). Familiar static visual warnings include those which appear on product packaging and labels and those found on signs in the workplace and in public areas (Lesch, 2006; Rousseau & Wogalter, 2006). A visual warning may also be dynamic, such as an animated hazard warning sign, an electronic scrolling traffic sign or even a set of hand signals to and from crane operators to those on the ground (Hammer, 1989; Wogalter, Racicot, Kalsher, & Noel Simpson, 1994). Some warnings may even involve more than one of these modalities. Several studies have specifically explored the efficacy of various warning modalities, both within and across sensory channels (Campbell et al., 2004; A. H. S. Chan & Ng, 2009; Haas & Edworthy, 2006). In fact, mixed modal warnings, especially those that utilize multiple sensory channels, have been shown to improve warning effectiveness in some contexts (Cohen et al., 2006).

Warnings are passive in their protective function in that they require a response from each warning recipient in order to be effective. Specifically, an effective warning must be noticed, understood and heeded (Miller & Lehto, 2001). Other researchers have defined more detailed models of the warning process (Clark, 1988; Lehto & Papastavrou, 1993; Rogers, Lamson, & Rousseau, 2000; Wogalter, Dejoy, & Laughery, 1999), and Lehto (2006) provides a good historical summary of this research. However, it is not the aim of this research to explore these models further or to comment on their adequacy. Rather, the purpose of this literature review is to examine the process of designing the graphical symbols used in warnings and other safety communications.

Warning Symbols

Much of the warnings research from the last two decades has focused on evaluating the effectiveness of warnings as a communication system, and in a majority of circumstances, visual warnings were the primary modality of interest (Smith-Jackson & Wogalter, 2006). Though they differ in their taxonomy, several researchers have reported that, regardless of modality, the warning process involves a series of stages which must all succeed in order for the warning to be effective at changing behavior (Lehto, 2006; Rogers et al., 2000; Wogalter et al., 1999). Though a discussion of these individual stages are not salient to this research, Rogers et al. (2000) provided a thorough summary of the variables identified in empirical research that affect a visual warning system's performance. They identified more than 50 person-related or warning-related variables that affect warning effectiveness based on their effect on at least one stage of the warning process. Laughery and Wogalter (2006) further contributed to this understanding by labeling some variables specifically as *design variables*.

Though several of these design variables (e.g. color, message length, signal word) can be present in warnings without symbols, the use of symbols as an important design component has been noted in several studies, according to Laughery and Wogalter (2006). The effect of symbols (pictorials, icons, graphics, pictograms, etc.) on the warning process has been studied extensively. In general, research has determined that symbols can aid warning performance by calling attention to the warning and enhancing the comprehension of the warning message (Wogalter, Silver, Leonard, & Zaikina, 2006). Specifically, Laughery, Young, Vaubel and Brelsford (1993) reported that symbols were useful in gaining attention for warnings, especially for those in which printed information is small or illegible (Kalsher, Wogalter, & Racicot, 1996), and Davies et al. (1998) found symbols to be especially valuable when space on the sign or label was restricted. Furthermore, Friedmann (1988) found that the presence of well-designed symbols increased the probability that salient information written in the warning would be read. Jaynes and Boles (1990) reported that pairing symbols with verbal warnings improved compliance over either component presented alone, while Lesch (2008a, 2008b) found that the pairing of accident scenarios and symbols increased comprehension and recall of prior knowledge more than did a pairing of symbols with verbal labels. Interestingly, Kalsher et al. (1996) notes that warnings that contain graphical symbols are preferred by people over warnings that do not.

Nevertheless there have also been empirical studies which found little or no benefit to the inclusion of symbols with warnings. Both Otsubo (1988) and Friedman (1988) found that symbols generally had no effect on noticeability of or compliance with warnings, while at the same time noting that the most noticed warnings, including some with symbols, were also the most heeded. More complex or abstract symbols were found to distract from the actual hazards by Mayer and Laux (1989), although the inclusion of simple and concrete symbols improved warning noticeability in their study. Jaynes and Boles (1990) qualified the benefits they reported from pairing symbols with written warnings by also reporting that symbols alone were heeded less often than written warnings alone. Though research has suggested that there are many benefits to the use of warning symbols, symbols that are designed poorly may actually be detrimental to warning effectiveness. Therefore, this research concentrates on the design and evaluation of warning symbols rather than on other aspects of the warning process.

Symbols as a Culture and Language Bridge

An additional advantage of warning symbols over other warning components is that symbols have the potential to be understood by a greater number of people (Wogalter et al., 2006). Research has reported warning symbols to be both language-independent (Liu, Hoelscher, & Gruchmann, 2005) and culture-neutral (Edworthy & Adams, 1996). Hodgkinson and Hughes (1982) found that pictorial instructions could circumvent language barriers among multi-national customers when unpacking and assembling IBM typewriters, though several design iterations were necessary to produce an adequate version. Foster and Afzalnia (2005) tested symbol comprehension in the UK, Korea and Iran, and they argue that agreement among the results suggests that standardizing international symbols may be possible. Kalsher et al. (1996) reported that well-designed pharmaceutical symbols may be critical in reaching patients who have low literacy or low language proficiency, though they caution that poorly designed symbols may actually decrease comprehension in these populations. However, some research challenges the notion that symbols are culturally neutral (Smith-Jackson, 2006). Huer (2000) reports on several studies that have found a dependency of symbolic communication on cultural experience, and she suggests that culture and language interact and cannot be easily separated in a communication context. Russo and Boor (1993) reported that symbols, such as the “X” (i.e. a cross) may have an opposite meaning in Egypt than in Western countries, and Dowse and Ehlers (2001) found an overwhelming preference among low-literate South Africans for symbols designed locally rather than internationally. Unfortunately, the involvement of potential users in symbol design is very rare. Dorris (2004) and Huer (2000) suggest that individuals with limitations in language proficiency bear the greatest risk from poorly designed symbols, yet both authors report that the few research studies that make use of potential users in symbol design almost exclusively do so only in the symbol evaluation stage. Thus, there remains a significant dearth in symbol design research that incorporates potential users in the design process. It is the intention of this research to fully utilize culturally diverse research participants to both design and evaluate warning symbols.

Designing Symbols

The development and implementation of the graphic symbols which comprise a portion of, or in some cases the entirety of, a safety warning has proven to be a challenge to researchers. According to Dorris (2004), the procedure for producing a safety warning symbol involves three steps. First, the symbol's intended message must be determined. The message intent may be to prohibit certain actions (e.g., "Do not touch."), to prescribe or require certain behavior (e.g., "Wear safety glasses."), or to communicate information about a hazard (e.g., "Danger. High Voltage.") (ISO, 2006). This message is known as the symbol's referent. Second, a pool of candidate symbols must be generated either from existing sources or by creating new symbols. Finally, the candidates must be evaluated to determine the most appropriate symbol for the referent based on empirical determinations of communicative effectiveness (Dorris, 2004).

Several voluntary standards exist, both American and international, which propose non-binding guidelines for the development of safety symbols for use on product labels, in product manuals, in industrial workplaces and in public areas (ANSI, 2007a, 2007b, 2007c; ISO, 2002, 2004, 2006, 2007, 2008). These guidelines set some presentation criteria for color, shape, font size, and component orientation, and they have grown more harmonious over the past two decades (Deppa, 2006). However, differences remain between ANSI and ISO standards. For example, ANSI Z535 encourages warning designers to include four hazard aspects: seriousness, hazard type, hazard consequences, and avoidance actions. Because European warnings may be viewed by recipients speaking as many as 16 different languages, the ISO 3864 standard adopted a text optional convention (Deppa, 2006). In most cases, only one of the four aspects of the hazard can be portrayed by a given symbol, which means that ISO style warnings may differ in both appearance and function from ANSI warnings. ANSI Z535.4 (2007c) also specifies the use of either a two- or three-panel format with separate panels that include a signal word panel (e.g. "Danger"), and either a message panel, a symbol panel or both. More recent ISO 3864.2 revisions have incorporated the use of optional message

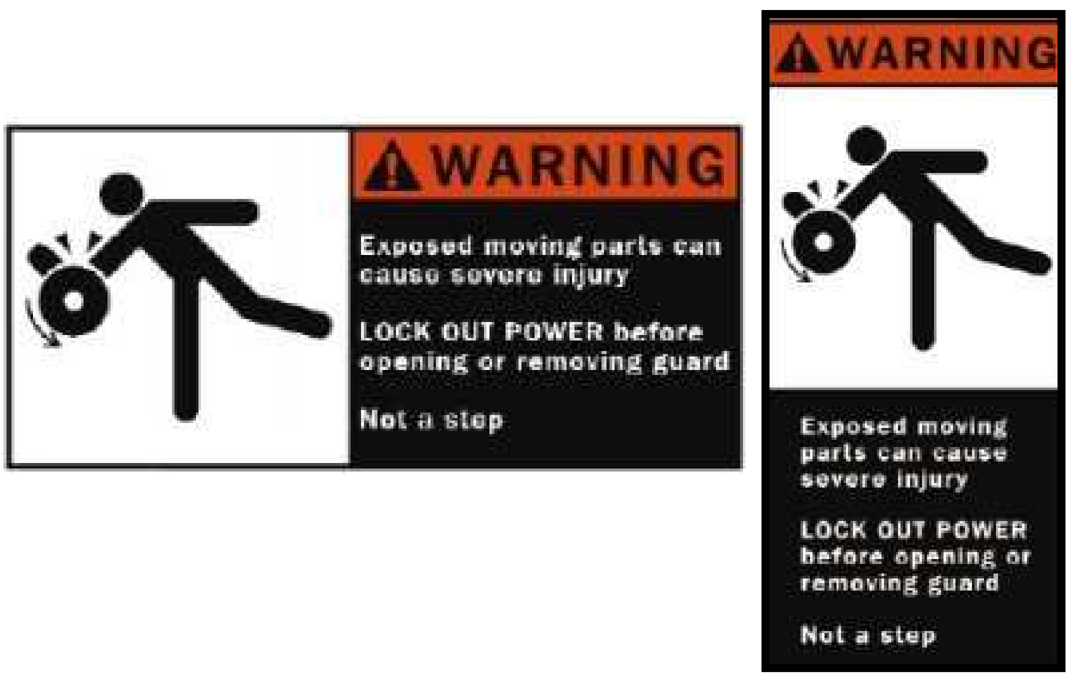


Figure 1. ANSI Z535.4 format with three panels, horizontal and vertical versions

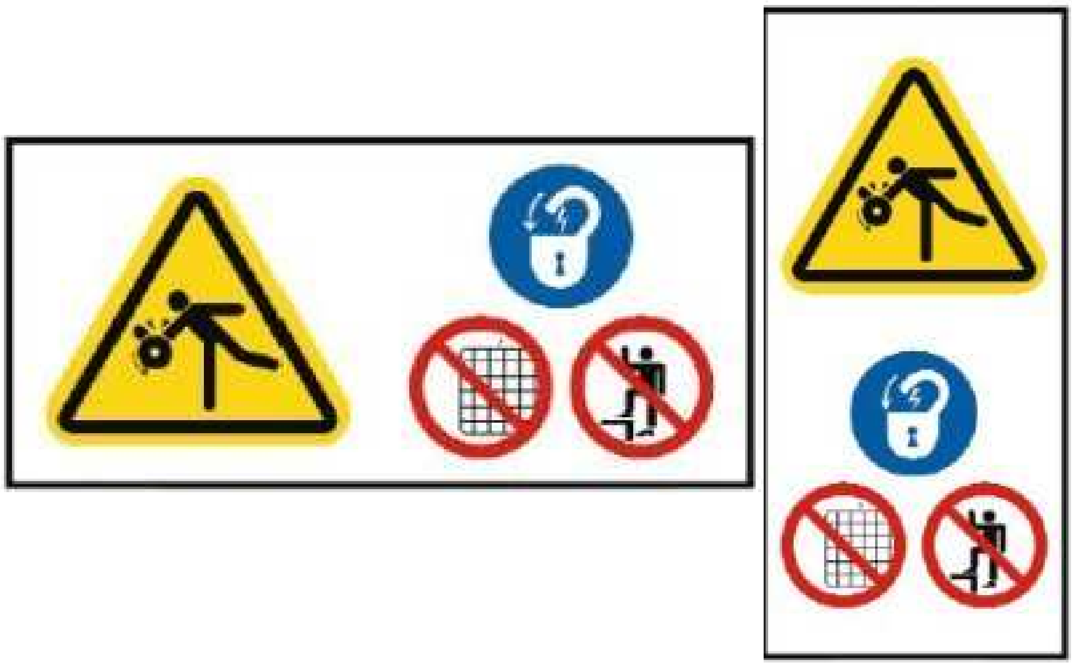


Figure 2. ISO 3846-2 format with multiple symbols, horizontal and vertical versions.

and signal word panels to communicate more than one hazard aspect, although multiple symbols may also be used for this purpose. Additional harmonization efforts have occurred between ANSI Z535.3 and ISO 3846-3 to provide synchronized guidance for symbol design criteria such as the use of representational rather than abstract symbols and solid graphical representations of the human body (ANSI, 2007a; ISO, 2006). Figures 1 and 2 provide an example of ANSI Z535.4 and ISO 3684-1 formats, respectively.

While the ANSI Z535 and ISO 3864 and 9186 families of standards offer guidance for the appearance and function of warning signs and labels including the use of symbols, there is little guidance provided on how to produce symbols for use in these warnings. Although ANSI Z535.3 includes a flow chart for the design of a symbol, the only guidance regarding how to proceed from *Step 1 – Identify Need for Symbol* to *Step*

2-Select Candidate Symbols to Test states that it should involve "Decisions based on graphic design principles and analysis of users" (ANSI, 2007a). Unfortunately, this offers little advice to symbol designers. Therefore, the methodologies for the production of warning symbols have developed primarily outside of these standardization organizations. Most researchers recognize two, and in some cases three, primary techniques for producing the graphical symbols used in safety warnings (Dorris, 2004; Green, 1993; Macbeth et al., 2000; Macbeth, Moroney, & Biers, 2006; Pettendorfer & Mont'alvao, 2006). The most traditional, and still widely used, method of developing symbols is also the least complex. In this method, a graphic artist interprets the verbalized wishes of the designers to create a set of symbol candidates. Sometimes these symbol sets are tested for comprehension; sometimes they are put directly into practice without evaluating their communicative effectiveness (Ringseis & Caird, 1995; Roberts et al., 2009). In order to improve the symbol design quality, features may be built gradually and tested at each stage (Dewar, 1999; Dorris, 2004). Whether tested or not, this method is often iterative (Zwaga & Mijksenaar, 2000) with symbols passed between designers, artists and test subjects multiple times before a symbol is finalized (Wisniewski, Isaacson, & Hall, 2007). In this dissertation, this method will be referred to as the *Designer Method*.

Another method of developing symbols actually recruits the participation of potential users of the symbols in their design. This method, pioneered in the automobile and defense industries for icon design, including safety symbols (Green, 1993; Howell & Fuchs, 1968; Karsh & Mudd, 1962; Mudd & Karsh, 1961), is known as the *Production Method*. In the production method, a sample of participants develops simple sketches of symbols individually from scratch. Rather than the symbol designers communicating their wishes and ideas to a graphic artist, the artist instead analyzes the drawings created by the participants. It is the responsibility of the artist to consolidate the themes found among the symbol drawings to create a final symbol or symbols from those themes. Green (1993) presents a thorough review of the early users of the production method, including actual line drawings produced in previous studies (Green, 1979; J. R. Sayer & Green, 1988). The production method has evolved over time to include many variants (Dorris et al., 2004; Goldsworthy & Kaplan, 2006; Green, 1993; Ringseis & Caird, 1995), which offer innovate new ways to make use of the unique design contributions of potential warning recipients. This method utilizes participatory design, a design strategy that suggests the involvement of potential users of a product or system in its design will produce a product or system more suited to its intended user (Schuler & Namioka, 1993). Sloan and Eshelman (1981) empirically compared symbols produce by the production method to those produced by the designer method. They determined that the symbols produced under the production method performed better in every case, and that the use of participatory design in the development of warning symbols appeared to contribute significant benefit.

While many methodological variants may fall under the production method (Green, 1993; Pettendorfer & Mont'alvao, 2006; Ringseis & Caird, 1995), some symbol designers have suggested that a distinct new method has emerged from the production method referred to as the *Focus Group* method. In this method, rather than drawing symbols individually and passing them directly to a graphic artist, participants are organized into small focus groups where their drawing designs are revealed and discussed

(Dorris, 2004; Goldsworthy & Kaplan, 2006; Macbeth & Moroney, 1994; Macbeth et al., 2000, 2006; Mayhorn & Goldsworthy, 2007). Based on this discussion, a consensus symbol design is produced within the focus group by the participants themselves. In this way, the group synthesizes the themes of the various participants into a consensus drawing with real-time input from the original designers of the candidate symbols and without interference from designers. In this paper, this variant of the production method is referred to separately as the *Focus Group Method*.

The proponents of the focus group method suggest that it removes from the graphic artist the responsibility of interpreting the thematic desires of the participants, instead placing that responsibility with the participants themselves (Macbeth & Moroney, 1994). The graphic artist is called upon only to clean up and professionalize the drawings produced from the focus group (Dorris, 2004). Since human factors engineers and designers have found participatory design to produce better products, more suited to the needs and preferences of their potential users (Dewar, 1999), one might hypothesize that the focus group method may produce the most effective symbols since this method allows its participants the most input and control over the design process.

Some empirical research supports this expectation. Macbeth et al. (2000) report that the focus group method proved superior to the production method for developing aircraft maintenance symbols using active aircraft maintainers as participants. They noted that the symbols designed in the focus groups were preferred by the evaluation participants and that the production process took significantly less real time using the focus group method. However, Dorris (2004) observes than in actual person-hours, the focus group method took far greater number of hours than did the production method.

Pettendorfer and Mont’alvao (2006) combined aspects of the focus group and production methods and reported qualitative improvements between the symbols produced under the production method with the consensus symbols designed in focus groups. However, the authors made no direct comparison between comprehension, preference, or production time between the two methods.

The focus group method of symbol production faces several challenges found in many focus groups which can impede the ability of the group to perform its task. Some of these challenges, such as culture and language barriers, variations in prior experience and topic familiarity and conflicting personality traits, seem particularly relevant to the development of warning symbols because the consequences of suppressed or unilateral design ideas could lead to poorly designed symbols (Dorris, 2004; Easton, Easton, & Belch, 2003; Garmer, Ylven, & Karlsson, 2004; Huer, 2000; Klein, Tellefsen, & Herskovitz, 2007; Newby, Soutar, & Watson, 2003; Sweeney, Soutar, Hausknecht, Dallin, & Johnson, 1997). The current study attempts to overcome these challenges by introducing a distributed interactive genetic algorithm for symbol development.

Evaluating Symbols

The incorporation of high quality symbols into safety warnings has many benefits (Friedmann, 1988; Wogalter et al., 2006), while the utilization of poor quality symbols can be detrimental to the comprehension of and subsequent compliance with the warning (Dorris, 2004; Huer, 2000). Though a large percentage of the warning symbol research has concentrated on the determination of adequate symbol performance and the characteristics that produce it, an unusually small percentage of this research involves real-world field studies (Dejoy, Cameron, & Della, 2006). ANSI Z535.3 (2007a) and ISO 9186-1 (2007) each specify testing procedures and performance criteria which must be met in order to determine that a symbol performs well. For example, ANSI proposes an 85% passing rate in open-ended comprehension testing from a test sample of at least 50 participants well representative of the intended users. ISO proposes a similar testing technique, but with a 67% score required to pass and 50 participants from each of three culturally diverse countries. Both standards insist that symbols have less than 5% critical confusion from the open-ended testing. Critical confusion occurs, according to Wogalter et al. (2006), when someone misinterprets the message of a symbol as encouraging an unsafe behavior that may lead to an injury or when the individual interprets the opposite of the intended meaning. Common means of delivering open-ended comprehension tests include the presentation of the symbol in either written or pictorial context with two questions are asked of the participant: "Exactly what do you think this symbol means?" and "What action would you take in response to this symbol.?". ANSI (2007a) recommends binary judging criteria of correct or incorrect, while ISO proposes a weighted scale of correctness (2007).

The open-ended comprehension test has been recommended as the gold standard for evaluating symbol designs (Hicks, Bell, & Wogalter, 2003). However, due to its expense and difficulty, other means of evaluating symbols have been proposed. To reduce the size of the symbol set for final testing, an intermediate step of comprehension estimation, or comprehensibility judgment, is described by both ANSI Z535.3 (2007a) and ISO 9186-1 (2007). In this test, participants are provided both the symbol and its meaning and are asked to estimate the percentage of the population that would understand the symbol. Once again, at least 50 well-representative participants are needed for the ANSI method, while 50 participants from each of three culturally diverse countries are needed for the ISO method. Young and Wogalter (2001) report on several studies of this evaluative test, which they call population estimation, noting that its results were found to correlate highly to the results of open-ended comprehension testing. However, Wolff (1995) observes that another common evaluation test, the multiple choice test, has proven to depend heavily on the quality of the distracters in identifying symbols that were judged as poor by other methods. Lesch (2005) notes that true comprehension is often underestimated by open-ended testing, creating a type I error, and overestimated by multiple choice, creating a type II error. She introduces semantic relatedness testing as one that is highly correlated to other high performing evaluations, but that avoids some of the overestimation and underestimation common in other tests. This evaluation mode is similar to a true-false test in that a symbol is paired with a label that may or may not be representative of its meaning. Users must determine whether or not it is accurately described by the label (Lesch, 2005). This research will rely heavily upon comprehension estimation to identify the final symbol designs since many design candidates will be considered for the same referent. Comprehension estimations can be made for multiple symbol variants from the same referent by the same participant, whereas open-ended comprehension testing cannot.

In addition to the manner of determining symbol effectiveness, several factors affecting warning comprehension and compliance have been identified by empirical research. Along with 39 warning-related factors, Rogers et al. (2000) identified 19 personal factors affecting warning efficacy. However, this dissertation will consider only those aspects of symbol design which contribute to effectiveness. Rogers et al. (2000) lump together most symbol-related factors into a single term they call *symbology*. In a similar summary, Laughery and Wogalter (2006) also define a single *pictorial* factor to represent the effect of symbols on warning effectiveness. However, other researchers have identified several symbol characteristics of interest to this discussion. McDougall, Curry and de Bruijn (1999) identified and evaluated five symbol-related factors, normalizing and measuring each factor for a set of 239 symbols. *Concreteness*, the degree to which a symbol pictorially matches a person, place or object, was found to positively influence usability for inexperienced users, but this effect waned over time as users gained experience (Isherwood, McDougall, J.P, & Curry, 2007; McDougall, de Bruijn, & Curry, 2000). *Visual complexity*, the amount of intricacy or detail in the symbol, may affect the amount of time needed to identify and interpret a symbol, thereby reducing its effectiveness for short term exposures (McDougall et al., 2000). *Familiarity* refers to both the frequency of exposure to the symbol as well as to the objects or situation it depicts (Isherwood et al., 2007). *Semantic distance*, or the closeness of a symbol's image to its intended function, has been recently proposed as a major contributor to effectiveness (McDougall et al., 1999), although more research is needed (Isherwood et al., 2007). Hicks et al. (2003) propose an additional factor referred to as *ease of visualization*, which measures the ease in which the symbol's message can be visualized. This is an important concept in that it is the only factor on the list that is independent of the actual symbol design. This is relevant to the current study because it affects the development of symbols, not just their evaluation. The symbol design process begins with a message, or referent (Dorris, 2004), and it must be visualized before it can be converted into a symbol. However, visualizing a referent and producing a symbol from it are not the same task, so the ease to which visualization is possible does not necessarily predict the ease of producing a symbol for the referent.

Interactive Evolutionary Computation

The process of design has long been the domain of discipline experts who use experience and creativity to propose new products or systems (Dorris, 2004). However, with advancements in computational power and artificial intelligence, technology can now play a significant role in the design process. Conceptualizing any design problem as a search space with an optimal solution to known or unknown objective functions allows the usage of meta-heuristic search algorithms to assist human designers with especially difficult problems (Roy, Hinduja, & Teti, 2008). Evolutionary computation (EC) refers to a collection of meta-heuristics that solves complex optimization problems by utilizing principles of biological evolution to evolve problem solutions in large solution spaces (Dreo, Petrowsdki, Siarry, & Taillard, 2003; Rees & Koehler, 2006). Takagi (2001) considers these meta-heuristics to be part of the EC family: Genetic algorithms (GA), Evolutionary Programming (EP), evolutionary strategies (ES) and genetic programming (GP). However, other researchers may consider additional meta-heuristics, such as Ant Colony Search or Particle Swarm Optimization, to be evolutionary computation because of their analogy to biological systems.

Recently, EC has been applied to human factors and safety problems such as avoiding pilot error (Chouraqui & Doniat, 2003), estimating chemical exposures (Johnston, Phillips, Esmen, & Hall, 2005; Nomen, Sempere, Pey, & Alvarez, 2003;

Northage, 2005), detecting sensor faults (Klimánek & Šulc, 2004, 2005; Lo, Wong, & Rad, 2006), and predicting crowd dynamics (Garrett et al., 2006; Langston, Masling, & Asmar, 2006; Muhdi et al., 2006). These design problems may involve single or multiple objective functions which are known or unknown, and Roy et al. (2008) discusses many of the current design challenges facing meta-heuristic optimization today. In each of the cases above, the objective to be maximized or minimized could be defined mathematically. However, some design problems depend largely, or even entirely, on the perception of humans (Dorris, 2004).

Interactive evolutionary computation (IEC) allows machine and human to work together to optimize a problem or design a solution. Parmee, Abraham and Machwe (2008) suggest that IEC is particularly suited to exploring open-ended concepts in design because the high level of human/machine interaction stimulates creativity and innovation. Takagi (2001) reports that IEC has been used to design music, hearing aids, clothing and animation, among others. He notes the superiority of IEC, rather than formulae defined by statistical regression, to search designs for which human perception or understanding is valuable. Carnahan and Dorris (2004) were the first to apply this technique to the design of safety warnings when they developed an IEC design tool to allow both English and Spanish-speaking sawmill workers to produce their own graphic symbols for two warning referents. Interactive evolutionary computation, specifically an interactive genetic algorithm, was a good design addition to the symbol design process because of its iterative nature observed by Wolff (1995). While the iterative nature of symbol design may improve the symbol quality (Zwaga & Mijksenaar, 2000), repetitive searches of the same search space are more well-suited to machines than to humans (Sanders &

McCormick, 1993). While these users had no previous experience designing hazard communication, Dorris (2004) was able to demonstrate that their individually-created symbol designs were statistically equivalent in estimated comprehension to symbols currently in use in industry.

Roy et al. (2008) states that many current design problems, such as complex mechanical systems, are complex enough that traditional EC algorithms cannot effectively solve them. A technique known as distributed evolutionary computation, which makes use of multiple processors in parallel to evaluate solutions (Rupela & Dozier, 2002), has provided substantial improvement to some of these iterative and complex design problems. This technique was applied to IEC by Dozier, Carnahan, Seals, Kuntz and Fu. (2005a; 2005b), which involved the evolution of design solutions using input from multiple participants simultaneously. Their experiment allowed 14 participants to design emoticons in parallel, comparing them to emoticons designed by individual users. The process uses an interactive distributed evolutionary algorithm (IDEA) to evolve solutions of multiple clients (e.g. participants) by using the judgment of one participant to affect newly proposed solutions to other participants. The IDEA is "distributed" because, rather than allowing only a series of individual participants to interact with the algorithm and evolve their own solution, many participants may interact in parallel, sharing information through the algorithm. This allows the IDEA to converge to single solutions that have incorporated multiple participants' judgments (Dozier et al., 2005a; Dozier et al., 2005b).

Essentially, adding a distributed element to the previous IEC design of safety symbols so that participants could design symbols in parallel would be analogous to

Macbeth and Moroney (1994) adding the focus group element to the production method. In each case, a design process existed that only allowed participants to develop symbol designs one at a time, with no interaction or shared information between other participants. Just as the focus group method produced more effective symbols in parallel than the serialized production method (Macbeth et al., 2000), it is anticipated that distributed interactive evolutionary computation, as a parallel search process, will produce the highest quality results. Thus, this dissertation explores the use of distributed IEC, specifically a distributed interactive genetic algorithm (DIGA), to replace the conceptual design focus group used in the focus group method..

Semantic Annotation and Clustering

One limitation of the previous research performed by Dorris (2004) is that the nature of search space provided to the IEC was defined by the investigators. While many have acknowledged the drawbacks associated with restricting the symbol design process to factors predetermined by designers (Dorris, 2004; Dowse & Ehlers, 2001; Huer, 2000; Smith-Jackson & Wogalter, 2007), it is understandable in this case since it is not practical to produce an IEC which draws on a blank canvas or searches an unbounded search space. The algorithm must have design variables upon which to search and construct solutions. In the case of Dorris (2004), these design variables took the form of an encoded vector of numerical angles and lengths which were converted to a graphical representation of a symbol when presented to the user. The determination of which variables to make available and their upper and lower bounds provided boundaries to the IEC search space, and these decisions were made largely on the basis of previously published symbol designs (Carnahan & Dorris, 2004). The implication to the participant of this encoding structure is that he or she is limited in his or her design to various combinations and permutations of the components already chosen by the investigators (in this case, to those found in the previously preferred design).

Participatory design strategies encourage the use of design participants in all feasible stages of the design process. Therefore, including participants in the determination of the design variables to be searched by the IEC represents an improvement in user participation in the design process. However, graphical symbols, even simple ones, represent complex pieces of data (Carneiro, Chan, Moreno, & Vasconcelos, 2007) for which the development of design parameters is not a simple task. Semantic annotation is a process which assigns qualitative attributes (i.e. descriptive terms) to complex pieces of information such as documents, music or photographs which often require a human to interpret (Carneiro & Vasconcelos, 2004; Turnbull, Liu, Barringon, & Lanckrie, 2007; Vasconcelos & Lippman, 2000a, 2000b). Semantic annotation has primarily been used to label information in a database for later search and retrieval (e.g. tagging photographs). However, the qualitative aspects of symbols (Wolff, 1995) combined with the need for the identification of design parameters to produce them with an IEC make the symbol design process an interesting opportunity for semantic annotation.

Hancock, Rogers, Schroeder and Fisk (2004) have already pioneered the use of participants to gather semantic phrases (i.e. qualitative attributes) related to symbols, though they used them to evaluate symbol effectiveness rather than to design symbols. Piper, Boelhouwer and Davis (2008) used an expert panel to attribute semantic terms to warning symbols in order to determine those symbols most salient characteristics. They then developed a matrix of row vectors each representing one symbol in the design pool and containing the presence or absence of each defined attribute. By replicating this method in the current study, this research aims to develop semantic annotations of symbol drawings in order to determine the most prevalent and interesting design criteria offered by those symbol sketches. From this information, the design variables for the proposed distributed interactive genetic algorithm (DIGA) can be determined based on participant design input rather than on designers' experiences or preferences.

Piper et al. (2008) reported the identification of at least 19, and as many as 27, design variables for each of the three symbol referents investigated in that study from only 38 symbol drawings available for each referent. In Dorris (2004), one symbol referent had only 16 variables, yet it still produced a search space of size 3.1×10^{31}. Thus, even with reduced resolution among the variables, it will quickly become necessary to reduce the size of the search space considerably, especially since fatigue among IEC users can set in quickly (Takagi, 2001). By transforming symbol sketches to an attribute matrix, as previously performed by Piper et al. (2008), the most primary design variables can be identified, and the remainder of variables reduced, through clustering.

It may at first seem counterintuitive or even redundant to use human subjective judgment to create data points and then systematically apply a formal clustering algorithm. However, Aggarwal (2004) suggests that for high-dimensional data that are inherently sparse in their solution space, a combination of human intuition and computerized clustering is the most optimal method of identifying data clusters. In the proposed procedure, the human panelists act as data reduction agents, greatly reducing the complexity of the data from millions of pixels to a simple one dimensional row of integers. Then, the clustering algorithm reduces the search space further by eliminating columns in the matrix which do not contribute to the clustering of the data.

Many clustering algorithms exist for grouping data into thematic families (Anil & Richard, 1988; H. M. Chan & Milner, 1981; Choi & Chang Hyo, 1993; Holman, Carnahan, & Thomas, 2006), and Frias-Martinez, Chen, Macredie, & Liu (2007) reviewed numerous studies using various clustering methods to group human factors data. K-means clustering is a relatively simple clustering technique that initially identifies a user-specified *k* random cluster centroids in the search space and assigns each solution to the nearest centroid. After assignment, the centroids are recalculated and the process repeats until a residual sum of square error function converges to a minimum value (Manning, Raghavan, & Schutze, 2008). Hierarchical clustering establishes a hierarchy or tree of clusters rather than a single layer. While a solution may only belong to one cluster in the same layer, higher order clusters usually contain two or more clusters of the next lower order, and so forth. Thus, a solution cannot be defined by its membership in a single cluster (Frias-Martinez et al., 2007). Fuzzy clustering, which includes the widely used Fuzzy C-means (FCM) technique, defines a fuzzy membership of each solution for each cluster in C. Centroids are recalculated based upon the fuzzy membership set, and the cluster or clusters to which a solution most belongs when the algorithm converges to a minimum value depending on its user-specified fuzzifier parameter, *m* (Bezdek, 1981). Finally, Frias-Martinez et al. (2007) introduces a novel method, robust clustering, which incorporates the clustering strategies of all three of the previous techniques, but only reports the clustering results when all three methods are in consensus.

For this research, a simple K-means algorithm was used from the Weka Data Mining Software suite (Hall et al., 2009) because it is simple to implement, is capable of handling a discrete data set and can report simple centroids of the multivariate symbol data which will be assumed to represent the most salient symbol attributes. As noted, the Weka simple K-means algorithm does require a predetermined number of clusters as an input into the algorithm. This cluster number, K, can be heuristically determined, however, by following a process described by Manning, Raghavan, and Schutze (2008). In this method, several clustering runs, each with different initialization points, are generated at each for each value in a range of likely K's. The actual number of clusters, K, is identified by plotting the residual sum of squares as a function of K and determining the value of K at which the curve's successive decreases become noticeably smaller. From the primary symbol attributes that can be identified using a semantic annotation and clustering process, the design variables and bounding criteria for the distributed interactive genetic algorithm (DIGA) can be identified (Roy et al., 2008).

Limitations of the Existing Research

Three primary limitations have been identified in the review of the existing literature. These limitations are reported in this section, and they are highlighted again in the manuscript chapters whose hypotheses address those limitations.

Lack of means to determine the ease of converting a referent to a symbol

Many factors have been identified to qualify and quantify warning symbols (Isherwood et al., 2007), and some of them have been shown to affect warning effectiveness (McDougall et al., 2000). While this research aims to develop and test a novel approach to symbol production, there is currently no direct means to identify sets of easy or difficult referents from which symbols can be developed. There are factors that attempt to evaluate a symbol's relationship to its referent (Hicks et al., 2003), but none attempt to determine which referents will be considered "easy" or "difficult" to turn into symbols. A specific aim of this research is to determine if referents can be distinguished based on their ease of conversion from referent to symbol.

Lack of participatory design in symbol production

Huer (2000) suggests that user participation in symbol production remains almost exclusively in evaluation of symbols rather than symbol development. Though some studies have recognized the need for meaningful participatory design (Dorris, 2004), there is still room for greater implementation of this design strategy. Previous research on the development of an interactive evolutionary computation design tool for symbol production using representative users made strides towards this goal, but there remains a gap between the current literature and complete participatory design in warning symbol development. This aim of this research is to narrow this gap by involving participants in defining the design variables used to create the search algorithm within the distributed interactive genetic algorithm. In this way, many of the restrictions placed on participants by the designers will be lifted in place of design criteria set by participants themselves.

Lack of IEC to model focus group method

The production method of symbol development (Green, 1993) is essentially a serial process where participants contribute to the design in isolation, never interacting with other designers or seeing the final designs. Dorris et al. (2004) used a similar technique with added interactive evolutionary computation to assist the individual in developing their design. The focus group method (Macbeth & Moroney, 1994) enhances the production method by allowing parallel interaction between users as they produce their symbols. A similar construct within IEC exists, known as distributed IEC (Rupela & Dozier, 2002), which allows for parallel searches and evaluations while working towards the same final solution. However, as yet there has been no attempt to model the focus group method using distributed IEC. This research aims to develop and test a distributed interactive genetic algorithm modeled after the focus group method to allow participants to produce symbol designs in parallel while sharing information and working towards a final design solution.

CHAPTER 3

DETERMINING A RANKED ORDER OF WARNING REFERENTS BY EASE OF CONVERSION FROM WRITTEN REFERENTS TO GRAPHICAL SYMBOLS

Introduction

According to Dorris (2004), the first step in producing a graphical warning symbol is to determine the referent safety message the symbol should portray. Similarly, when testing a new method of symbol development, it is important to carefully select the referents on which the design method will be evaluated. A robust design method should be able to produce high quality symbols from warning referents that are both easy and difficult to convert into graphical symbols. However, it is rare in the literature to find such a factor of association between referents and symbols. The relationship of a symbol to its referent, such as its concreteness or its semantic distance, has been used in many studies to predict or test symbol communicative effectiveness once a symbol has been generated (Isherwood, McDougall, J.P, & Curry, 2007; S. J. McDougall, Curry, & de Bruijn, 1999; S. J. P. McDougall, de Bruijn, & Curry, 2000; Young & Wogalter, 2001). It is conceivable in some instances there may exist a relationship between the referent's difficulty of conversion from text to graphical symbol and the developed symbol's effectiveness in communicating its message. However, evaluating an existing symbol's effectiveness, while important, is certainly very different than determining how difficult it might be to generate a new symbol from an original referent. In fact, only one study was found that sought to characterize symbols before they were generated, while in the written referent stage. Still with the goal of predicting symbol effectiveness rather than categorizing referent difficulty, Hicks, Bell and Wogalter (2003) defined the concept of “ease of visualization” as a scale of perception by potential users regarding the ease of imagining or visualizing the concept portrayed by a referent message. The study compared survey responses for 50 referents’ perceived ease of visualization and perceived concreteness, among other factors, and determined that ease of visualization correlated most highly with open-ended comprehension testing of the symbols produced from those referents. The authors recommended the use of both ease of visualization and concreteness perceptions as screening tools prior to symbol production to identify those symbols which may prove difficult to produce.

Ease of visualization, as used by Hicks et al. (2003), is not the same concept as ease of conversion from referent to symbol, which is defined in the current research. The previous study instructed survey respondents to rate their ease of visualizing or imagining the referent message itself (e.g. “radioactive” or “slippery surface”), whereas the current study focused on soliciting user perceptions of the ease of portraying a referent as a graphical symbol. A few studies have considered the concept that there may be aspects of certain referents that make them more difficult to convert to a symbol (Hicks et al., 2003; Mayhorn & Goldsworthy, 2007; McDougall et al., 2000). However, those authors only determined that certain abstract or complex concepts (e.g. the passage of time or conditional states) are considered difficult to portray pictorially. None of these studies attempted to assign a specific difficulty level to a particular symbol referent or to sort or rank a list of referents by their ease of symbol conversion, as the current study aims to do.

The purpose of the current research is to sort a list of written warning referents by their ease of conversion from referent to symbol. By selecting referents from this list, warning symbol design methods can be evaluated on referents that vary substantially in their relative perceived difficulty. In this way, comparisons of the quality of symbols produced by a one method over another will be less likely to be biased by the arbitrary selection of an *easy* or *difficult* referent. In other words, when testing a new symbol production method, selecting test referents from the list that are dissimilarly ranked can help ensure that the method is robust.

Methods

Objective and Hypotheses

The objective of this experiment is to sort a list of written warning referents by their relative ease of conversion from written referent to graphical symbol based on the perceptions of potential symbol users of varied safety experience. The hypotheses of the experiment are:

Hypothesis 1: There is no significant difference between the mean ranks of the perceived ease of conversion from referent to symbol of any of the nine warning referents.

H_0: $\mu_{referent\ 1} = \mu_{referent\ 2} = \ldots = \mu_{referent\ 9}$

H_1: $\mu_{referent\ 1} \neq \mu_{referent\ 2}$ or $\mu_{referent\ 1} \neq \mu_{referent\ 2}$ or …or $\mu_{referent\ 8} \neq \mu_{referent\ 9}$

<u>Hypothesis 2:</u> There is no significant association between the ranked order of referents made by university students, by uncertified safety professionals, and by certified safety professionals.

H_0: $\tau_{all\text{-}undergraduates} = \tau_{all\text{-}uncertified} = \tau_{all\text{-}certified} = \tau_{undergraduates\text{-}uncertified}$

$= \tau_{undergraduates\text{-}certified} = \tau_{uncertified\text{-}certified} = 0$

H_1: $\tau_{all\text{-}undergraduates} \neq 0$ or $\tau_{all\text{-}uncertified} \neq 0$ or $\tau_{all\text{-}certified} \neq 0$ or

$\tau_{undergraduates\text{-}uncertified} \neq 0$ or $\tau_{undergraduates\text{-}certified} \neq 0$ or $\tau_{uncertified\text{-}certified} \neq 0$

Experimental Design

In order to test these hypotheses, a randomized, balanced, 50% incomplete block experiment (Figure 3) was designed with the level of significance (α) set at 0.05. The independent variables were warning referent (*No Access for Persons with Metallic Implants*, *Warning: Flooring Surface Changes*, *Do Not Touch with Wet Hands*, *Confined Space— Entry by Permit Only*, *Steel-toed Shoes Required*, *No Reaching In*, *Disconnect Main Plug from Electrical Outlet*, *Hot Exhaust*, *Walk Down Stairs Backwards*) and safety

	1	2	3	4	5	6	7	8	9
1	1	■				■		■	■
2	■	1		■			■		■
3			1	■	■	■		■	
4		■	■	1	■	■			
5			■	■	1	■	■		
6	■		■	■	■	1			
7		■			■		1	■	■
8	■		■				■	1	■
9	■	■					■	■	1

Figure 3. A reciprocal table for a nine-treatment balanced incomplete block experiment.

professional status (*uncertified university students*, *uncertified safety professionals*, *BCSP certified safety professionals*) (BCSP, 2009). The response variable was relative rank of perceived ease of conversion from referent to symbol measured by pairwise comparison. Figure 3 illustrates the balanced, incomplete block design used in this experiment.

Subjects

A volunteer sample of 174 participants was recruited to participate in the study, out of which 145 participants completed the protocol. Twenty-nine participants were omitted from these results because they terminated participation prior to completion of the study. Participants were recruited in three strata. The uncertified university student stratum (55 participants) was recruited by email invitation to Auburn University's student population using the Department of Industrial and Systems Engineering undergraduate and graduate student email lists. The uncertified safety professional (44 participants) and certified safety professional strata (which includes 46 participants holding either the Associate or Certified Safety Professional designation) were recruited using email invitations to the membership of the American Society of Safety Engineers Region IV chapters. Participants were invited to read an online information letter approved by the Auburn University Institutional Review Board (IRB) prior to participation in the study. Participation was anonymous, with no directly identifiable information collected from any of the participants. Thus, all information used to stratify the participants was self-reported and not subject to verification by the investigators.

Experimental Instrument

An online survey was designed and revised through three pilot trials involving 46, 56 and 119 participants, respectively. A limited validation experiment (the equivalent of

3 blocks) was also conducted on the pilot results to estimate whether the survey results describing the expected perception of ease of conversion corresponded to the perceptions of actual symbol designers producing symbols for those same referents. The validation results, though limited, provided positive evidence that the referent rank order of ease of conversion after symbol production was similar to the rank order estimated by the survey participants beforehand. The survey was administered electronically by SurveyMonkey.com as a series of 18 pairwise comparisons (see Appendix 3.3 for a sample comparison set) in which participants compared the first listed referent message to the second by selecting one of these three options: 1) The first referent is more difficult to draw, 2) The two messages are equally difficult to draw, 3) The second referent is more difficult to draw.

The nine warning referents ranked by the survey participants were chosen to meet three criteria. First, three referents were chosen from each of the following types of warning: prohibited actions, mandatory actions, and hazard warnings (ISO, 2004). Second, referents were selected from a variety of occupational safety topical areas. Finally, referents were needed both which already had symbols available from ANSI or ISO and which did not have archived symbols available. The nine referents selected for the survey are shown in Table 1. Each referent was paired randomly with four other referents according to the randomized, incomplete block design (i.e. the non-shaded cells in Figure 3). Additionally, referents were randomly assigned as first or second member of each comparison pair. A complete copy of the survey instrument is found in Appendix 3.1.

Table 1

Referents used in the ease of conversion survey

Referent	Referent Type	29CFR1910 Subpart & Topic[†]	ISO 7010 Referent
No Access for Persons with Metallic Implants	Prohibited Action	G - Nonionizing Radiation	P014
No Reaching In	Prohibited Action	O - Machine Guarding	P015
Do Not Touch with Wet Hands	Prohibited Action	H - Hazardous Materials	*
Walk Down Stairs Backwards	Mandatory Action	D - Walking-Working Surfaces	N/A
Steel-toed Shoes Required	Mandatory Action	I - PPE	M008
Disconnect Main Plug from Electrical Outlet	Mandatory Action	S - Electrical	M006
Hot Exhaust	Hazard Warning	L - Fire Prevention	N/A
Warning: Flooring Surface Changes	Hazard Warning	D - Walking-Working Surfaces	N/A
Confined Space; Entry by Permit Only	Hazard Warning	J - Confined Spaces	N/A

* "Do not touch with wet hands" is not listed in ISO 7010, but ISO 3864-2 does provide a symbol for this referent as an example.

† 29 CFR 1910 includes the Occupational Safety and Health Administration (OSHA) regulations for general industry. These regulations are divided into subparts A – T & Z by safety topic.

Protocol

Participants were invited via email through group membership lists to navigate to a secure link at SurveyMonkey.com. Upon entry into the electronic survey, participants reviewed the study information letter (Appendix 3.2). Participants who wished to continue provided basic demographic and professional information to verify their membership in one of the three experimental strata, and instructions were presented.

Participants then reviewed written referents along with brief descriptions of the hazards involved, why such warning information is important in an occupational setting, and how a symbol portraying this information might be used. Since it might be difficult to articulate an absolute measurement of the difficulty of producing a symbol without actually doing so, participants were simply asked to estimate which of a pair of referents would be the more difficult from which to draw a symbol. Specifically, participants were prompted to select one of the referents as the more difficult to draw or to indicate that the two referents were equally difficult to convert to symbols. After evaluating each pair of referents, the users moved to a new page in the survey which presented a new referent pair for comparison using the same survey process. Eighteen pairs of comparisons were evaluated in this manner by each user. Each written referent was repeated four times within the survey, but two referents were paired together more than once. Of the 36 possible pairs of the nine referents, one half (18 pairs) were evaluated directly by each participant according to the balanced incomplete block design.

A modified analytical hierarchy process (AHP) was used to generate a ranked order of referent difficulty from the experimental results (Chen & Pu, 2004; Duke & Aull-Hyde, 2002; Fielding, Riley, & Oyejola, 1998; Lenton, 2007; Saaty, 1986; Teknomo, 2006; Zio, 1996), including a modification of the AHP for incomplete designs based on Kirkwood and Sarin's (1985) method. According to this procedure, for each participant's pairwise responses, a value of 5 is assigned to the "more difficult" referent while a reciprocal value of 1/5 is assigned to the "less difficult" referent. In the case of an equally difficult pair of referents, values of 1 are assigned to each referent, and a value of 1 is always assigned to the diagonal in the resulting reciprocal table. Using this numerical encoding system, the reciprocal table shown in Figure 3 can be completed for each participant, and from that table, the participant's rank order can be produced by simply summing the table rows. The highest sum receives a rank of 1, while the lowest sum receives a rank of 9. Referents with equal row sums receive an average of their rank positions (e.g. if two referents each have the highest row sum, then they each receive a rank of 1.5, which is the average of ranks 1 and 2). In this manner, each participant indirectly produces a ranked order of all nine referents.

Results

Using AHP, ranked orders of the nine referents' ease-of-conversion were produced from the survey results for each of the 145 participants, and this ranked data is found in Appendix 3.3. No assumptions regarding the distribution of this ranked data were made, and therefore non-parametric statistical tests were used to test the hypotheses. For Hypothesis 1, a Friedman's test was used to compare the mean ranks of each of the nine referents first across all 145 participants, then by the three individual strata. For each of these tests, the response variable was rank, the treatment variable was referent, the blocking variable was participant, and there were 8 degrees of freedom. At $\alpha = 0.05$, the Q statistic for all participants, adjusted for ties, exceeds χ^2_8 (338.54 > 15.51), which implies that a significant difference ($p < 0.001$) exists between at least two of the mean referent ranks. To determine which ranks differed significantly from one another, the post-hoc multiple comparisons test described by Connover (1999) and Bortz, Lienert and Boehnke (2000) was conducted (see Table 2 for results). For 32 of the 36 referent pairs, the difference in mean ranks exceeded the critical t-value (0.523), which indicates that these referents differed significantly in rank from one another. Only referents E, F and G and referents G and H (highlighted in Table 2) had non-significant differences in rank from one another, as indicated by the horizontal lines drawn above the statistically similar referents.

Table 2**.**

Post-hoc analysis results for All 145 participants; critical value = 0.523.

Referent	A	B	C	D	E	F	G	H	I
A. No Access for Persons with Metallic Implants	X								
B. Do Not Touch with Wet Hands	0.790	X							
C. Warning: Flooring Surface Changes	1.345	0.555	X						
D. Confined Space; Entry by Permit Only	2.121	1.331	0.776	X					
E. Disconnect Main Plug from Electrical Outlet	2.855	2.066	1.510	0.734	X				
F. No Reaching In	3.010	2.221	1.666	0.890	0.155	X			
G. Steel-toed Shoes Required	3.317	2.528	1.972	1.197	0.462	0.307	X		
H. Hot Exhaust	3.828	3.038	2.483	1.707	0.972	0.817	0.510	X	
I. Walk Down Stairs Backwards	4.366	3.576	3.021	2.245	1.510	1.355	1.048	0.538	X

Similar Friedman's tests were conducted to compare the mean ranks of the nine referents for the university, uncertified, and certified participant strata. For the 55 participants in the university stratum, the Q statistic, adjusted for ties, exceeds χ^2_8 (338.54 > 15.51), which implies that a significant difference ($p < 0.001$) exists between at least two of the mean referent ranks in this stratum. The post-hoc analysis results (Table 3) for the university stratum revealed significant differences between 23 of 32 comparisons. Those mean ranks which are statistically similar are highlighted in Table 3 and are connected by horizontal lines drawn above them. Similarly, for the 44 participants in the uncertified stratum (141.17 > 15.51) and the 46 participants in the certified stratum (118.14 > 15.51), the Q statistic exceeds χ^2_8 ($p < 0.001$) in both cases. Post-hoc analysis results for the uncertified and certified strata are presented in Table 4 and Table 5, respectively, and those comparisons that did not reveal significant differences are highlighted. The final ranked order of referents by ease of conversion from written referent to graphical symbol for each stratum is shown in Table 6.

Table 3.

Post-hoc analysis results for 55 University Students; critical value = 0.893.

							--------	--------	--------
						--------	--------	--------	--------
				--------	--------	--------	--------		
		--------	--------	--------	--------	--------			

Referent	A	C	B	D	G	F	E	H	I
A. No Access for Persons with Metallic Implants	X								
C. Warning: Flooring Surface Changes	1.389	X							
B. Do Not Touch with Wet Hands	1.518	0.129	X						
D. Confined Space; Entry by Permit Only	1.833	0.444	0.315	X					
G. Steel-toed Shoes Required	2.277	0.888	0.759	0.444	X				
F. No Reaching In	2.509	1.12	0.991	0.676	0.232	X			
E. Disconnect Main Plug from Electrical Outlet	3.287	1.898	1.769	1.454	1.01	0.778	X		
H. Hot Exhaust	4.064	2.675	2.546	2.231	1.787	1.555	0.777	X	
I. Walk Down Stairs Backwards	4.12	2.731	2.602	2.287	1.843	1.611	0.833	0.056	X

Table 4.

Post-hoc analysis results for 44 Uncertified Professionals; critical value = 0.880.

								--------	--------
							--------	--------	--------
						--------	--------	--------	
				--------	--------	--------	--------		

	--------	--------							
Referent	A	B	C	D	E	F	H	G	I
A. No Access for Persons with Metallic Implants	X								
B. Do Not Touch with Wet Hands	0.273	X							
C. Warning: Flooring Surface Changes	1.364	1.091	X						
D. Confined Space; Entry by Permit Only	2.545	2.273	1.182	X					
E. Disconnect Main Plug from Electrical Outlet	2.773	2.500	1.409	0.227	X				
F. No Reaching In	3.170	2.898	1.807	0.625	0.398	X			
H. Hot Exhaust	3.852	3.580	2.489	1.307	1.080	0.682	X		
G. Steel-toed Shoes Required	4.273	4.000	2.909	1.727	1.500	1.102	0.420	X	
I. Walk Down Stairs Backwards	4.761	4.489	3.398	2.216	1.989	1.591	0.909	0.489	X

Table 5.

Post-hoc analysis results for 46 Certified Professionals; critical value = 0.917.

Referent	A	B	C	D	E	F	H	G	I
							--------	--------	--------
						--------	--------	--------	
				--------	--------				
			--------	--------					
		--------	--------						
	--------	--------							
A. No Access for Persons with Metallic Implants	X								
B. Do Not Touch with Wet Hands	0.554	X							
C. Warning: Flooring Surface Changes	1.391	0.837	X						
D. Confined Space; Entry by Permit Only	2.141	1.587	0.750	X					
E. Disconnect Main Plug from Electrical Outlet	2.489	1.935	1.098	0.348	X				
F. No Reaching In	3.511	2.957	2.120	1.370	1.022	X			
H. Hot Exhaust	3.554	3.000	2.163	1.413	1.065	0.043	X		
G. Steel-toed Shoes Required	3.641	3.087	2.250	1.500	1.152	0.130	0.087	X	
I. Walk Down Stairs Backwards	4.435	3.880	3.043	2.293	1.946	0.924	0.880	0.793	X

Table 6

Ease of conversion rank order of nine referents by strata.

Stratum	Final Ranks of Ease-of-Conversion								
University Students	A	C	B	D	G	F	E	H	I
Uncertified Safety Professionals	A	B	C	D	E	F	H	G	I
Certified Safety Professionals	A	B	C	D	E	F	H	G	I
All	A	B	C	D	E	F	G	H	I

To test Hypothesis 2 to determine if these rankings were in agreement between strata, Kendall’s Tau-b (Pett, 1997) was used to determine concordance between the final ranked order of each pair of strata, and between each stratum and the overall rank. These results are shown in Table 7, and in each case, $\tau > 0.7$, the confidence intervals excluded the null value, and $p < 0.01$. Thus, it can be inferred that the rank order of ease-of conversion between all strata are concordant and that each stratum is concordant with the overall ranked order of the nine referents by ease-of-conversion from referent to symbol.

Table 7

Kendall's Tau-b concordance between strata for the final ranked order of referents.

Stratum	University			Uncertified			Certified		
	τ	CI	p-value	τ	CI	p-value	τ	CI	p-value
University	---	---	---						
Uncertified	0.722	0.344-1	0.006	---	---	---			
Certified	0.722	0.344-1	0.006	1	1-1	< 0.001	---	---	---
All	0.778	0.441-1	0.002	0.944	0.778-1	< 0.001	0.944	0.778-1	< 0.001

Discussion

The objective of this research was to determine whether a ranked list of written safety referents can be obtained based on their perceived ease of conversion from written message to graphical symbol. Additionally, since this ranking survey depended entirely on the perception of its responders, it was also desirable to determine the effect of previous safety experience on the ranking process.

Referent
1. No Access for Persons with Metallic Implants
2. Do Not Touch with Wet Hands
3. Warning: Flooring Surface Changes
4. Confined Space; Entry by Permit Only
5. Disconnect Main Plug from Electrical Outlet
No Reaching In
Steel-toed Shoes Required
Hot Exhaust
6. Walk Down Stairs Backwards

Legend
Prohibited Action
Hazard Warning
Mandatory Action

Figure 4. Final ranked order of warning referents by ease of conversion for all strata.

The results of the Friedman's and post-hoc analyses demonstrate that significant differences exist between the user-perceived difficulties of developing graphical symbols from certain warning referents. Furthermore, as illustrated in Figure 4, not all of the nine sorted referents were statistically distinguishable in ease of conversion from every other referent for these 145 participants. However, five of the nine referents were statistically different in ease of conversion from all other referents. Therefore, the final ranked order of referents shown in Figure 4 was generated considering those statistically similar referents as ties with essentially the same ease of conversion difficulty. While not all of the tied referents were statistically similar to every other tied referent, at least one was statistically similar to all others. From this list, symbol designers can select several combinations of referents that vary statistically in relative perceived difficulty. It is possible that an association exists between the type of referent (e.g. prohibited action) and its perceived difficulty to convert to a symbol, but this research did not investigate such an association.

Table 6 shows the nine referents sorted by their mean ranks regardless of statistical similarity for all three strata individually and combined. Both the uncertified safety professional and the certified safety professional strata produced identical ranked orders, each differing by one discordant pair from the rankings produced by all participants. In both cases, only the referents "Hot Exhaust" and "Steel-toed Shoes Required" were differently ranked from the results of all participants, and these two referents had statistically interchangeable mean ranks even among the entire sample of 145 participants. However, the university student stratum produced a ranked order that contained four discordant pairs of referents from those of all strata, including two discordant referents that were not statistically interchangeable. Though the concordance analysis suggests that there is a significant positive association between ranked order of the university stratum and the other strata, the Kendall's Tau value for the university-to-all comparison ($\tau = 0.778$) is substantially less than the Tau value for the other two strata ($\tau = 0.944$) when compared to the overall ranked order. This may suggest that safety experience, but not necessarily safety professional certification, is an important factor in developing a perceived ease of conversion factor.

Conclusion

This study surveyed three groups of participants—university students, uncertified safety professionals, and certified safety professionals—to investigate their ability to produce a ranked list of safety referents by estimating the difficulty of converting them into graphical symbols. Results of the study indicate that a simple ranked ordering of the written referents can be achieved using pairwise estimations of symbol design difficulty even when participants have not attempted to design an actual symbol. Substantial agreement was found between all participants, with essentially identical results found between uncertified and certified safety professionals. By using such a ranked list of referents, symbol designers can test symbol design methodology to ensure that it is equally valid for warning referents that are relatively easy to convert to symbols and for referents that may present substantial challenges.

This study generated only a relative ease of conversion between the nine referents considered. While an absolute ease of conversion factor that does not depend on any other referents would be valuable, such a factor developed from a perception survey would seem speculative. Limiting participants to a simple trinary comparison (more, less, or equally difficult) of referent pairs limits the output to a relative ranked order of the referents. But, this type of comparison minimizes the measurement bias that could occur from respondents attempting to estimate referent difficulty on a larger absolute scale when they have not actually attempted to draw any symbols. Thus, while it may be valuable to symbol designers as an estimator, this research has not validated perceived ease of conversion as a predictor of the actual difficulty in drawing or designing a symbol for the referent of interest. Future research should attempt to validate this estimation by combining a pre-design survey with an actual symbol production exercise. Following such an experiment, more absolute measures of ease of conversion from referent to symbol may become available. Further investigation could ascertain whether user perception accurately predicts user-experienced difficulty when attempting to produce a symbol. Additionally, various aids (e.g. photographs, hazard descriptions, etc.) could be added to the estimation survey to determine if such additions improve the ease of conversion estimate.

CHAPTER 4

SYNTHESIS AND CLUSTERING OF SYMBOL ATTRIBUTE MATRICES FROM HAND-DRAWN SAFETY SYMBOLS

Introduction

Most researchers recognize two, and in some cases three, primary techniques for producing the graphical symbols used in safety warnings (Dorris, 2004; Macbeth et al., 2000, 2006; Pettendorfer & Mont'alvao, 2006). The most traditional method of developing symbols, icons or pictograms is also the simplest. In this method, designers communicate their needs to a graphic artist who develops a set of symbols. Sometimes these symbol sets are tested for comprehension; sometimes they are put directly into practice without evaluating their communicative effectiveness (Ringseis & Caird, 1995; Roberts et al., 2009). Whether tested or not, this method is often iterative with symbols passed between designers, artists and test subjects multiple times before a symbol is finalized (Wisniewski et al., 2007). This paper will refer to this method as the *Designer Method*.

Another method of developing symbols involves the participation of potential users of the symbols in their design. This method, pioneered in the automobile and defense industries (Green, 1993; Howell & Fuchs, 1968; Karsh & Mudd, 1962; Mudd & Karsh, 1961), has been termed the *Production Method*. In this method, a sample of participants is asked to draw symbols individually from scratch for a set of referents. Rather than the symbol designers communicating their wishes and ideas to a graphic artist, the artist instead receives the drawings created by the participants. It is the responsibility of the artist to synthesize the themes found among the symbol drawings to create a final symbol or symbols from those themes. Green (1993) presents a thorough review of the early users of the production method, including actual line drawings produced in previous studies (Green, 1979; J. R. Sayer & Green, 1988).

While there have been several variants of this method (Green, 1993; Pettendorfer & Mont'alvao, 2006; Ringseis & Caird, 1995), some symbol designers have suggested that a distinct new method has emerged from the production method referred to as the *Focus Group* method. In this variant, rather than drawing symbols individually and passing them directly to a graphic artist, participants are organized into small focus groups where their drawing designs are revealed and discussed (Goldsworthy & Kaplan, 2006; Macbeth et al., 2000; Mayhorn & Goldsworthy, 2007). Based on this discussion, a consensus symbol design is produced within the focus group by the participants themselves. In this way, the group synthesizes the themes of the various participants into a consensus drawing with real-time input from the original designers of the candidate symbols. Its proponents suggest that this method removes from the graphic artist the responsibility of interpreting the thematic desires of the participants, instead placing that responsibility with the participants themselves. The graphic artist is called upon only to clean up and professionalize the drawings produced from the focus group (Dorris, 2004).

Human factors engineers and designers have found participatory design to produce better products, more suited to the needs and preferences of their potential users (Dewar, 1999). Applying this principle to the design of symbols suggests that the focus group method may produce the most effective symbols because this method allows its participants the most input and control over the design process. Some empirical research has supported this expectation (Macbeth et al., 2000; Pettendorfer & Mont'alvao, 2006). However, this method must overcome several challenges found in any focus group which can impede the ability of the group to perform its task. Three of these challenges, culture and language barriers, variations in prior experience and conflicting personality traits, seem particularly relevant because of their potential to suppress design ideas and to lead to symbol designs that are biased towards specific participants' preferences (Easton et al., 2003; Garmer et al., 2004; Klein et al., 2007; Newby et al., 2003; Sweeney et al., 1997). The current study attempts to overcome these challenges by introducing the DIGA method of symbol development.

A New Method Proposed

The proposed symbol design method involves the use of evolutionary computation to interact with a focus group of design participants by both producing suggested designs and consolidating the symbol designs of individual participants simultaneously, thereby acting as both a focus group participant and de facto group moderator. While the development and details of the DIGA design process are discussed elsewhere (Chapter 5 of this dissertation), its main objectives are to provide a computerized design interface to receive symbol designs from participants, share design concepts between participants, and to even propose new designs using a distributed interactive genetic algorithm (Dozier et al., 2005a). In this way, the reduction of design idea sharing caused by culture or language factors and dominant or quiet personalities (Sweeney et al., 1997) should be limited since all designs are treated equally with the same opportunity to be shared among the participants of the DIGA system with minimal need for verbal or written communication. Rather than creating designs from scratch, DIGA users instead develop symbols using a predetermined set of graphical attributes available for incorporation into their designs. The genetic algorithm receives, modifies and proposes new symbol designs to participants using group feedback from previous design combinations and permutations of these attributes. Since all users have the same attribute selections available to them regardless of referent familiarity, bias towards those with more experience with the safety referent should also be reduced (the background and design details of the genetic algorithm are discussed in Chapter 5 of this dissertation).

The purpose of this study is to identify the symbol attributes to be made available to DIGA participants. In a similar study, Dorris (2004) developed an evolutionary computation design tool which interacted with participants using a procedure similar to the production method. Participants could manipulate the orientation and size of the attributes to form a symbol; however, the symbol attributes available to those participants were chosen in advance, limiting the design possibilities to those conceived by the designers. To further minimize this bias, the current study expands the previous study's theme of participatory design by developing the graphical attributes available to the DIGA tool using participants themselves. To accomplish this, aspects of the original production method were utilized to produce symbol drawings upon a blank digital canvas prior to the development of the DIGA symbol design software itself. These drawings were not used to design specific symbols. Rather, they define the design parameters from which the DIGA design software can produce symbols. They can therefore be thought of as ancestral designs, or proto-drawings, from which all symbols produced by the DIGA tool in the future will be able to trace their heritage.

Methods

Objective

The objective of this experiment is to produce a set of semantic attributes that are capable of pictorially describing the centroid member of each cluster in a clustered set of safety symbols. The list of primary symbol attributes produced by this experiment will be used to develop the DIGA system by establishing the boundaries of the search space in which the DIGA algorithm is allowed to propose symbol designs. The three phases involved in the determination of these boundary attributes are explained in this section.

Phase 1 – Producing Symbol Proto-Drawings for Analysis

Phase 1 of this experiment recruited 72 participants to produce hand-drawn symbols from each of two written warning referents using a blank digital canvas, a method which is well established in the literature (Green, 1979, 1993; Karsh & Mudd, 1962; Mudd & Karsh, 1961; J. R. Sayer & Green, 1988; Wisniewski et al., 2007). Prior to the experiment, participants were allowed to view the information letter (Appendix 4.1) and ask questions about their role in the study. Each participant received both written and oral instructions (Appendix 4.2) and performed the experimental protocol individually.

Auburn University students were recruited for this study by email invitation to limited membership lists such as the Department of Psychology, the Department of Industrial and Systems Engineering, and the International Student Organization. In addition, more than 100 paper flyers were posted in public areas around the Auburn University campus inviting students to participate. Previous research (Piper et al., 2008) found that 30-40 symbol drawings provided enough information to synthesize a robust list of design attributes. However, a demographic stratification using country-of-origin was employed in the current study to explore cultural variation in the symbol drawing process. Therefore, participants were recruited in two strata, each with 36 members. Stratum #1 included participants who were current students in the U.S. but who were born and raised in India. India was selected because of the prevalence of its educated citizens who learn two or three languages simultaneously, English, Hindi and often a third native tribal language, in an immersive educational setting (Hadi-Tabassum, 2005; Raman, 2004). Stratum #2 included participants who were current students born in the U.S and educated in a primarily English language environment. All participants in both strata reported fluency with the English language for at least 5 years prior to the experiment. Participants were compensated $20 for their efforts.

To begin the symbol drawing process, each participant selected at random one of two written safety messages, which included a warning referent and a brief description of the hazard(s) to which the referent pertained (see Chapter 3 and Appendix 3.1 of this dissertation for examples of these descriptions). Since all participants were university students, investigators encouraged each participant to ask questions regarding the nature of safety warnings, symbols and of the hazards themselves. Participants used a SmartBoard 600i digital whiteboard to draw their symbols and were instructed to portray each warning message as a simple pictogram without using any numbers, text or symbols (e.g. $, %, etc.). Each participant received a tutorial on using the Smartboard 600i prior to making their drawing, and neither the investigators nor other participants were permitted to witness the drawing process. Investigators were available to answer questions or assist in case of a technical problem, and investigators verified periodically throughout the experiment that no questions or problems had arisen. When a participant announced that the first symbol was complete, the process was repeated using the second referent. After both symbols were designed in this manner, the participant was excused.

To ensure that the DIGA design tool could be tested on referents for which there were significant differences in expected symbol development difficulty, the two referents chosen for this experiment were selected from the referent list reported in the previous chapter. Figure 5 shows that the two referents selected for this study have significantly different relative ease of conversion on this ranked list of nine referents. In addition, these two referents were selected because they differed in referent type and in the availability of published, standardized symbols in the literature.

In total, 140 symbol drawings were produced in Phase 1 of this experiment, including 70 for each referent. Two drawings from each referent were omitted (see the Results section of this paper). While these symbol drawings will not serve directly as candidates for final symbol designs in the remainder of this dissertation, they did assist in the evolution of the DIGA design tool and, therefore, serve as ancestral designs, or proto-designs, from which future symbol designs will descend.

Referent	Referent Type	ISO Availability
1. No Access for Persons with Metallic Implants	Prohibited Action	Available
2. Do Not Touch with Wet Hands	Prohibited Action	Available
3. Warning: Flooring Surface Changes	Hazard Warning	Not Available
4. Confined Space; Entry by Permit Only	Hazard Warning	Not Available
5. Disconnect Main Plug from Electrical Outlet	Mandatory Action	Available
No Reaching In	Prohibited Action	Available
Steel-toed Shoes Required	Mandatory Action	Available
Hot Exhaust	Hazard Warning	Not Available
6. Walk Down Stairs Backwards	Mandatory Action	Not Available

Figure 5. The two warning referents selected for use in the current study, ranked by perceived ease of conversion from written to graphical forms (1 is the most difficult).

Phase 2 – Semantic Annotation

Phase 2 of the experiment convened a panel of trained engineers to evaluate the symbol drawings produced in Phase 1. Expert analysis and ratings have been used to evaluate symbols, including hand-drawn images, in previous studies (Dorris & Davis, 2003; Green, 1979; J. R. Sayer & Green, 1988; T. B. Sayer, 2002), but those evaluations were generally used to group symbols into tiers or to cull out the top designs. In the current study, expert panelists were used to develop a qualitative matrix of semantic attributes capable of adequately describing the significant components of each symbol drawing. Similar semantic annotation processes have been performed in other research domains involving the assigning of qualitative descriptors to visual or auditory content, such as the labeling or "tagging" of photographs for image search retrieval and the assigning of semantic descriptions to songs (Carneiro et al., 2007; Turnbull et al., 2007). In these two cases, the semantic annotation process was used to develop a list of keywords that could be used for later retrieval of artistic content.

To the best knowledge of the author, only one study has utilized semantic annotation of a content set as an antecedent to the design of new content (Piper et al., 2008). That research suggested that three panelists could perform this task effectively. Therefore, three panelists comprised the panel for the current study, each holding either an Associate or Certified Safety Professional designation (BCSP, 2009), and all panelists were trained prior to the experiment in the semantic annotation task, the nature of warning symbols, and the requirements of the DIGA software tool that will make use of the attributes found by the panel. Each panelist produced a matrix of qualitative symbol attributes (e.g. "person's body", "head only", "fan", "directional arrow", "puddle", etc.)

for each referent. The columns of the matrix represent the symbol attributes, and the matrix contains enough attributes to sufficiently describe each symbol drawing produced in Phase 1 of the experiment. Each drawing occupies a unique row in the matrix, and each cell in the matrix contains a binary response to the question, “Is this attribute present in this symbol drawing?” In addition to annotating symbol attributes and creating the attribute matrix, the panel also vetted each symbol drawing to ensure that it was not an example of an egregious error or critical confusion. In this protocol, egregious error simply represents a drawing resulting from a substantial misunderstanding or misrepresentation of the referent (e.g. drawing “slippery when wet” when the referent specifies “hot exhaust”). Critical confusion is defined as portrayal of the opposite message or a message that could lead to severe injury (ANSI, 2007a).

Each panelist followed the procedure provided in Appendix 4.3 to create a matrix for each referent, beginning with the first symbol in the first referent and continuing until all symbols had been evaluated in both referents. The symbol drawings were presented to panelists in random order without regard to country-of-origin, and panelists were not made aware of who created any of the drawings. A sample of the panelist’s data collection form can be found in Appendix 4.4. The three individual panelist matrices produced for each referent were then combined by summation to create a final consensus matrix for each referent. A sample row from this consensus matrix, which represents the complete combined semantic annotation of a single symbol drawing, is shown in Figure 6. Only the consensus matrices were analyzed further in Phase 3 of this experiment.

Drawing 1	3	1	3	0	3	0	0	0	0	2	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0

Figure 6. Row vector representing the semantic attributes of a single symbol drawing.

Phase 3 – Clustering of the Attribute Matrices

From the previous phase of the experiment, each symbol drawing was represented by a vector, $\vec{x}$, of integer values ranging from 0 to 3. The values contained in the vector represent the number of affirmative votes by the panelists for the presence of an attribute in the drawing (e.g. unanimously absent, present by minority, present by majority, unanimously present). The attribute matrices containing these representations were clustered using a simple K-means clustering algorithm, and only those attributes possessed by the median of each cluster were retained. Many clustering algorithms exist for grouping data into thematic families (Anil & Richard, 1988; H. M. Chan & Milner, 1981; Choi & Chang Hyo, 1993; Holman et al., 2006). Frias-Martinez, Chen, Macredie, & Liu (2007) reviewed numerous studies using various clustering methods to group human factors data. For this study, a simple K-means algorithm was chosen from the Weka Data Mining Software suite because it easily handled the discrete data set and could produce simple centroid values of multivariate data.

In their similar study, Piper et al. (2008) found six clusters among a comparable number of drawings using a direct clustering algorithm which does not require a prior assumption of the number of clusters (Holman et al., 2006). Since the Weka simple K-means algorithm does require a predetermined number of clusters, the cluster number, K, was selected considering the number of clusters found in the previous research and a heuristic process described by Manning, Raghavan, and Schutze (2008). In this heuristic, several clusterings, each with a different initialization point, are generated at each integer value of K in the range K = 2, 3, …, 8. The minimum value of the residual sum of squares, RSS, defined in Equation 1, among all the clusterings at each value of K is recorded as RSS(K). $\vec{\mu}$, defined in Equation 2, is the centroid of each cluster containing ω symbol vectors, represented by $\vec{x}$ vectors.

$$RSS = \sum_{k=1}^{K} \sum_{\vec{x} \in \omega_k} \left| \vec{x} - \vec{\mu}(\omega_k) \right|^2 \quad (1)$$

$$\vec{\mu}(\omega) = \frac{1}{|\omega|} \sum_{\vec{x} \in \omega_k} \vec{x} \quad (2)$$

In the heuristic method proposed by Manning et al. (2008), the actual number of clusters, K, is identified by plotting the discrete function RSS(K) and determining the value of K at which the curve's successive decreases become noticeably smaller. Using the "knees" in the curve to make this decision assumes that the primary objective of determining cluster quality is to minimize RSS. However, as Manning et al. (2008) admit, a minimal RSS may sometimes occur with clusters of only 1 symbol. Regardless of the value of RSS, for this study it is useful to define a minimum and maximum cluster size. The centroids of very small clusters (e.g. size 1 or 2) may overemphasize one or two outlying symbol drawings, while the centroids of overly large clusters (containing more than 50% of the symbols) may mask some of the interesting symbol design attributes.

To address this concern, in addition to the minimization of RSS, a second objective for determining the optimal cluster number, K, was defined. For each clustering run, the percentage of symbols, *s*, contained by the smallest cluster, ω_{small}, was compared to the percentage of symbols, *l*, contained in the largest cluster, ω_{large}. Equation 3 defines the ratio, r, where a value of 1.0 is considered optimal in which all clusters, ω_k, are the same size. Like RSS, direct comparisons are only meaningful between clusterings runs that have the same number of clusters (e.g. K=4). For this reason, the best (e.g. lowest) value of r for each set of clusterings, i, was denoted as $r_{\min_i}$. Likewise, the smallest value of RSS for each set of clusterings was denoted as $RSS_{\min_i}$. By comparing each RSS_i and r_i to the best values in that set of clusterings, d is defined in Equation 4 as a normalized larger-the-better decision variable used to determine the correct number of clusters, K.

$$r_i = \frac{l_i}{s_i} \tag{3}$$

$$\max \quad d_i = \textit{geometric mean} \left\{ \frac{r_{\min_i}}{r_i}, \frac{RSS_{\min_i}}{RSS_i} \right\} \tag{4}$$

By conducting i clustering runs on a set of symbols at each value of K, the run producing the highest value of d was selected as the best clustering of the data for that K. However, since d is a relative factor valid only for comparison within a set of i clusterings at the same value of K, each winning clustering run, i_K, was placed in set J. The overall best clustering was determined by the run in J containing the lowest value of r. At this point, all attributes which were absent in all cluster centroids were ignored, and the clusters were reproduced considering only the remaining attributes. These final attributes present in at least one cluster centroid in the final clustering run comprise the primary attribute set for that referent.

Results

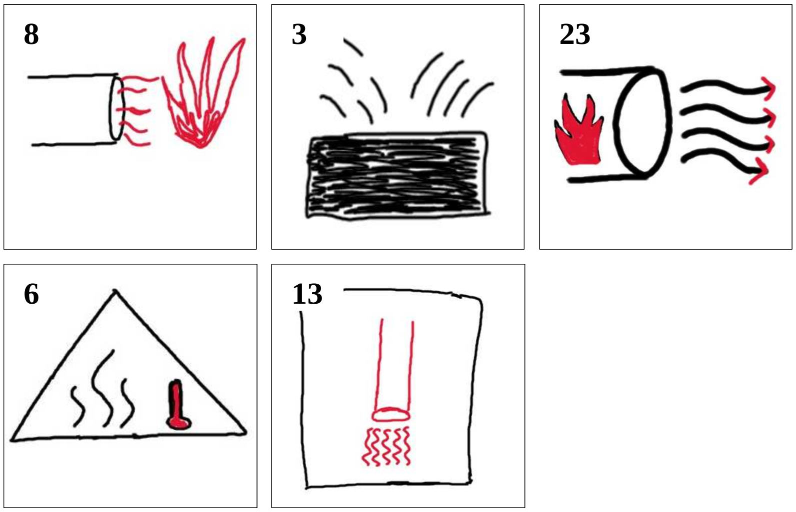
The purpose of this study was to determine sets of qualitative symbol attributes to be used to create design boundaries for the production of graphical symbols for the warning referents “Hot Exhaust” and “Do Not Touch with Wet Hands.” A total of 72 Auburn University student participants joined the study (36 from India and 36 from the U.S.). Each participant created two symbol drawings, one for each referent. However, two drawings from each referent were excluded due to a malfunction of the Smartboard system. For the “Hot Exhaust” referent, 35 drawings were recorded for both the U.S. and Indian strata; however, for the “Do Not Touch with Wet Hands” referent, both system failures occurred during drawings made by Indian participants. Thus, for this referent, there are 36 drawings from the U.S. stratum and 34 drawings for the Indian stratum. Appendix 4.5 contains these drawings, and Appendix 4.6 contains the attribute matrices produced by the expert panel’s analysis, including both the individual panelist matrices and the combined summation matrix for each referent. Table 8 summarizes the results of the panelists’ evaluations, including the percent disagreement, which is the percentage of

Table 8.

Semantic annotation summary of two drawing sets by a three-member panel.

Referent	Stratum	Total Symbols Considered	Discarded for Critical Confusion	Discarded for Egregious Error	Surviving Symbols	% Disagreement
Hot Exhaust	Indian	35	0	4	31	5.7%
	American	35	0	0	35	6.2%
	All	70	0	4	66	6.0%
Do Not Touch With Wet Hands	Indian	34	4	1	29	3.8%
	American	36	0	4	32	2.9%
	All	70	4	5	61	3.3%

Attributes	Attributes present in Cluster Median					
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	All
Emissions	Dissension	Unanimous	Unanimous	Unanimous	Unanimous	Unanimous
Pipe	Unanimous	Dissension	Unanimous		Unanimous	Unanimous
Flame	Unanimous		Unanimous			
# of Symbols	16	12	11	11	16	66



Hot Exhaust
Nearest Drawings to Cluster Medians

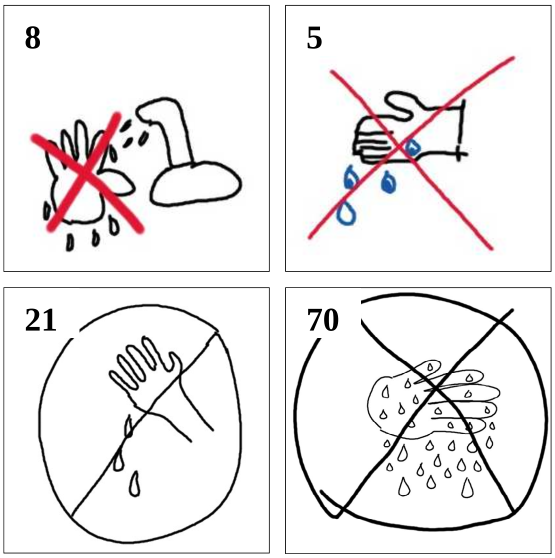
Cluster 1	#8
Cluster 2	#3
Cluster 3	#23
Cluster 4	#6
Cluster 5	#13

Figure 7. K-means cluster results from “Hot Exhaust” attribute matrix with combined strata, and the clustered drawings most nearly representing the centroids (medians) of each cluster.

all attribute ratings for which one dissenting panelist voted differently than the other two regarding the presence of that attribute in a particular symbol. Appendix 4.7 shows the symbols discarded for critical confusion and egregious error.

Figure 7 summarizes the results of the clustering analysis performed on the “Hot Exhaust” drawings. The drawings were grouped into five clusters whose centroids could be constructed from only three symbol attributes: Emissions, Pipe and Flame. Similar analysis was performed on the “Do Not Touch with Wet Hands” drawings, and a summary of those results is shown in Figure 8. These drawings were grouped into four

Attributes	Attributes present in Cluster Median				
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	All
Single Hand	Unanimous	Unanimous	Unanimous	Unanimous	Unanimous
Water Drops	Unanimous	Unanimous	Unanimous	Unanimous	Unanimous
Prohibition Symbol			Unanimous	Dissension	
Faucet	Unanimous				
Prohibition "X"	Unanimous	Unanimous		Dissension	
# of Symbols	7	23	25	6	61



Do Not Touch with Wet Hands

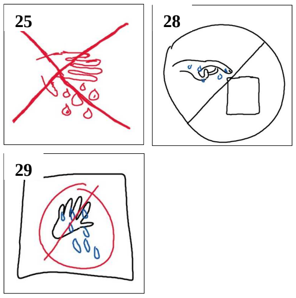
Nearest Drawings to Cluster Medians

Cluster 1	#8
Cluster 2	#5
Cluster 3	#21
Cluster 4	#70

Figure 8. K-means cluster results from "Do Not Touch with Wet Hands" attribute matrix with combined strata, and the clustered drawings most nearly representing the centroids (medians) of each cluster.

clusters whose centroids could be constructed from only five symbol attributes. The results of the clustering analysis are found in Appendix 4.8. The attribute matrices were also stratified by country-of-origin and clustered using the same technique. The results of the stratified clustering are summarized in Figures 9-10, and the detailed analysis results are available in Appendix 4.7.

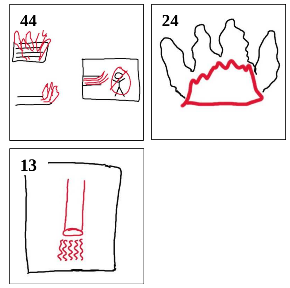
Attributes	Attributes present in Cluster Median			
	Cluster 1	Cluster 2	Cluster 3	All
Single Hand	Unanimous	Unanimous	Unanimous	Unanimous
Water Drops	Unanimous	Unanimous	Unanimous	Unanimous
Prohibition Symbol		Unanimous	Unanimous	Unanimous
Prohibition "X"	Unanimous			
2-D Panel		Unanimous		
# of Symbols	12	5	15	32



Do Not Touch with Wet Hands, U.S.
Nearest Drawings to Cluster Medians

Cluster 1 #25
Cluster 2 #28
Cluster 3 #29

Attributes	Attributes present in Cluster Median			
	Cluster 1	Cluster 2	Cluster 3	All
Emissions	Unanimous		Unanimous	Unanimous
Pipe	Unanimous		Unanimous	Unanimous
Person	Unanimous			
Flame		Unanimous		
# of Symbols	12	12	11	35

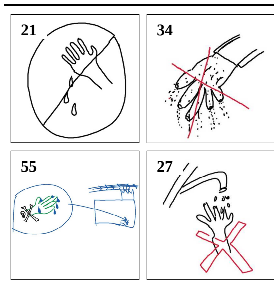


Hot Exhaust, US
Nearest Drawings to Cluster Medians

Cluster 1 #4
Cluster 2 #24
Cluster 3 #13

Figure 9. K-means clustering results for the U.S. stratification, “Do not touch with wet hands” referent (left) and “Hot exhaust” referent (right). Drawings most closely representing the centroids (medians) of each cluster are also included.

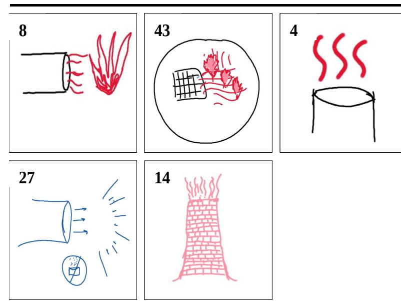
Attributes	Attributes present in Cluster Median				
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	All
Single Hand	Unanimous	Unanimous	Unanimous	Unanimous	Unanimous
Water Drops	Unanimous	Unanimous	Unanimous	Unanimous	Unanimous
Prohibition Symbol	Unanimous				
Faucet				Unanimous	
Prohibition "X"		Unanimous	Unanimous	Unanimous	Unanimous
Energized Equip.			Unanimous		
# of Symbols	10	11	4	4	29



Do Not Touch with Wet Hands, Indian
Nearest Drawings to Cluster Medians

Cluster 1 #21
Cluster 2 #34
Cluster 3 #55
Cluster 4 #27

Attributes	Attributes present in Cluster Median					
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	All
Emissions	Dissension	Unanimous	Unanimous	Unanimous	Unanimous	Unanimous
Pipe	Unanimous	Dissension	Unanimous		Unanimous	Unanimous
Flame	Unanimous		Unanimous			
# of Symbols	16	12	11	11	16	66



Hot Exhaust, Indian
Nearest Drawings to Cluster Medians

Cluster 1 #8
Cluster 2 #43
Cluster 3 #4
Cluster 4 #27
Cluster 5 #14

Figure 10. K-means clustering results for the Indian stratification, “Do not touch with wet hands” referent (left) and “Hot exhaust” referent (right). Drawings most closely representing the centroids (medians) of each cluster are also included.

Discussion

From the 70 “Hot exhaust” symbol proto-drawings, 35 qualitative graphical attributes were defined by the expert panel. From the clustering analysis of those 70 attribute vectors, three primary attributes were identified from which all five centroids of the five clusters can be constructed. Similarly, the 70 “Do not touch with wet hands” proto-drawings yielded 28 graphical attributes which were reduced to five centroidal, or primary, attributes by the clustering process. Table 9 lists these primary attributes for both referents.

The purpose of this study was to develop lists of primary attributes for incorporation into the DIGA symbol design tool. The referents in these lists are all that are needed to produce each cluster centroid $\vec{\mu}_k$, meaning these attribute lists are sufficient to produce at least k different symbol families representing the cluster centroids. Specifically, the three primary attributes identified for hot exhaust, when incorporated into the DIGA software, should allow at least five substantially different families of symbol designs to be produced (See Figure 7). Likewise, the five primary attributes identified for “Do not touch with wet hands” should allow at least four different families of symbols to be created (See Figure 8).

When the pool of symbol proto-drawings was stratified by country of origin and clustered separately, the resulting constituents of the primary attribute sets differed from those of the original clustering. In addition, the number of clusters varied by stratum, even for the same referent. Table 9 lists the primary attribute sets for the stratified data, and Figures 9 and 10 show a sample drawing for each cluster, the centroidal attributes describing the clusters, and the unanimity of each centroidal attribute.

Table 9.

Primary attribute sets that describe the centroid vectors of each symbol cluster.

	Stratum	Total Attributes in Stratum	Primary Attributes	Symbol Families (Clusters)
Hot Exhaust	Indian	25	Emission Lines Pipe/Stack Arrow Vent / Grate	5
	U.S.	33	Emission Lines Pipe/Stack Person Flame	3
	All	35	Emission Lines Pipe/Stack Flame	5
Do Not Touch with Wet Hands	Indian	22	Single Hand Water Drops Prohibition Symbol Faucet Prohibition "X" Energized Equip.	4
	U.S.	27	Single Hand Water Drops Prohibition Symbol Prohibition "X" 2-D Surface	3
	All	28	Single Hand Water Drops Prohibition Symbol Faucet Prohibition "X"	4

Table 10.

Attribute subsets by stratum.

	Universal	Recessive		Dominant	
		Indian	U.S.	Indian	U.S.
Hot Exhaust	Emission Lines Pipe/Stack	Arrow Vent/Gate	Person		Flame
Do Not Touch with Wet Hands	Single hand Water Drops Prohibition Symbol Prohibition "X"	Energized Equip.	2-D Surface	Faucet	

For each referent, there was a universal subset of attributes that appeared in both strata as well as in the combined data. This implies that the attributes in the universal subset may be less sensitive to cultural or country of origin factors. For the "Hot Exhaust" referent, the universal subset included two attributes: "Emission Lines" and "Pipe/Stack". For the "Do Not Touch with Wet Hands" referent, the universal subset included four attributes: "Single Hand", "Water Drops", "Prohibition Symbol" and "Prohibition 'X'". A second subset of attributes identified for each referent can be referred to as the dominant attribute subset. The attributes in this subset appear in both the combined data analysis as well as one of the strata. However, these attributes do not appear in the other stratum. There was one member of the dominant attribute subset for each referent, "Flame" for "Hot Exhaust and "Faucet" for "Do Not Touch with Wet Hands". Finally, a recessive subset of attributes was also identified. As the name implies, these attributes only appear in an individual stratum. They do not appear in the opposite stratum or in the combined data set. For "Hot Exhaust", there were three total recessive attributes—two found in Indian stratum ("Arrow" and "Vent/Gate") and one found in the U.S. stratum (Person). Only two total recessive attributes were identified for

“Do Not Touch with Wet Hands”, “Energized Equipment” in the Indian stratum and “2-D Surface” In the U.S. stratum. Table 10 summarizes these attribute subsets.

Certainly, the universal subsets of attributes should demand primary interest when designing warning symbols for a diverse population since they were found in the centroids of both strata of participants. The insensitivity of some attributes to country of origin suggests that symbols may be able to bridge at least some of the cultural barriers to risk communication. However, the presence of the recessive and dominant subsets of attributes seems also to reinforce the notion that symbols are not completely culturally neutral.   Nevertheless, the process demonstrated in this study of identifying the universal and non-universal attributes should be valuable to symbol designers attempting to work with diverse populations

Conclusions

Developing a symbol design tool that utilizes evolutionary computation to assist design participants has the potential to capitalize on the benefits of participatory design. However, in order to receive the best design concepts from the participant designers, investigators must do everything possible to minimize investigator bias. By developing primary attribute subsets in this experiment, a new symbol design tool can be constructed that will both engage the participant designer in innovative ways and reduce the investigator’s input in selecting the design parameters. Future research should investigate the incorporation of these symbol attributes into an actual distributed interactive genetic algorithm interface. In order to do so, certain decisions must be made regarding the manner in which the attributes found in this study should be encoded in the software. For example, how should the attribute "Single Hand" be portrayed by the DIGA design tool?

The results of this study imply that there may be a relationship between the specific graphical attributes appearing in symbol drawings and country of origin. This study did not investigate the nature of this relationship, should it exist. Future research should explore this relationship across a variety of nationalities as well as other similar factors, such as cultural and language experience. Furthermore, this study included only novice university students with relatively little design experience as the generators of the symbol drawings. While participatory design principles suggest that the inclusion of realistic users in the design process, in this case the general population, is likely to improve the design, it is possible that participants unfamiliar with the hazards but skilled in industrial or graphic design might produce different symbol drawings for these referents. Future studies should compare the attribute matrices generated from participant groups of various experiences in product or system design. Finally, though the sample size used in this study proved adequate in previous research, the multivariate nature of the computational analysis would benefit from more data. Future research should consider producing additional symbol drawings for the same two referents used in this study so that greater clustering resolution can be achieved.

CHAPTER 5

DEVELOPING AND TESTING A DISTRIBUTED INTERACTIVE GENETIC ALGORITHM TO DESIGN SAFETY WARNING SYMBOLS

Introduction

Evolutionary computation (EC) is a form of artificial intelligence that has been typically used to solve complex optimization problems by utilizing principles of biological evolution to evolve problem solutions in a large solution space (Dreo et al., 2003; Rees & Koehler, 2006). EC has been applied to human factors and safety problems such as avoiding pilot error (Chouraqui & Doniat, 2003), estimating chemical exposures (Johnston et al., 2005; Nomen et al., 2003; Northage, 2005), detecting sensor faults (Klimánek & Šulc, 2004, 2005; Lo et al., 2006), and predicting crowd dynamics (Garrett et al., 2006; Langston et al., 2006; Muhdi et al., 2006). A genetic algorithm (GA) is a particular implementation of evolutionary computation that emphasizes natural selection and random mutation to search a population of solutions using a survival of the fittest approach (Goldberg, 1989). Genetic algorithms are among the more common forms of EC.

While traditional evolutionary computation attempts to optimize a mathematical function, interactive evolutionary computation (IEC) instead attempts to optimize performance of a system that requires subjective human evaluation (Takagi, 2001). In human factors, there is often an element to system performance that depends on human preference or subjectivity. IEC allows machine and human to work together to optimize these systems and to design solutions to these kinds of problems. Furthermore, the involvement of potential users of a product or system in its design, known as participatory design, is believed to improve the quality of the final products (Schuler & Namioka, 1993). Parmee, Abraham and Machwe (2008) suggest that IEC is particularly suited to exploring open-ended concepts in participatory design because the high level of human/machine interaction stimulates creativity and innovation.

The design of safety warning symbols has long made use of participatory design to develop and evaluate symbol candidates because it is believed to produce the highest likelihood of meeting symbol comprehension criteria (ANSI, 2007a; Green, 1993; ISO, 2007). The design process generally includes the identification of a safety message to portray as a symbol, the production of simple sketches of possible designs, the analysis of these designs for thematic elements, and the evolution of final designs representing the identified themes (ANSI, 2007a; Dorris, 2004; Green, 1993). Depending on the design method, human participants representative of potential symbol users can be involved in one or more of these design phases (Green, 1979; Macbeth et al., 2000). The process of evaluating potential symbol designs to determine one or more best designs is essentially a search task that incorporates user subjective assessment of symbol quality as its fitness function.

Carnahan and Dorris (2004) were the first to apply evolutionary computational search to the design of safety warnings when they developed an IEC design tool to allow both English and Spanish-speaking sawmill workers to produce their own graphic symbols for two warning messages, or referents. While these users had no previous experience designing hazard communication, Dorris (2004) was able to demonstrate that their individually-created symbol designs were statistically equivalent in estimated comprehension to symbols currently in use in industry. The Carnahan and Dorris (2004) IEC search algorithm was similar in design intent to the production method of symbol design which recruits many participants to produce independent symbol designs that are evaluated by designers to produce a final design. By replacing the human search task of identifying the best symbol from an infinite set of undrawn possibilities with an IEC search that evolves a symbol design fit to each user, Carnahan and Dorris (2004) began the process of transforming the symbol design system.

A new approach to IEC design was developed by Dozier et al. (2005b), which involves the evolution of design solutions using input from multiple participants simultaneously. The process uses an interactive distributed evolutionary algorithm (IDEA) to simultaneously evolve solutions of multiple participants by incorporating the judgment of one participant into the genetic material available to other participants. The design space shared by the participants where symbol designs are mated and mutated was labeled *Meme Space* (Dozier et al., 2005b).   Prior to this work, distributed evolutionary computation had primarily focused on decreasing computation time for complex problems by running the EC search simultaneously on many processors (Rupela & Dozier, 2002). The IDEA algorithm of Dozier et al. (Dozier et al., 2005b) is "distributed" because, rather than allowing only a series of individual participants to interact with the algorithm and evolve their own solution, many participants may interact in parallel. This allows the IDEA to converge to single solutions that have incorporated multiple participants' judgments (Dozier et al., 2005a).

Participatory design of warning symbols has also progressed in its design strategies. Macbeth et al (2000) proposed the focus group method of symbol development which allows a group of 6-12 participants to develop symbol designs in parallel, sharing and critiquing ideas verbally and on paper until a final group design is chosen. Just as the production method was analogous to IEC, the focus group method of parallel, shared symbol design is similar in strategy to the distributed IEC pioneered by Dozier et al. (Dozier et al., 2005a). Thus, this study explores the use of distributed interactive evolutionary computation, specifically a distributed interactive genetic algorithm (DIGA), to computationally model the focus group method of symbol design developed by Macbeth et al. (2000).

The Algorithm

The search for high quality symbol designs is almost certainly a non-polynomial hard, multivariate problem involving an unknown mathematical formulation of a single participant's judgment. Furthermore, the problem becomes multi-objective when it must attempt to optimize the various subjective judgments of a group of 6-12 participants, in the case of the focus group method (Macbeth & Moroney, 1994; Macbeth et al., 2000). Fortunately, Dozier et al (2005a) developed a distributed interactive evolutionary algorithm (IDEA) to computationally model a very similar process. The IDEA was designed to evolve emoticons (e.g. "smilies"), and the IDEA pseudo code is shown in Figure 11. To design emoticons, IDEA participants received 9 randomized initial emoticons from the system. The user responded by selecting their favorite emoticon, *e*, and a preferred mutation operator, *o*. The user submitted emoticon *e* to the Meme space server and received a random emoticon from Meme space, *m*. Emoticons *e* and *m* became the parents for 7 daughter emoticons, 4 generated by mutation using the specified operator *o*, and 3 by recombination, which in this case was blend crossover (Eshelman & Schaffer, 1993). This process repeated until the user determined the process was complete.

```
Procedure IDEA_Client {
        t = 0
        Initialize Pop(t)              // Randomly generate initial emoticons
        Present Pop(t) to User;
        While (Not Done)
        {
                Allow user to select an emoticon(e);
                Allow user to select a mutation_op(o);

                Send(e) to MEME space;
                Receive(m) from MEME space;

                Parents(t) =  {e,m}
                Offspring(t) = {
                                Create 4 Mutants(e,o);
                                Create 3 Recombinations(e,m,o);
                                }


                Pop(t+1) = Parents(t) ∪Offspring(t):
                t = t+1;
        }
}
```

Figure 11. IDEA pseudo code (Dozier et al., 2005a).

Selection, Crossover and Mutation in the DIGA Algorithm

In order to computationally model the focus group method of Macbeth et al. (2000), a simple genetic algorithm employing two-point crossover and single-point mutation (Goldberg, 1989) at the server level was combined with a client graphical interface similar to that used by Dozier et al. (2005a). However, this distributed interactive genetic algorithm (DIGA), unlike the IDEA emoticon algorithm shown in Figure 11, handles the majority of the computational steps on the server side. The client interface is primarily used to solicit participant design evaluations. Flow charts of the server and client portions of the algorithm are shown in Figures 12 and 13, respectively.

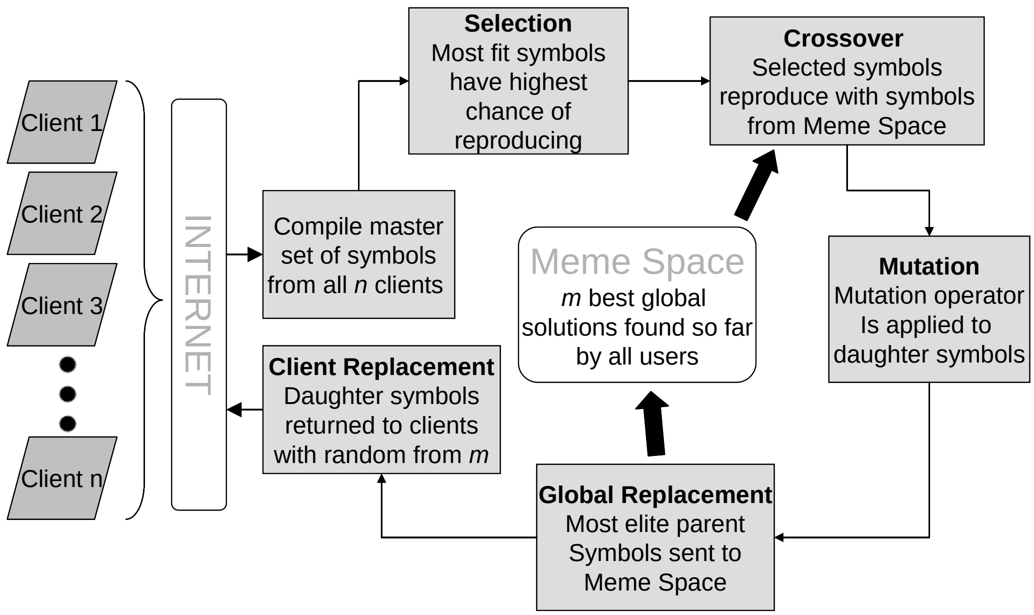


Figure 12. Server-side DIGA Flow Chart.

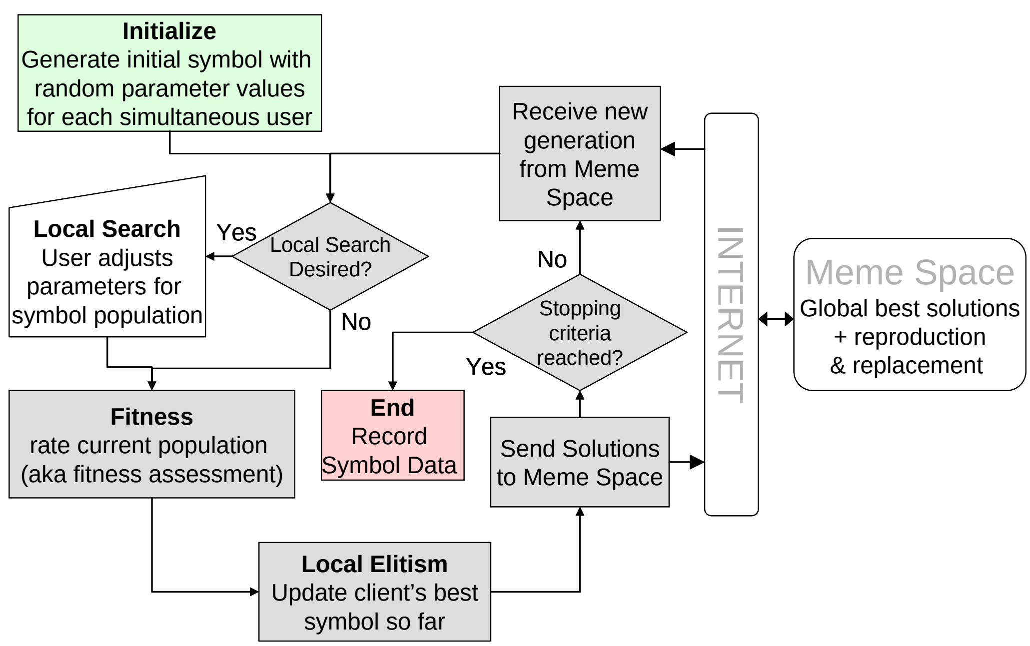


Figure 13. Client-side DIGA Flow Chart

```
Procedure DIGA_Server {
        Initialize Server(g,c,)             // Max # of generations & # of clients
        t = 0;
        For all clients(c) {
                Initialize Pop(c,t);        // Randomly generate initial 9 symbols
        }

        While (t < g) {
                Send Pop(c,t);              // Deliver symbols to clients
                For all clients ∈ c {
                        For all i ∈ [1,9] {
                                User selects ith most favorite symbol, s(c,i)
                        }
                }
                Send[s(c,i)] to Meme space;

                Elitism(t) = s(c,1) + s(c,2) for all clients ∈ c;
                                // Preserve 1st & 2nd favorites of each client

                Begin_Tournament(t) {
                        P[s(c,i)] = (10-i)/45;   // Assign selection probabilities
                        While j < 7*c {          // Make 7 offspring per client
                                Select Candidate1(P);
                                Select Candidate2(P);
                                Parent(j) = candidate with lower rank, i;
                                j = j+1
                }

                While k < 7*c {
                        Offspring(t) = Crossover[Parent(k), Parent(k+1)];
                        Mutate_Offspring(t);
                        k = k+2;
                }

                Pop(t+1) = Elitism(t) ∪ Offspring(t):
                t = t+1;
        }
```

Figure 14. Pseudo code for DIGA symbol design algorithm

DIGA pseudo code is shown in Figure 14. To design warning symbols, each DIGA participant receives 9 randomized initial symbols from the system. The participant responds by selecting their favorite symbol based on how well it portrays the written message (i.e. the referent) provided on the screen. The participant *c* repeats the ranking of the next best symbol until all symbols (*i*=1-9) have been ranked, *s(c,i)*. The symbols are then submitted to the server, which is analogous to Meme space of Dozier et al. (2005a). Symbols s(c,1) and s(c,2) from each participant are preserved; the 1st ranked symbol returns to its original participant and the 2nd ranked symbol is submitted to any participant at random. The remaining symbols in the population are replaced by the two-point crossover shown in Figure 15. Each parent in the crossover is the winner of a selection tournament in which a pair of symbols is chosen randomly and compared. The symbol ranked higher by its participant wins the job, and ties are broken randomly.

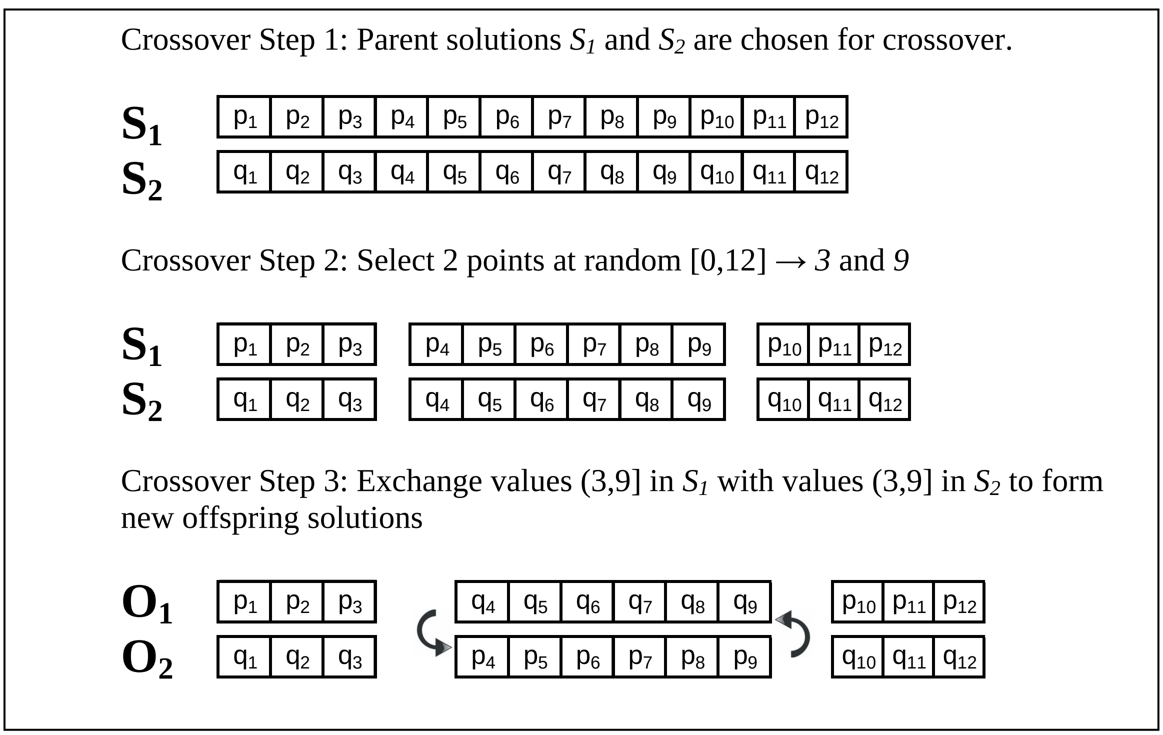


Figure 15. Illustration of two-point crossover.

At the conclusion of the crossover, parents have been selected and recombined to replace the seven lowest ranked symbols for each client, (e.g. ranks 3-9). These symbols are now subject to mutation. A mutation probability specific to the experiment is applied so that only a fraction of newly formed offspring experience mutation. If an offspring symbol is selected for mutation, a single variable allele in the genome (Figure 16) is changed to a new value in its range with uniform probability for any single value. After all applicable offspring are mutated, the offspring are combined with the elitist symbols preserved from the previous generation and resubmitted to the clients as generation t+1. Each client receives nine symbols to evaluate as the next generation, including his pervious top ranked symbol, a randomly chosen 2nd ranked symbol from any client, and 7 randomly chosen offspring who have just undergone crossover and mutation. To maintain continuity in the number of symbol designs searched from one participant session to the next, the algorithm repeats until a maximum number of generations specified at the start of each experiment is reached.

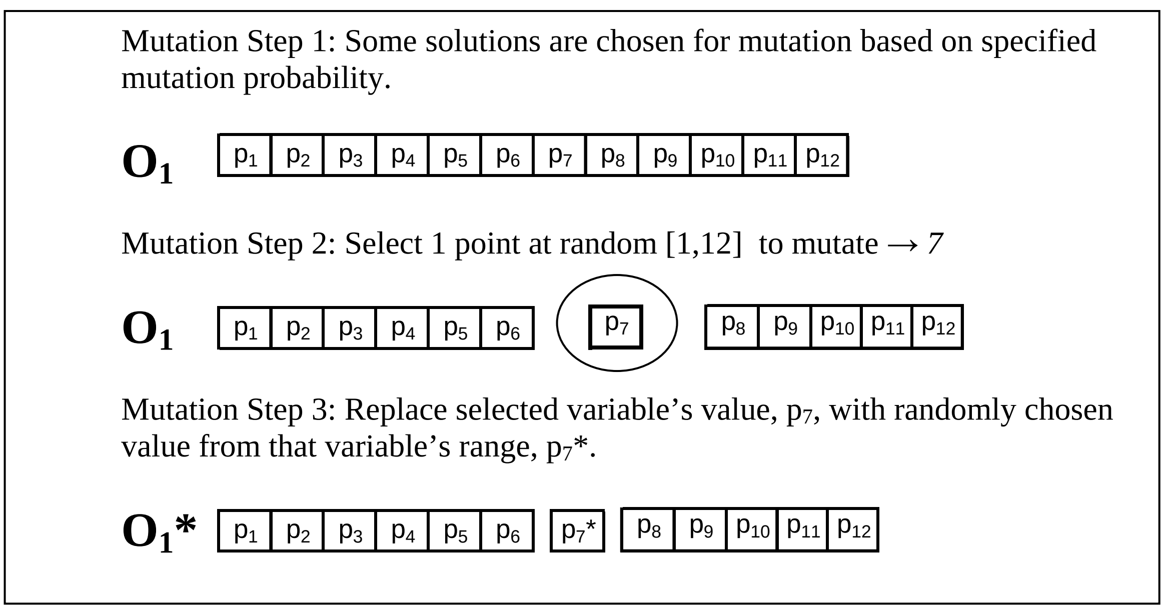


Figure 16. Illustration of single-point mutation.

Encoding the DIGA Genotype for Warning Symbols

Two implementations of the DIGA algorithm were developed, each implementation capable of designing a different safety symbol. Based on the procedure performed in Chapter 4 of this dissertation, the warning referents “Hot Exhaust” and “Do Not Touch with Wet Hands” were selected. Evolutionary computation involves both solution encoding into a genotype and decoding into a phenotype. In this case, the solution phenotype for each implementation is the graphical symbol presented to the participant on the client side of the system. However, in order for the server side of the algorithm to perform its computations, the solution must be encoded into its genotype.

To ensure that the DIGA produces symbols representative of the design participants wishes from the previous experiment, the primary design variables determined by the clustering process (Chapter 4, Table 9), such as “flame” or “pipe” for Hot Exhaust, are included in the phenotype. However, the design parameters themselves must be converted to a range of realistic parameters. Returning to the participants’ symbol drawings and expert panel analyses presented in Appendices 4.5 and 4.6, the range of each primary design parameter was determined. From a review of this information, the solutions for each DIGA implementation were encoded as vectors of integer values shown in Figure 17. The design parameters, their description, their ranges and their resolutions between adjacent values are presented in Tables 11 and 12.

Hot Exhaust:	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}	p_{12}	
Do Not Touch with Wet Hands:	q_1	q_2	q_3	q_4	q_5	q_6	q_7	q_8	q_9	q_{10}	q_{11}	q_{12}	q_{13}

Figure 17. Genotype encoding of both symbol phenotypes.

Table 11.

Design Parameters of the Hot Exhaust genotype.

Parameters	Description	Range	Resolution
p_1	Size of the Flame (width in pixels)	[20,70]	10
p_2	Horizontal position of Flame (pixels)	[60,440]	20
p_3	Vertical position of Flame (pixels)	[60,400]	20
p_4	Diameter of the Pipe (pixels)	[20,100]	10
p_5	Length of the Pipe (pixels)	[25,65]	5
p_6	Angular Orientation of Pipe (degrees)	[0,360]	30
p_7	Breadth of Pipe Spray (pixels)	[5,65]	5
p_8	Length of Pipe Spray (pixels)	[25,65]	5
p_9	Pipe Visibility Toggle (on/off)	[0,1]	1
p_{10}	Spray Visibility Toggle (on/off)	[0,1]	1
p_{11}	Flame visibility Toggle (on/off)	[0,1]	1
p_{12}	Type of Spray Lines (dashed, dotted, solid, wavy)	[1,4]	1

Table 12.

Design Parameters of the Do Not Touch with Wet Hands genotype.

Parameter	Description	Range	Resolution
q_1	Size of the Hand (width in pixels)	[50,120]	10
q_2	Angular Orientation of Hand (degrees)	[0,360]	30
q_3	Size of the Water Droplets (width in pixels)	[20,80]	10
q_4	Size of the Faucet (width in pixels)	[20,60]	10
q_5	Horizontal Position of Faucet (pixels)	[50,240]	10
q_6	Vertical Position of Faucet (pixels)	[50,150]	10
q_7	Diameter of the Prohibition Symbol (pixels)	[30,100]	10
q_8	Hand visibility Toggle (on/off)	[0,1]	1
q_9	Droplet Visibility Toggle (on/off)	[0,1]	1
q_{10}	Faucet Visibility Toggle (on/off)	[0,1]	1
q_{11}	Prohibition Symbol Visibility Toggle (on/off)	[0,1]	1
q_{12}	Type of Hand (flat palm, reaching, pointing)	[1,3]	1
q_{13}	Type of Prohibition Symbol (circle/slash, circle/x, lone x)	[1,3]	1

The genotype described above for “Hot Exhaust” produces a search space that includes 12 parameters and more than 8.2×10^9 possible solutions. Similarly, the “Do

Not Touch with Wet Hands" genotype includes 13 parameters and more than 4.6 x 10^6 possible solutions. By developing first the phenotype, then the genotype, based on participatory design methods rather than on simply the insights of the researchers, the search space for each of these referents has been constrained by more representative boundaries.

Methods

Objectives and Hypotheses

The objectives of these three experiments are to determine whether a DIGA can be used by novice participants to develop and converge warning symbol designs and to compare symbols designed by DIGA with those designed by more traditional methods. The hypotheses of the experiment are:

Hypothesis 1: There is no significant difference between subjects in the coefficient of variation of symbol parameter values of favorite symbols between the first and final generations.

H_0: $\frac{\sigma_{Gen1}}{\mu_{Gen1}} = \frac{\sigma_{Gen20}}{\mu_{Gen20}}$ for all design parameters and all referents

H_1: $\frac{\sigma_{Gen1}}{\mu_{Gen1}} > \frac{\sigma_{Gen20}}{\mu_{Gen20}}$ for all design parameters and all referents

Hypothesis 2: There is no significant difference in the preference ranking between DIGA designed symbols and Focus Group designed symbols.

H_0: $\rho_{DIGA} = \rho_{FG}$

H_1: $\rho_{DIGA} \neq \rho_{FG}$

<u>Hypothesis 3:</u> There is no significant difference in the preference ranking between DIGA designed symbols and published symbols.

H0: $\rho_{DIGA} = \rho_{published}$

H1: $\rho_{DIGA} \neq \rho_{published}$

<u>Hypothesis 4</u> There is no significant difference in the preference ranking between DIGA symbols when stratified by country of origin.

H0: $\rho_{Multi} = \rho_{U.S.} = \rho_{India} = \rho_{China}$

H1: $\rho_{Multi} \neq \rho_{U.S.} \neq \rho_{India} \neq \rho_{China}$

Experiment #1 – DIGA

Subjects. The DIGA algorithm is modeled after the focus group method of participatory symbol design proposed by Macbeth and Moroney and Macbeth et al. (1994; 2000). They found that using 6 – 12 participants provided enough design diversity without the process becoming cumbersome. For comparison, Experiment #1 recruited four groups of 12 Auburn University students each (N=48) to participate in a DIGA design session, each group representing a different treatment of the independent variable *country of origin*. Participants were recruited by email to departmental mailing lists within the university as well as a by flyers posted on public boards around the university campus. Each participant was paid $40 for two hours of effort.

Group 1 consisted of a heterogeneous mix of participants that included two participants from China, Turkey, Sri Lanka and the U.S., and one participant each from India, Mauritius, Korea, and Chile. Groups 2 – 4 were homogeneous groups of participants who hailed from the same nation. Group 2 consisted of 12 participants from the U.S. Group 3 consisted of 10 participants from India (two participants withdrew before the study began) who were attending graduate school in the U.S., and Group 4 consisted of 12 participants from China also attending graduate school in the U.S. All participants reported at least moderate fluency with the English language, and all participants were at least 19 years of age.

Experimental Apparatus. The experiment was conducted using a series of networked computers running the Linux operating system. The DIGA was coded in the *Java* programming language, and the graphical user interface operated by the participants is shown in Figure 18. One computer served as the server and was operated by the investigators. Each participant performed the experiment individually on his or her own client computer, and the participants' only interactions with the system were to select the

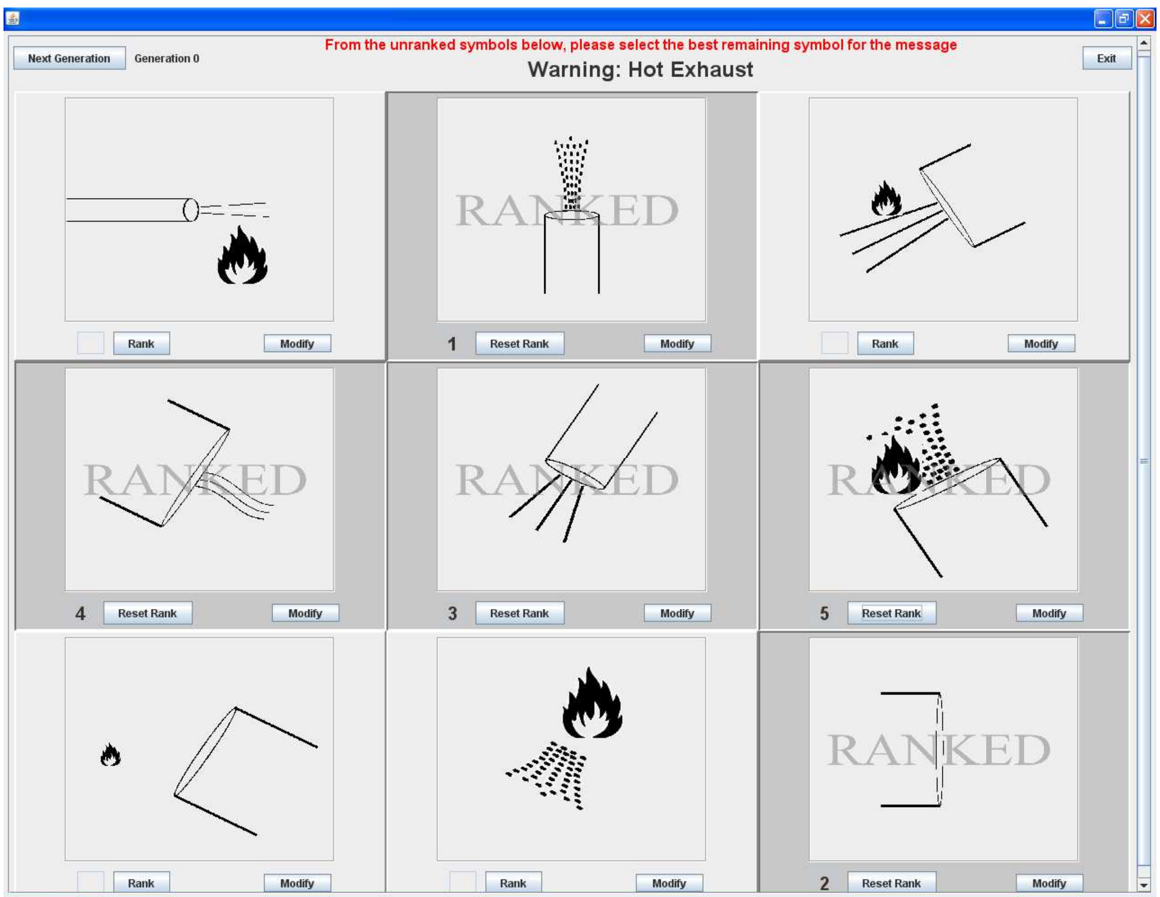


Figure 18. Client interface for Hot Exhaust operated by DIGA participants.

"Rank" button to rank a symbol as the best symbol remaining, to "Reset Rank" if a mistake was made, and to submit the "Next Generation" when all symbols were ranked. The "Modify" button was used by the investigators only when an error was made.

Protocol. Prior to participating in the experiment, each participant reviewed the information letter approved by the Auburn University IRB (Appendix 5.1) and read and completed the research instruction form (Appendix 5.2). The investigators also read the instructions aloud in English and fielded questions and requests for explanations of the warning referents. Participants were assigned random seats in the research lab, and each was instructed on the operation of the DIGA program. Without consulting other participants, each individual first ranked the best symbol displayed on the monitor for the initial generation, and then they ranked each successive "best remaining" symbol. When all nine symbols in the initial generation were ranked in this manner, the individual clicked the "Next Generation" button and waited on delivery of the next generation of symbols for evaluation. Once all members of the experimental group had submitted their generation of symbols in this fashion, the DIGA processed them and submitted a new generation to each participant for evaluation. Takagi (2001) recommended a maximum of 10-20 generations for interactive evolutionary computation to avoid fatigue-related bias in participant responses. Therefore, after the submission of the 20th generation, the experiment terminated, and the process was repeated using the second referent. Participants then viewed anonymously the favorite symbol of each participant in the group, and evaluated them by three methods: comprehension estimation, a Likert-type scale of perceived effectiveness, and a ranking of most to least effective. Since open-ended comprehension was not feasible because the participants already knew the intended meaning, this composite evaluation analysis should provide adequate information to determine the most representative symbol from each DIGA group.

Experiment #2 – Development of Comparison Symbols by the Focus Group Method

Macbeth et al. (2000) and Pettendorfer and Mont'alvao (2006) reported that the focus group method produced more effective symbols than previous non-IEC methods, while Dorris (2004) demonstrated that an IEC symbol design tool could produce symbols that performed at least as well as those produced by other methods. To provide a means of comparison, Experiment #2 developed a companion set of symbols using the focus group method with similar demographic stratification to Experiment #1.

Subjects. Four groups of 12 Auburn University students each (N=48) were recruited using the same emails and flyers for Experiment #1, each group again representing a different treatment of the independent variable *country of origin*. However, 11 participants withdrew before completing the experiment. Group 1 consisted of a heterogeneous mix of 10 participants (two participants withdrew) that included three participants from the U.S., two participants each from Turkey and Korea, and one participant each from India, Zimbabwe, and Japan. Groups 2 – 4 were homogeneous by country-of-origin. Group 2 consisted of 12 participants from the U.S. Group 3 consisted of six participants from India (six withdrawals) who were attending graduate school in the U.S., and Group 4 consisted of nine participants from China (three withdrawals) also attending graduate school in the U.S. All participants reported at least moderate fluency with the English language, and all participants were 19 years of age or older. Each participant was paid $40 for two hours of effort.

Experimental apparatus. For the first portion of Experiment #2, participants were assigned to random seats in a conference room, and each was provided a pencil, a pen and a blank page for drawing a symbol (See Appendix 5.3). After completion of the drawing, the hand drawn symbols were scanned and converted into electronic images and a Smartboard 600i digital whiteboard was used to evaluate the drawings.

Protocol. Prior to participating in the focus group phase of the experiment, each participant reviewed the approved information letter (Appendix 5.1), read and completed the research instruction form (Appendix 5.2). The instructions were also read aloud in English by the investigator, and questions and requests for explanations of the warning referents from the participants were fielded. Participants were assigned random seats in the research lab, and each was provided several copies of the blank symbol drawing form for the first referent (chosen at random). Without consulting other participants, each individual sketched a simple drawing of a symbol that portrayed the referent without using words. After all participants had completed their drawings, the symbols were scanned and converted to an electronic image. The participants then introduced themselves to one another and selected a moderator from among the group. The moderator presented the symbol drawings anonymously and solicited feedback from the group, while also providing feedback on the symbol designs herself. The best ideas were recorded, and one participant was nominated to sketch a final consensus symbol drawing based on the group's collective preferences. The investigators were present during this process to answer questions and assist with any problems that arose, but they avoided direct participation in the focus group. Once the group consensus symbol was designed and saved, the process was repeated with the second referent.

Experiment #3 – Comparing DIGA and Focus Group Symbols

Subjects. To compare the symbol designs, 501 participants were recruited using the Amazon Mechanical Turk anonymous electronic task recruitment system which recruits respondents globally via requests for assistance. One hundred participants withdrew before completing the experiment, resulting in a completion rate of 80%. The countries of origin represented by the 401 participants who completed the survey included 249 from the U.S., 105 from India, 11 from Canada, 5 from the U.K., 4 from China, 3 from Nigeria, 3 from The Philippines, 2 from Mexico, and 18 participants from 18 other countries. All participants reported moderate fluency with the English language, and all participants were 19 years of age or older. Each participant was paid $0.10 for their efforts.

Experimental Instrument. For Experiment #3, an electronic survey was designed that included symbols placed in a photographic context appropriate for their hazard. Since the DIGA and focus group symbols would also be compared along side of previously published symbols, a graphic artist was employed to standardize the designs (Dorris, 2004) based upon published design criteria (ANSI, 2007a; ISO, 2003). A sample symbol design with context was presented first, followed by comprehension questions inquiring of the precise meaning of the symbol and the most appropriate response action that should be taken. Photographic context was also provided for the eighteen actual symbols, and similar questions were asked. Participants were randomly assigned to only two of the eighteen contextualized symbols for evaluation, one from each referent, so that previous experience with that referent would not bias their responses. The final portion of the survey included a single presentation of nine symbols for each referent: four produced by the DIGA, four produced by the focus group method, and one already in use. One final question asked participants to select the symbol for each referent which most effectively communicates its intended message. Examples of the comprehension questions with context and of the comparison ranking portions of the survey are located in Appendix 5.4.

Protocol. Each participant recruited by Amazon Mechanical Turk was directed to SurveyMonkey.com to complete only a portion of the evaluation survey. Respondents were asked to provide their country-of-origin and the date, but not the month or year, in which they were born. This date was used as a surrogate to approximate a uniformly distributed random variable to assign respondents to a portion of the survey since the survey software in SurveyMonkey.com does not provide other means of partial assignment of survey portions. Each participant was directed first to a sample symbol design with photographic context and asked to give a precise meaning for the symbol as well as a response action that should be taken. Participants were then shown the actual symbol meaning as well as an appropriate response. Then, one random symbol for each referent was shown to the participant with photographic context, and the same questions were asked. Finally, for each referent, participants were shown the four symbols designed in Experiment #1, the four symbols designed in Experiment #2, and a symbol design already in use, and they were asked to select the symbol that they feel is most effective at communicating the intended message without knowledge of the source of each symbol.

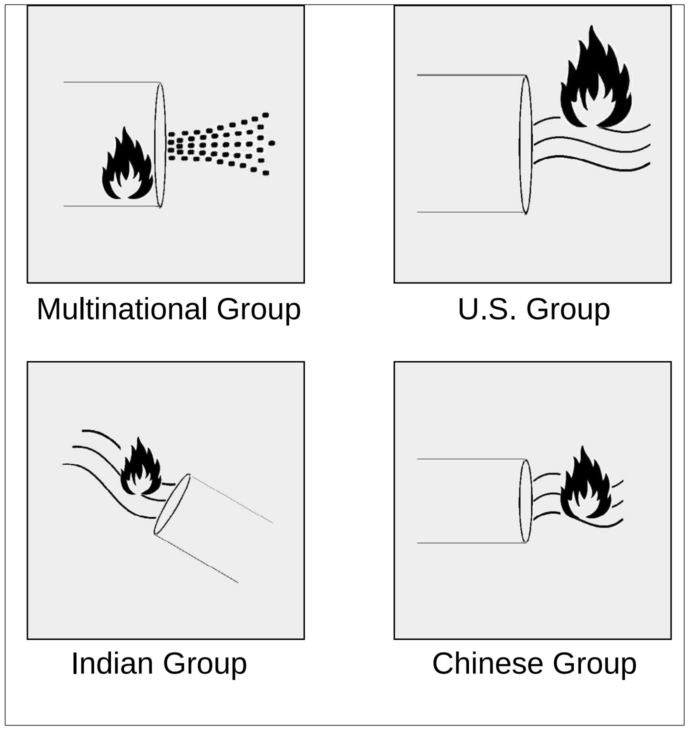


Figure 19. Best “Hot Exhaust” symbols from each DIGA group.

Figure 20. Best “Do Not Touch with Wet Hands” symbols from each DIGA group.

Results

The symbols produced by DIGA Groups 1-4 of Experiment #1 are found in Appendix 5.5. Each symbol was evaluated using the composite analysis discussed in the previous section by its design group, and the top performing symbols from each group are presented in Figures 19 and 20. A summary of the results of these evaluations are listed in Table 13.

Table 13.

Composite evaluation results of the best symbol by each DIGA design group

	Design Group	Quality Rating (1-7)*	Comprehension Estimate*	Subjective Rank
Hot Exhaust	Multinational	5.75 (1st)	81.25% (1st)	6.5
	U.S.	5.25 (1st)	74.58% (2nd)	3
	Indian	5.60 (1st)	76.00% (1st)	2
	Chinese	5.25 (1st)	78.33% (1st)	4
Do Not Touch with Wet Hands	Multinational	5.00 (1st)	60.00% (1st)	1
	U.S.	5.50 (1st)	78.75% (1st)	1
	Indian	5.50 (1st)	74.50% (1st)	1
	Chinese	5.50 (1st)	75.83% (3rd)	1

* Parenthetical ranks are in comparison to other symbols produced in the same group.

Though Takagi (2001) recommends a limit of 10-20 generations to avoid participant fatigue, this recommendation does not guarantee that the algorithm has begun to converge. To demonstrate convergence, Figures 21 and 22 plot the number of times participants selected a new favorite symbol (i.e. found a better design) across all participants in a particular design group for each referent. In the first few generations, it was not uncommon for more than half of the participants to find a new favorite symbol in a given generation. In each case, however, the function of design changes per generation decreases, though not necessarily to zero.

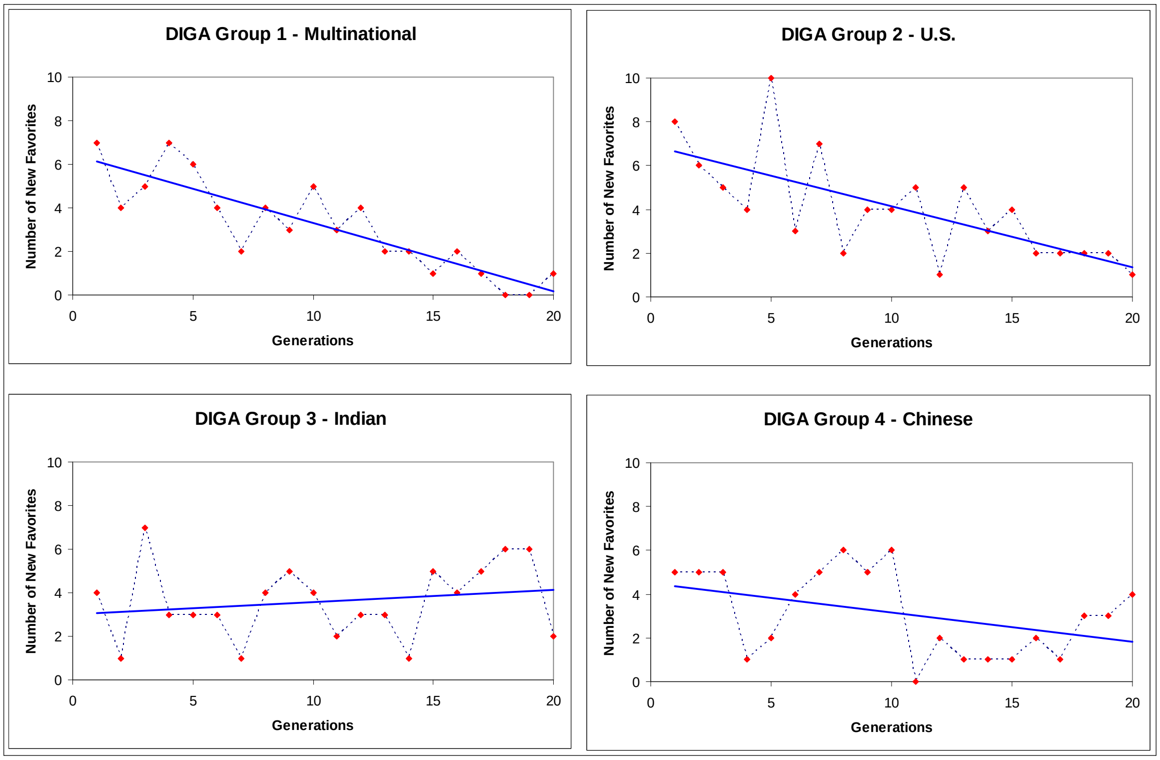


Figure 21. Convergence of "Hot Exhaust" algorithm based on number of times a participant selected a new best symbol per generation.

One-tail paired t-tests were performed to determine whether a significant reduction in symbol diversity occurred between the top-ranked symbols of each participant from generation 1 to generation 20. The coefficient of variation (CV) was calculated for each design parameter, since they have very different ranges, to normalize the variance, and the CV of each parameter was found at generation 1 and at generation 20. Table 14 summarizes the paired t-tests for each of the eight trials. Only two trials did not result in a significant decrease in the coefficient of variance between the highest ranked symbols of each participant from the first to the final generation.

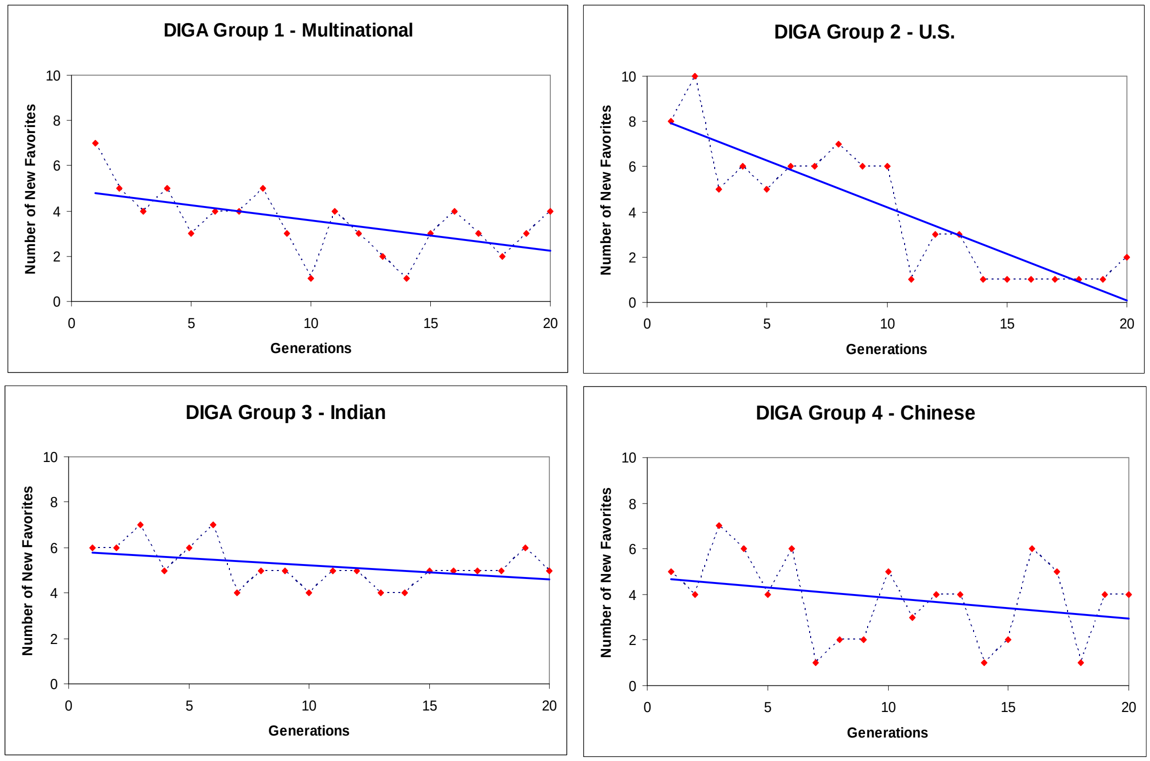


Figure 22. Convergence of “Do Not Touch with Wet Hands” algorithm based on number of times a participant selected a new best symbol per generation.

Table 14.

Convergence analysis of one-tail paired t-test statistics comparing the coefficient of variation of the first and final generations between subjects for each DIGA trial.

	DIGA Design Groups			
	Multinational (n=12)	U.S. (n=12)	Indian (n=10)	Chinese (n=12)
Hot Exhaust	2.13 (p=0.028)	1.20* (p=0.128)	3.96 (p=0.001)	3.31 (p=0.003)
Do Not Touch with Wet Hands	-0.36* (p=0.362)	2.53 (p=0.013)	1.87 (p=0.042)	1.98 (p=0.036)

***** Indicates results that were not significant at the $\alpha = 0.05$ level.

The symbols produced by the focus group participants in Experiment #2 served as a control for comparison to the DIGA symbols. An additional control symbol for each referent found in the literature was also included. The focus group symbols are shown in Figures 23 and 24, and Figure 25 contains the previously published symbols.

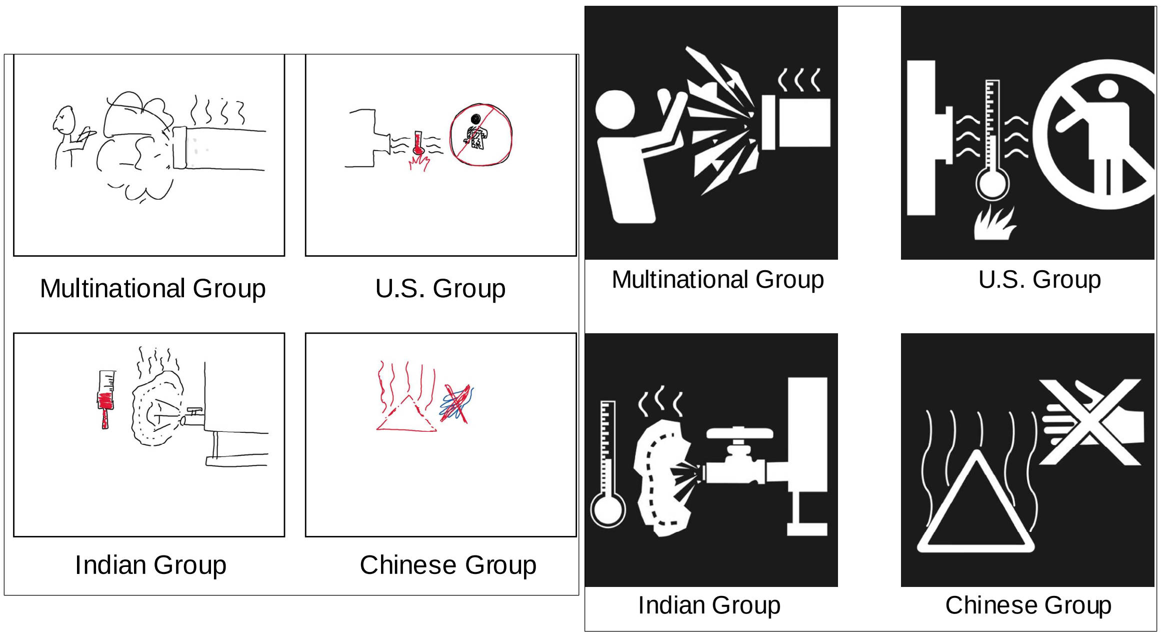


Figure 23. Draft and final focus group symbols for “Hot Exhaust”.

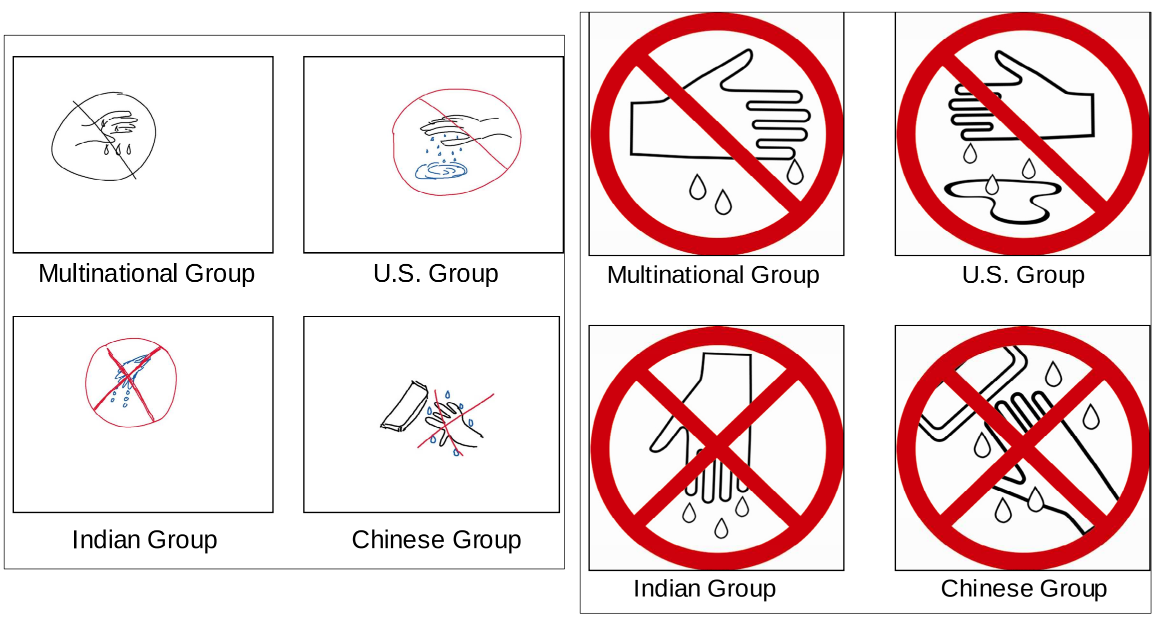


Figure 24. Draft and final focus group symbols for “Do Not Touch with Wet Hands”.

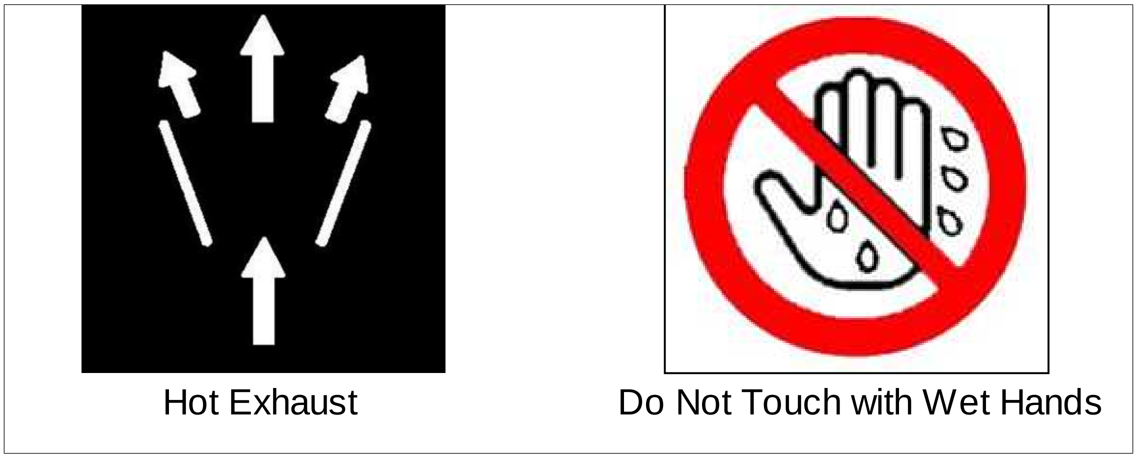


Figure 25. Previously published manufacturer's symbol for "Hot Exhaust" (Lewis, 2008) and ISO symbol for "Do Not touch with Wet Hands" (ISO, 2004).

A one-way Analysis of Variance (ANOVA) revealed that significant differences existed in the ranking of the symbols by the evaluation survey participants (N=401). Tukey HSD multiple comparisons analysis revealed that Hot Exhaust symbols DIGA-Group4, FG-Group1 and FG-Group2 were preferred significantly more frequently than the other symbols. Similarly, Do Not Touch with Wet Hands Symbol FG-Group2 was preferred significantly more frequently than the others. The ANOVA and Tukey HSD results are shown in Tables 15 and 16.

Table 15.

Results of ANOVA and Tukey HSD analysis for "Hot Exhaust" Symbol Evaluations.

Symbol	% Preferred	Subsets of Equivalent Symbols (α = 0.05)				
		1	2	3	4	5
HE DIGA Chinese	23.2%	X	X			
HE FG U.S.	22.2%	X	X			
HE FG Multinational	19.7%	X	X	X		
HE FG Indian	14.2%		X	X	X	
HE FG Chinese	11.0%			X	X	
HE DIGA U.S.	4.2%					X
HE DIGA Indian	2.5%					X
HE DIGA Multinational	1.8%					X
HE Manufacturer's	1.2%					X

Table 16.

Results of ANOVA and Tukey HSD analysis for “Do Not Touch with Wet Hands” Symbol Evaluations.

Symbol	% Preferred	Subsets of Equivalent Symbols (α = 0.05)							
		1	2	3	4	5	6	7	8
WH FG U.S.	32.4%	X							
WH ISO	19.0%		X	X					
WH FG Multinational	16.2%		X	X	X				
WH FG Chinese	11.2%		X	X	X	X	X		
WH DIGA U.S.	8.5%			X	X	X	X		
WH DIGA Chinese	5.2%				X	X	X	X	
WH FG Indian	4.7%				X	X	X	X	X
WH DIGA Indian	2.5%					X	X	X	X
WH DIGA Multinational	0.2%						X	X	X

Discussion

Interactive evolutionary computation must balance two competing constraints when human judgment serves as the fitness evaluation for design solutions. Like any form of evolutionary computation, the convergence velocity (Back, Fogel, & Michalewicz, 2000) must be gradual enough to allow for adequate diversity of designs and exploration of the search space (Dumitrescu, Lazzerini, Jain, & Dumitrescu, 2000). However, Takagi (2001) insists that fatigue can set in and degrade the design process if convergence takes longer than 10-20 generations. Figures 19 and 20 suggest that the DIGA did not converge too quickly since many new best solutions were being discovered well after the 10^{th} generation in all 8 trials. Furthermore, the algorithm successfully converged to near zero (2 or less) best symbol replacements in three of the eight trials. However, in the other trials, the DIGA did not produce consistent near zero symbol replacements by generation 20, though the number of replacements was decreasing in all but one trial. This finding implies that it is possible, but not necessarily probable, that the DIGA can come to convergence between generations 10-20 for symbol referents similar to those tested. The fact that two of the three converging trials occurred among the two U.S. groups of participants may suggest that factors related to the participants, not just the algorithm, affected convergence. Further implications that participant related factors might affect convergence likelihood arise from the observation that the poorest convergence occurred in the two homogeneous Indian participant trials. In addition to the country-of-origin factor, these two trials were also the only trials that differed in number of participants (i.e. 10 participants instead of 12). Thus, there may also be an association between the size of the participant group and the rate of convergence. Finally, a 0.10 mutation probability was utilized in all eight trials, and it is certainly possible that this parameter, or the two-point crossover method used in each trial, could be adjusted to optimize convergence velocity.

Despite these considerations, six out of eight symbols produced by these experiments were shown to have converged between participants with significantly less diversity between each participant's favorite symbol at generation 20 than at generation 1. This implies that the symbol chosen by the group as most comprehensible following the design session represents well the group's consensus design ideas since they were converging well at the end of the experiment. Once again, it is possible that an association exists between country-of-origin and the convergence of the participant's symbols over time; but if so, it is not an obvious association. The two trials which failed to significantly reduce symbol diversity over the course of the 20 generations were not found within the same demographic stratum nor the same warning referent. Further investigation is necessary to determine the distinguishing factors between the significantly convergent and non-significantly convergent results.

For the "Hot Exhaust" referent, a DIGA-produced symbol (DIGA-Group 4) was found to be more preferred, along with Focus Group 1 and Focus Group 2 symbols, than the others, including the manufacturer's symbol currently in use. It should be noted that no design or evaluation information was published with the manufacturer's symbol, so there is no way to know if it was designed and evaluated according to ANSI or ISO testing standards. In addition, the remaining 3 DIGA-produced symbols, along with the FG-2 symbol, were statistically least preferred. These results suggest that it is possible to design a symbol using a distributed interactive genetic algorithm that is understood at least as well as symbols designed by other means. It is also possible to produce a symbol from a DIGA design experiment that is perceived to be inferior to symbols designed by other means. The statistical difference between the DIGA-Group 4 symbol and the other DIGA symbols implies that the design parameters existed in the algorithm to produce a viable symbol. However, since the algorithm converged upon symbols that were poorly perceived as well as on symbols understood well by the evaluation group, it seems that local rather than global optimums were sometimes found. More investigation is necessary to determine what design factors in the DIGA experiment affect the eventual evaluation results of the symbol it produces. Interestingly, the most preferred DIGA symbol for "Hot Exhaust" was produced in DIGA Group 4 (i.e. group of all Chinese participants), which did not appear to be converging to near zero changes of favorites at generation 20 according to the plot of best symbol changes vs. generation number shown in Figure 20.

For the “Do Not Touch with Wet Hands” referent, the symbol from Focus Group 2 was preferred far more frequently than the others with nearly a third of the evaluation participants selecting it as the most comprehensible. In this case, the four DIGA-produced symbols performed poorly. Among the five control symbols, only the Focus Group 3 symbol was preferred by fewer people than the best of the DIGA symbols, and three of the control symbols (FG-2, ISO, and FG1) were statistically more preferred than all of the DIGA symbols. The poor performance of the DIGA for this referent is not well understood. However, one potential cause is the inclusion of the “Circle and X” prohibition symbol, in addition to the traditional “Circle and slash” symbol. Although this variant of the prohibition symbol was found to be a valuable addition in to the attribute matrix during the semantic annotation process (see Chapter 4 of this dissertation), it may produce a negative effect on symbol effectiveness since it appears in three of the four least preferred symbols. A negative effect associated with the “X” portion of this prohibition symbol would be consistent with findings in the literature which suggest that prohibitives that obscure the image the least are typically the most preferred (Murray, Magurno, Glover, & Wogalter, 1998; Shieh & Huang, 2003).

Conclusions

Developing warning symbols using a distributed interactive evolutionary algorithm can be an effective means of engaging diverse participants in sharing designs without the need for verbal communication. The experiments conducted in this study have demonstrated that convergence is possible in the 10-20 generations for which human participants can be expected to contribute judgments meaningfully. However, the experiment also revealed that the DIGA can be inconsistent in its convergence and the symbols it produces, potentially due to both programming decisions within the algorithm as well as personal factors associated with the participants.

Several limitations in this experimental protocol are noted. First, several factors which may have a large impact on the convergence of the DIGA as well as the content of the final designs were not allowed to vary in this experiment. The mutation probability can have a large impact on the convergence velocity as well as the diversity of the solutions, especially in the early generations. Research should be performed to determine whether there an optimal value or set of values for this and other DIGA parameters. In addition, only a maximum of 12 participants were allowed to interact with the DIGA in a given trial. A larger cohort of participants would have been able to search a larger percentage of the design space, potentially developing more diverse symbol designs. Finally, the evaluation survey did not use open-ended comprehension testing, the best approach for assessing the ability of a symbol to communicate its message. This limitation was primarily due to the 50 unique evaluators recommended per symbol variant for a given referent, and the need to replicate this evaluation in three countries. For nine variants, this would require 1350 participants, 450 in each of three countries. Although this quantity of human participation was beyond the capacity of this research, future investigation into the comprehension of DIGA-produced symbols should attempt to employ this evaluation technique.

CHAPTER 6

CONCLUSIONS

Introduction

Participatory design of safety warning symbols has progressed from the early days of the designer's method with very little user involvement to the production method of generating many symbol candidates from user-drawn images to the focus group method that allows users to analyze designs and determine a consensus symbol. Unfortunately, not all of the benefit of participatory design is captured when the designers must intervene in the content development or design reduction portion of the process or when the challenge of overcoming participant diversity discourages the adequate sharing of ideas. However, since comprehension of and compliance with warning symbols depends significantly on their design, there is a significant need to improve the participatory design of warning symbols to increase the likelihood of effective communication to those who need this important protective information.

In essence, the design of symbols constitutes a search task of all symbol design possibilities (both real and hypothetical) to determine the most effective. Given the incredibly broad scope of possible symbol designs for a given warning referent, various techniques have been proposed to bound this search space, either by developing a short list of candidate symbols or by evolutionary computational searches using predetermined graphical search boundaries. Evidence exists that the focus group method performs better than other methods at producing comprehensible symbols. It has also been shown that interactive evolutionary computation can produce symbols of similar quality to more traditional methods for users of diverse cultural and national demographics. The aim of this study was to remodel the top performing traditional symbol design method (i.e. the focus group method) using distributed (i.e. multiuser) interactive evolutionary computation that was designed based on user-contributed search boundary criteria.

Summary of Findings

Three primary experiments were performed in this dissertation. First, in order to ensure that the proceeding distributed interactive genetic algorithm (DIGA) symbol design method could be tested on symbol referents that were considered both easy and difficult from which to design a symbol, a relative “ease of conversion” factor was defined using a perception survey. Next, an experiment was conducted to define the search parameters to be made available to the DIGA by examining and clustering hand drawn versions of the symbols to be designed. Finally, the DIGA experiment allowed participants to interact with the distributed genetic algorithm to propose ideas, share them with one another, and receive new symbol ideas from the system. The final symbols produced in this experiment were compared to symbols produced by the focus group method and to symbols currently in the field.

The findings of the research are summarized below.

1. Survey participant perception can be used to develop a ranked list of referents with regard to their ease of conversion from written warning referent to graphical symbol. New and existing symbol design methods should be evaluated based on their ability to produce quality symbols from referents both easy and difficult to convert.

2. Similar perceptions of ease of conversion were noted for novice participants as well as for two groups of safety professionals, though the perceptions of these groups were not statistically identical. Certified Safety Professional and non-certified members of the American Society of Safety Engineers did have identical perceptions of warning referent difficulty, while a novice group of university students differed in their perceptions by a small, yet statistically significant amount. It appears that the experience gained from working as a safety professional affects the perception of warning referents significantly, though not to such a degree as to invalidate the perceptions of others.
3. Hand-made drawings of safety symbols can be analyzed by a three-member panel to transform the set of graphical images to a set of binary attribute matrices. The attribute matrices completely define the gross characteristics of each symbol drawing. Agreement between panelist evaluations was high (~95%).
4. When the symbol attribute matrices are clustered using a simple K-means clustering algorithm, the centroidal characteristics of each symbol cluster creates a reduced set of symbol attributes capable of completely defining the gross characteristics of each cluster of symbols. In this way, general concentrations of symbol designs can be identified for each safety referent without having to sort the symbols into themes by human judgment alone, as has been required by previous design methods.
5. Distributed interactive genetic algorithms can be used as a substitute for the focus group method of symbol development that does not require communication in a common language between participants. In general, the algorithms demonstrated solution convergence for 10-12 participants after 20 generations, which falls within

the recommendations for both interactive evolutionary computation and for symbol design in groups.

6. Convergence appeared to differ between the easy to convert referent ("Hot Exhaust") and the difficult to convert referent ("Do Not Touch with Wet Hands"). The more difficult referent followed an interesting profile, decreasing in diversity during the first 10 generations and increasing in diversity again during the last 10 generations, regardless of participants. However, the easier referent either increased or decreased with a linear trend across all 20 generations, depending on the demographics of the participants.
7. Convergence of the DIGA algorithm appeared to depend on country of origin. The rate of selection of new top symbols decreased more rapidly among Multinational and homogeneous U.S. experimental groups than it did for homogeneous Chinese and homogeneous Indian groups, when compared across both symbol referents.
8. One of the symbols designed by the DIGA method for the easier safety referent, "Hot Exhaust", received the highest preference ranking when compared to eight other variants, and it was statistically tied for the highest ranking with two symbols designed via the focus group method. All four DIGA symbols were preferred over the currently used manufacturer's symbol. This implies that the DIGA is capable of producing symbols for easy to convert warning referents that are at least as effective as other current methods. However, the DIGA symbols designed for the more difficult referent, "Do Not Touch with Wet Hands", did not perform well in comparison to symbols designed by other means, including the currently published symbol. For more difficult referents, modifications to the search strategy, such as

local searches or extended DIGA sessions, may be needed to ensure a quality design. This also reinforces the need to evaluate warning referents for ease of conversion and to ensure that design methods function adequately for all difficulty levels.

Limitations of the Research

The key limitations of this research are described below.

1. The ease of conversion factor attempted to ascertain the perceived difficulty a survey respondent would have in attempting to produce a symbol from a written safety referent. However, the study did not attempt to validate the authenticity of this difficulty estimate, and the respondents were not asked to actually attempt to produce any symbols to verify whether their perception was accurate.
2. The participatory design strategy of ascertaining symbol design criteria from actual participant symbol drawings involved only two demographic strata: U.S.-born and Indian-born students attending college in the Southeastern United States. To build confidence that the semantic annotation and attribute matrix clustering processes produced symbol clusters representing adequate demographic diversity, additional drawings should be analyzed from other regional, international and cultural groups.
3. Only one replication of the DIGA experiment was performed with each research group and referent. This study did not attempt to measure whether similar designs were repeatable by the same individuals in a second trial or whether a learning curve effect would alter the convergence velocity in a second trial.
4. The DIGA parameters and algorithm design decisions were held constant during the experimentation. It is likely that adjustments to these parameters and to the algorithm

design could significantly affect performance of the system with regard to convergence and to the diversity of the search space explored.

5. Though the DIGA demonstrated good convergence in most trials, the final generation still resulted in separate designs for each participant which necessitated a vote by the group members to determine which final symbol would serve as the group's design. A method within the algorithm of selecting a representative design out of the final 12 candidates should be pursued.
6. The best approach for assessing the ability of symbols to communicate their messages, open-ended comprehension testing, was not used in this research, primarily due to the sample size needed to test nine symbol variants according to ANSI and ISO specifications. The combined method of preference ranking, comprehension estimation and quality rating, while diverse, should be supplemented with open-ended comprehension testing with context cues to ensure that both the DIGA and Focus Group symbols are adequately evaluated.

Recommendations for Future Research

Several opportunities for future research have arisen from this study. First, a validation study to determine the accuracy of the ease of conversion factor with regard to predicting the difficulty of producing a graphical symbol from a written warning referent should be undertaken. Such a study should recruit participants similar to those surveyed in this research to draw sets of symbols matching the referent pairs compared in the current survey. In addition, research should be conducted to validate the robustness of the attribute matrices defined from the U.S. and Indian research participants. Analyzing symbol drawings produced by participants from additional demographic groups for the same symbol referents without heed to the previously defined symbol attributes should produce a parallel attribute matrix for each symbol. These parallel attribute matrices should then be compared to determine if they are products of statistically equivalent populations. Furthermore, additional replications of the DIGA design experiment are recommended to test the effect of replication, algorithm and parameter adjustments on the performance of the system. Another research need involves the exploration of means with the DIGA algorithm to narrow multiple "final designs" to a single consensus. While the algorithm itself converges towards a final design, the diversity remaining in the final generation makes declaring a consensus symbol difficult. Finally, symbols designed by distributed interactive genetic algorithms should be tested according to ANSI and ISO standards, including open-ended comprehension testing, to fully determine their effectiveness.

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APPENDICES

APPENDIX 3.1

Survey of ease of conversion from written referent to graphical symbol for nine referents compared pair-wise.

1. IRB Approved Information Letter

Auburn University
Samuel Ginn College of Engineering

Department of Industrial and Systems Engineering
Principal Investigator: Adam Piper
(334)844-1415 – piperak@auburn.edu
3301 Shelby Center
Faculty Advisor: Dr. Jerry Davis
(334) 844-1411 – davisga@auburn.edu
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(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.) IRB Approval # 08-170 EX 0807

INFORMATION LETTER
for a Research Study entitled "Perception of Difficulty in Drawing Warning Symbols"

You are invited to participate in a research survey to study the difficulty of drawing warning symbols for written messages. The study is being conducted by Adam Piper, under the direction of Dr. Jerry Davis in the Auburn University Department of Industrial and Systems Engineering. You were selected as a possible participant because you are an ISE student, you are an ASSE member, or you hold a BCSP certification AND you are age 19 or older.

What will be involved if you participate? If you decide to participate in this research study, you will be asked to complete a short survey comparing the difficulty of converting textual warning messages to symbols. Your total time commitment will be approximately 10-15 minutes.

Are there any risks or discomforts? No reasonable risks are foreseen with regard to your participation in this research; however, extra precaution will still be made to ensure that all data is recorded anonymously and that you may end your participation in the survey at any time.

Are there any benefits to yourself or others? You may increase your familiarity with safety warning messages which could increase your comprehension of important safety warning signs encountered in the future.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University or the Department of Industrial and Systems Engineering.

Any data obtained in connection with this study will remain anonymous. Survey responses cannot be traced to individual participants; therefore your privacy and the data you provide will be protected. Information collected through your participation may be published in a professional journal and/or presented at a professional meeting.

If you have questions about this study contact Adam Piper at (334) 844-1415 or piperak@auburn.edu , or Dr. Jerry Davis at (334) 844-1411 or davisga@auburn.edu.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION ABOVE, YOU MUST DECIDE IF YOU WANT TO PARTICIPATE IN THIS RESEARCH PROJECT. IF YOU DECIDE TO PARTICIPATE, PLEASE CONTINUE WITH THE SURVEY ENTITLED: "Difficulty in Drawing Safety Symbols"

FOR A COPY OF THIS LETTER TO KEEP THAT INCLUDES THE OFFICIAL IRB-APPROVED SEAL, PLEASE EMAIL THE INVESTIGATOR AT THE ADDRESS BELOW.

Adam Piper, Investigator
piperak@auburn.edu
Dated 6/15/2009

2. Introduction and General Information

The purpose of this survey is to determine if safety messages can be categorized into groups based on how difficult they are to convert into pictures or symbols. A warning is a message, often found on a sign or label placed near the location of a hazard, that communicates important safety information. Symbols are often used to communicate this safety information as a supplement to, and sometimes in place of, written messages.

This research will assist in the development of a method for producing these warning symbols. In order to develop a method of producing good quality symbols, we must first ensure that we can test the technique on both easy-to-draw and difficult-to-draw symbols. Your participation in this research will make it possible to evaluate a new symbol design technique on both difficult and easy messages.

Your role in this study will be to examine pairs of written safety messages and then answer the following question:

"If you were asked to draw a simple wordless symbol to communicate each of these safety messages, which one would you think would be more difficult to draw?"

You will be shown 18 pairs of written safety messages one pair at a time. The messages in each pair will be labeled, "a" and "b." Select the message that you believe is more difficult to draw as a symbol. If you believe that both messages are equally difficult, please select "a and b are equally difficult". Each safety message will have additional information to help you understand when and why such a message would be needed on a warning sign.

If you change your mind about participating, you may withdraw at any time during the survey. To withdraw, simply close your browser window and your responses will not be recorded.

Thank you for your participation in this research study! Please complete the information below before we begin.

I am (select one)

○ Male ○ Female

My age is between (select one)

○ 19-39

○ 40-59

○ 60 and above

I am (select all that apply)

- ☐ Current Auburn Univ. ISE Undergraduate Student
- ☐ Current Auburn Univ. ISE Graduate Student
- ☐ Auburn Univ. Undergraduate Student, Non-ISE
- ☐ Auburn Univ. Graduate Student, Non-ISE
- ☐ Certified Safety Professional (CSP)
- ☐ Associate Safety Professional (ASP)
- ☐ Certified Professional Ergonomist (CPE)
- ☐ Associate Ergonoimcs Professional (AEP)
- ☐ Safety / Ergonomics Professional, non-certified
- ☐ AIHA Member
- ☐ ASSE Member
- ☐ HFES Member
- ☐ IIE Member
- ☐ Safety/Human Factors/Ergonomics Faculty
- ☐ Faculty, other than Safety/Human Factors/Ergonomics
- ☐ None of These

What language do you speak at home most often?

What Country do you consider your "Birth Country" or "Country of Origin"?

3. Safety Message Pair #1

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Walk down stairs backwards.

(Steep stairways and ladders can be dangerous to descend facing forward, away from the steps. However, people often try to walk down stairs or ladders facing out to save time, especially if there are only a few steps. This symbol might appear on a ladder or at the top and bottom of a steep industrial stairway.)

b) No access for persons with metallic implants.

(Metallic implants might include repaired joints, metal plates, or medical sutures implanted in the body. Certain processes can react to metal nearby, so it is important to prevent those who have these types of implants from getting to close to these processes. This symbol might be located on a door or entrance way into a room or area where one of these processes is located.)

○ a is more difficult to draw ○ a and b are equally difficult to draw ○ b is more difficult to draw

4. Safety Message Pair #2

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Steel-toed shoes required.

(Many workplaces require foot and toe protection. Heavy objects which may fall onto or roll over toes can cause severe injury. This symbol might be located on a doorway, entrance way or wall in the area where steel-toed shoes are required.)

b) Disconnect main plug from electrical outlet.

(Many pieces of electrical equipment must be disconnected from their electrical source during maintenance, when functioning incorrectly, or when left unattended. This symbol might appear on a piece of electrical equipment.)

- ○ a is more difficult to draw
- ○ a and b are equally difficult to draw
- ○ b is more difficult to draw

5. Safety Message Pair #3

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) No reaching in.

(There are many locations where placing hands inside an opening can be dangerous. This symbol might be located on a wall, sign or machine next to a small or medium-sized opening containing a hazard into which human hands may be tempted to reach.)

b) Do not touch with wet hands.

(Many processes and products can be dangerous when they become wet. This symbol might be placed on a product's label, on an electric machine, or on a container containing hazardous substances.)

○ a is more difficult to draw ○ a and b are equally difficult to draw ○ b is more difficult to draw

6. Safety Message Pair #4

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) No access for persons with metallic implants.

(Metallic implants might include repaired joints, metal plates, or medical sutures implanted in the body. Certain processes can react to metal nearby, so it is important to prevent those who have these types of implants from getting to close to these processes. This symbol might be located on a door or entrance way into a room or area where one of these processes is located.)

b) Hot exhaust.

(Many processes and pieces of equipment vent heated air or fumes into the working environment. It can be dangerous for people or combustible materials to be placed too close to the exhaust exit point. This symbol might be placed near an exhaust vent, pipe or opening.)

○ a is more difficult to draw

○ a and b are equally difficult to draw

○ b is more difficult to draw

7. Safety Message Pair #5

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Steel-toed shoes required.

(Many workplaces require foot and toe protection. Heavy objects which may fall onto or roll over toes can cause severe injury. This symbol might be located on a doorway, entrance way or wall in the area where steel-toed shoes are required.)

b) Warning: Flooring surface changes.

(Changing from concrete to carpet, from tile to hardwood, or from asphalt to dirt can significantly affect a pedestrian's ability to maintain his/her balance, especially if this change is unexpected. This symbol might be located on a doorway or entranceway or on a sign in the vicinity of the border between two different flooring surfaces.)

○ a is more difficult to draw

○ a and b are equally difficult to draw

○ b is more difficult to draw

8. Safety Message Pair #6

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Do not touch with wet hands.

(Many processes and products can be dangerous when they become wet. This symbol might be placed on a product's label, on an electric machine, or on a container containing hazardous substances.)

b) Walk down stairs backwards.

(Steep stairways and ladders can be dangerous to descend facing forward, away from the steps. However, people often try to walk down stairs or ladders facing out to save time, especially if there are only a few steps. This symbol might appear on a ladder or at the top and bottom of a steep industrial stairway.)

○ a is more difficult to draw ○ a and b are equally difficult to draw ○ b is more difficult to draw

9. Safety Message Pair #7

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Warning: Flooring surface changes.

(Changing from concrete to carpet, from tile to hardwood, or from asphalt to dirt can significantly affect a pedestrian's ability to maintain his/her balance, especially if this change is unexpected. This symbol might be located on a doorway or entranceway or on a sign in the vicinity of the border between two different flooring surfaces.)

b) Confined space; entry by permit only.

(A confined space is a location that isn't designed for human occupancy, has limited means of entrance and exit, and which may contain hazards from which escape can be difficult. Entrance to these spaces is tightly controlled and must not be attempted without approval. However, recognition that a particular space is a confined space is not always easy. This symbol would be located on each entrance into the confined space so that everyone is aware that it should not be entered unless authorized.)

- ○ a is more difficult to draw
- ○ a and b are equally difficult to draw
- ○ b is more difficult to draw

10. Safety Message Pair #8

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Disconnect main plug from electrical outlet.

(Many pieces of electrical equipment must be disconnected from their electrical source during maintenance, when functioning incorrectly, or when left unattended. This symbol might appear on a piece of electric equipment.)

b) No reaching in.

(There are many locations where placing hands inside an opening can be dangerous. This symbol might be located on a wall, sign or machine next to a small or medium-sized opening containing a hazard into which human hands may be tempted to reach.)

◯ a is more difficult to draw ◯ a and b are equally difficult to draw ◯ b is more difficult to draw

11. Safety Message Pair #9

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Do not touch with wet hands.

(Many processes and products can be dangerous when they become wet. This symbol might be placed on a product's label, on an electric machine, or on a container containing hazardous substances.)

b) Steel-toed shoes required.

(Many workplaces require foot and toe protection. Heavy objects which may fall onto or roll over toes can cause severe injury. This symbol might be located on a doorway, entrance way or wall in the area where steel-toed shoes are required.)

- ◯ a is more difficult to draw
- ◯ a and b are equally difficult to draw
- ◯ b is more difficult to draw

12. Safety Message Pair #10

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Hot exhaust.

(Many processes and pieces of equipment vent heated air or fumes into the working environment. It can be dangerous for people or combustible materials to be placed too close to the exhaust exit point. This symbol might be placed near an exhaust vent, pipe or opening.)

b) No reaching in.

(There are many locations where placing hands inside an opening can be dangerous. This symbol might be located on a wall, sign or machine next to a small or medium-sized opening containing a hazard into which human hands may be tempted to reach.)

◯ a is more difficult to draw

◯ a and b are equally difficult to draw

◯ b is more difficult to draw

13. Safety Message Pair #11

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Confined space; entry by permit only.

(A confined space is a location that isn't designed for human occupancy, has limited means of entrance and exit, and which may contain hazards from which escape can be difficult. Entrance to these spaces is tightly controlled and must not be attempted without approval. However, recognition that a particular space is a confined space is not always easy. This symbol would be located on each entrance into the confined space so that everyone is aware that it should not be entered unless authorized.)

b) Walk down stairs backwards.

(Steep stairways and ladders can be dangerous to descend facing forward, away from the steps. However, people often try to walk down stairs or ladders facing out to save time, especially if there are only a few steps. This symbol might appear on a ladder or at the top and bottom of a steep industrial stairway.)

- ◯ a is more difficult to draw
- ◯ a and b are equally difficult to draw
- ◯ b is more difficult to draw

14. Safety Message Pair #12

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) No access for persons with metallic implants.

(Metallic implants might include repaired joints, metal plates, or medical sutures implanted in the body. Certain processes can react to metal nearby, so it is important to prevent those who have these types of implants from getting to close to these processes. This symbol might be located on a door or entrance way into a room or area where one of these processes is located.)

b) Disconnect main plug from electrical outlet.

(Many pieces of electrical equipment must be disconnected from their electrical source during maintenance, when functioning incorrectly, or when left unattended. This symbol might appear on a piece of electric equipment.)

○ a is more difficult to draw

○ a and b are equally difficult to draw

○ b is more difficult to draw

15. Safety Message Pair #13

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) No reaching in.

(There are many locations where placing hands inside an opening can be dangerous. This symbol might be located on a wall, sign or machine next to a small or medium-sized opening containing a hazard into which human hands may be tempted to reach).

b) Steel-toed shoes required.

(Many workplaces require foot and toe protection. Heavy objects which may fall onto or roll over toes can cause severe injury. This symbol might be located on a doorway, entrance way or wall in the area where steel-toed shoes are required.)

◯ a is more difficult to draw ◯ a and b are equally difficult to draw ◯ b is more difficult to draw

16. Safety Message Pair #14

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Walk down stairs backwards.

(Steep stairways and ladders can be dangerous to descend facing forward, away from the steps. However, people often try to walk down stairs or ladders facing out to save time, especially if there are only a few steps. This symbol might appear on a ladder or at the top and bottom of a steep industrial stairway.)

b) Warning: Flooring surface changes.

(Changing from concrete to carpet, from tile to hardwood, or from asphalt to dirt can significantly affect a pedestrian's ability to maintain his/her balance, especially if this change is unexpected. This symbol might be located on a doorway or entranceway or on a sign in the vicinity of the border between two different flooring surfaces.)

○ a is more difficult to draw

○ a and b are equally difficult to draw

○ b is more difficult to draw

17. Safety Message Pair #15

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Hot exhaust.

(Many processes and pieces of equipment vent heated air or fumes into the working environment. It can be dangerous for people or combustible materials to be placed too close to the exhaust exit point. This symbol might be placed near an exhaust vent, pipe or opening.)

b) Confined space; entry by permit only.

(A confined space is a location that isn't designed for human occupancy, has limited means of entrance and exit, and which may contain hazards from which escape can be difficult. Entrance to these spaces is tightly controlled and must not be attempted without approval. However, recognition that a particular space is a confined space is not always easy. This symbol would be located on each entrance into the confined space so that everyone is aware that it should not be entered unless authorized.)

○ a is more difficult to draw ○ a and b are equally difficult to draw ○ b is more difficult to draw

18. Safety Message Pair #16

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Disconnect main plug from electrical outlet.

(Many pieces of electrical equipment must be disconnected from their electrical source during maintenance, when functioning incorrectly, or when left unattended. This symbol might appear on a piece of electric equipment.)

b) Do not touch with wet hands.

(Many processes and products can be dangerous when they become wet. This symbol might be placed on a product's label, on an electric machine, or on a container containing hazardous substances.)

○ a is more difficult to draw ○ a and b are equally difficult to draw ○ b is more difficult to draw

19. Safety Message Pair #17

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Confined space; entry by permit only.

(A confined space is a location that isn't designed for human occupancy, has limited means of entrance and exit, and which may contain hazards from which escape can be difficult. Entrance to these spaces is tightly controlled and must not be attempted without approval. However, recognition that a particular space is a confined space is not always easy. This symbol would be located on each entrance into the confined space so that everyone is aware that it should not be entered unless authorized.)

b) No access for persons with metallic implants.

(Metallic implants might include repaired joints, metal plates, or medical sutures implanted in the body. Certain processes can react to metal nearby, so it is important to prevent those who have these types of implants from getting to close to these processes. This symbol might be located on a door or entrance way into a room or area where one of these processes is located.)

- ◯ a is more difficult to draw
- ◯ a and b are equally difficult to draw
- ◯ b is more difficult to draw

20. Safety Message Pair #18

Consider each pair of safety messages below and their descriptions. Which message (a or b) will be more difficult to draw as a wordless warning symbol?

a) Warning: Flooring surface changes.

(Changing from concrete to carpet, from tile to hardwood, or from asphalt to dirt can significantly affect a pedestrian's ability to maintain his/her balance, especially if this change is unexpected. This symbol might be located on a doorway or entranceway or on a sign in the vicinity of the border between two different flooring surfaces.)

b) Hot exhaust.

(Many processes and pieces of equipment vent heated air or fumes into the working environment. It can be dangerous for people or combustible materials to be placed too close to the exhaust exit point. This symbol might be placed near an exhaust vent, pipe or opening.)

- ◯ a is more difficult to draw
- ◯ a and b are equally difficult to draw
- ◯ b is more difficult to draw

21. Thank You!!!

Thank you for completing this survey. Your input will greatly help in the design of an improved method of developing effective and comprehensible safety warning symbols.

For more information on this and other research projects of the Auburn University Occupational Safety and Ergonomics Lab, please visit our website at

eng.auburn.edu/programs/insy/

APPENDIX 3.2

Information letter approved by the auburn university institutional review board for conducting surveys of ease of referent-to-symbol conversion.

Auburn University

Auburn University, Alabama 36849-5346

Samuel Ginn College of Engineering

Department of
Industrial and Systems Engineering
3301 Shelby Center
Fax: (334) 844-1381

Principal Investigator: Adam Piper
(334) 844-1411 – davisga@auburn.edu
Faculty Advisor: Dr. Jerry Davis
(334) 844-1415 – piperak@auburn.edu

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMATION LETTER
for a Research Study entitled
"Perception of Difficulty in Drawing Warning Symbols"

You are invited to participate in a research survey to study the difficulty of drawing warning symbols for written messages. The study is being conducted by Adam Piper, under the direction of Dr. Jerry Davis in the Auburn University Department of Industrial and Systems Engineering. You were selected as a possible participant because you are an ISE student or alumnus or you hold a CSP certification and you are age 19 or older.

What will be involved if you participate? If you decide to participate in this research study, you will be asked to complete a short survey comparing the difficulty of converting textual warning messages to symbols. Your total time commitment will be approximately 10-15 minutes.

Are there any risks or discomforts? No reasonable risks are foreseen with regard to your participation in this research; however, extra precaution will still be made to ensure that all data is recorded anonymously and that you may end your participation in the survey at any time.

Are there any benefits to yourself or others? You may increase your familiarity with safety warning messages which could increase your comprehension of important safety warning signs encountered in the future.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University or the Department of Industrial and Systems Engineering.

The Auburn University
Institutional Review Board
has approved this document for use
from 7/14/08 to 7/13/09
Protocol # 08-170 EX 0807

Page 1 of 2

Any data obtained in connection with this study will remain anonymous. Survey responses cannot be traced to individual participants; therefore your privacy and the data you provide will be protected. Information collected through your participation may be published in a professional journal and/or presented at a professional meeting.

If you have questions about this study contact Adam Piper at (334) 844-1415 or piperak@auburn.edu , or Dr. Jerry Davis at (334) 844-1411 or davisga@auburn.edu.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION ABOVE, YOU MUST DECIDE IF YOU WANT TO PARTICIPATE IN THIS RESEARCH PROJECT. IF YOU DECIDE TO PARTICIPATE, PLEASE CLICK ON THIS LINK
"Survey of Perceived Difficulty in Drawing Warning Messages"

YOU MAY PRINT A COPY OF THIS LETTER TO KEEP.

Investigator's signature Date

Adam Piper

The Auburn University
Institutional Review Board
has approved this document for use
from 7/14/08 to 7/13/09
Protocol # 08-170 EX 0807

APPENDIX 3.3

Reciprocal table with a sample set of pairwise comparison results taken from a single participant (participant #51).

	1	2	3	4	5	6	7	8	9	Sum	Rank
1. Walk Down Stairs Backwards	1	1/5				1/5		1	1	3.4	7
2. No Access for Persons with Metallic Implants	5	1		1			1		5	13	2.5
3. Steel-toed Shoes Required			1	1/5	5	5		1		12.2	4
4. Disconnect Main Plug from Electrical Outlet		1	5	1	5	5				17	1
5. No Reaching In			1/5	1/5	1	1/5	1/5			1.8	9
6. Do Not Touch with Wet Hands	5		1/5	1/5	5	1				11.4	5
7. Hot Exhaust		1			5		1	1	5	13	2.5
8. Warning: Flooring Surface Changes	1		1				1	1	5	9	6
9. Confined Space; Entry by Permit Only	1	1/5					1/5	1/5	1	2.6	8

A value of "5" in the table means that the referent in the row (horizontal) is considered more difficult than the referent in the column (vertical) by direct comparison of a single participant. A value of "1/5" means that the referent in the column was considered more difficult than the referent in the row by direct comparison. Values of "1" in the table mean that both referents were considered equally difficult; a referent is always equally difficult when compared to itself.

Red cells signify that the referent listed in the intersecting row was presented to the user first and the referent listed in the intersecting column was presented second in the survey for their comparison. The opposite is true for the non-red numerical cells in the table. Finally, shaded cells represent comparisons that were not directly measured in this balanced, incomplete block design.

APPENDIX 3.4

Pairwise comparison of referent difficulty converted to ranks

Participant	Stratum	Referent Ranks								
		Stairs	Implants	Steel-toes	Disconnect	No Reaching	Wet Hands	Exhaust	Flooring	Confined Space
1	Certified SP	3	3	7	6	8	1	3	5	9
2	Certified SP	5.5	1.5	5.5	9	4	3	7	1.5	8
3	Certified SP	7.5	1.5	7.5	4	7.5	3	5	1.5	7.5
4	Certified SP	8.5	1.5	1.5	8.5	3.5	5	6.5	3.5	6.5
5	Certified SP	8.5	1.5	6	7	3.5	1.5	8.5	5	3.5
6	Certified SP	5.5	1.5	3	9	1.5	7.5	7.5	5.5	4
7	Certified SP	6.5	1	6.5	2.5	2.5	8.5	8.5	4.5	4.5
8	Certified SP	7.5	4	7.5	4	7.5	1.5	4	1.5	7.5
9	Certified SP	8.5	1.5	6.5	3.5	6.5	3.5	8.5	1.5	5
10	Certified SP	5.5	7	8.5	3.5	3.5	1.5	5.5	1.5	8.5
11	Certified SP	5.5	3	7	3	8.5	1	3	5.5	8.5
12	Certified SP	6	3	4.5	7	8	2	4.5	1	9
13	Certified SP	6.5	3.5	1	6.5	8.5	3.5	3.5	8.5	3.5
14	Certified SP	7	2.5	9	4.5	6	4.5	8	2.5	1
15	Certified SP	6	4	1	9	4	8	4	7	2
16	Certified SP	9	2	5.5	7.5	7.5	1	5.5	3	4
17	Certified SP	9	1	6	6	4	3	8	6	2
18	Certified SP	8.5	1	4	6	4	4	8.5	7	2
19	Certified SP	9	3.5	8	3.5	6	1.5	7	5	1.5
20	Certified SP	8	3.5	8	1	6	3.5	8	3.5	3.5
21	Certified SP	5	1	8.5	3.5	6.5	3.5	6.5	2	8.5
22	Certified SP	7	2.5	9	4	8	1	6	2.5	5
23	Certified SP	9	1.5	7.5	5	6	1.5	7.5	3	4
24	Certified SP	9	1.5	5	5	5	3	7.5	1.5	7.5
25	Certified SP	2	6.5	8.5	2	4.5	6.5	2	4.5	8.5
26	Certified SP	5.5	2.5	8	2.5	7	4	5.5	1	9
27	Certified SP	4	1.5	7	7	5	1.5	7	3	9
28	Certified SP	8	1	8	5.5	8	5.5	3.5	3.5	2
29	Certified SP	8.5	2	8.5	4	6	2	6	2	6
30	Certified SP	9	4.5	7.5	4.5	6	1.5	7.5	3	1.5
31	Certified SP	9	1.5	7.5	4	6	4	7.5	4	1.5
32	Certified SP	8.5	1	4	8.5	6	2	7	5	3
33	Certified SP	5	4	7.5	1.5	7.5	3	7.5	7.5	1.5
34	Certified SP	7	4	8.5	6	5	1.5	8.5	3	1.5
35	Certified SP	6	2.5	8.5	2.5	4.5	4.5	8.5	1	7
36	Certified SP	8.5	2.5	5.5	1	8.5	5.5	7	4	2.5
37	Certified SP	8.5	1.5	8.5	4	7	3	6	5	1.5
38	Certified SP	2	8.5	4	4	6.5	6.5	1	8.5	4
39	Certified SP	9	2	5	6	7.5	2	7.5	4	2
40	Certified SP	9	1	8	4	6.5	5	6.5	2.5	2.5
41	Certified SP	9	2.5	2.5	6	7.5	2.5	7.5	5	2.5
42	Certified SP	9	5	7	3	8	1	3	6	3
43	Certified SP	8	1	3	9	5	2	6.5	6.5	4
44	Certified SP	6.5	2.5	4	8.5	6.5	1	5	8.5	2.5
45	Certified SP	7	1	3.5	6	9	2	5	3.5	8
46	Certified SP	3	3	8.5	5.5	7	1	5.5	3	8.5
47	Uncertified SP	8	1.5	8	6	4	1.5	8	4	4
48	Uncertified SP	8.5	1.5	8.5	5	6.5	1.5	6.5	3.5	3.5
49	Uncertified SP	8.5	2	8.5	4.5	4.5	2	6.5	2	6.5
50	Uncertified SP	1.5	3	7.5	5	5	1.5	7.5	9	5
51	Uncertified SP	7	2.5	4	1	9	5	2.5	6	8
52	Uncertified SP	6.5	1.5	8.5	5	3.5	3.5	8.5	1.5	6.5
53	Uncertified SP	8.5	2.5	2.5	7	8.5	1	5	5	5
54	Uncertified SP	4.5	1.5	4.5	3	7.5	1.5	7.5	7.5	7.5
55	Uncertified SP	5	3	8	4	8	1	6	2	8
56	Uncertified SP	6.5	1.5	9	3.5	6.5	3.5	6.5	1.5	6.5
57	Uncertified SP	7.5	2.5	9	6	2.5	5	7.5	2.5	2.5
58	Uncertified SP	8	2.5	1	8	6	4	8	5	2.5
59	Uncertified SP	8.5	2	4	8.5	2	5	7	6	2
60	Uncertified SP	6	1.5	3	6	8.5	4	8.5	1.5	6
61	Uncertified SP	8.5	1.5	6.5	5	8.5	1.5	6.5	3.5	3.5
62	Uncertified SP	5.5	2	9	5.5	1	3	8	4	7
63	Uncertified SP	9	2	1	8	7	3	5	5	5

Participant	Stratum	Referent Ranks								
		Stairs	Implants	Steel-toes	Disconnect	No Reaching	Wet Hands	Exhaust	Flooring	Confined Space
64	Uncertified SP	7.5	3.5	9	5	6	1	3.5	2	7.5
65	Uncertified SP	9	2.5	7	4.5	7	1	4.5	7	2.5
66	Uncertified SP	7.5	1	9	4.5	6	2.5	4.5	2.5	7.5
67	Uncertified SP	8.5	3.5	8.5	6.5	1.5	3.5	5	1.5	6.5
68	Uncertified SP	6	2	8.5	6	4	2	6	2	8.5
69	Uncertified SP	5	4	7	7	3	1.5	9	7	1.5
70	Uncertified SP	7	3	9	4.5	7	1.5	4.5	7	1.5
71	Uncertified SP	8.5	2	7	5	6	2	8.5	2	4
72	Uncertified SP	7	4	8.5	6	5	1.5	8.5	3	1.5
73	Uncertified SP	7	1.5	8.5	5	6	3.5	8.5	1.5	3.5
74	Uncertified SP	8.5	2	6.5	4.5	8.5	2	4.5	2	6.5
75	Uncertified SP	5	2	8.5	3.5	3.5	6.5	6.5	1	8.5
76	Uncertified SP	9	4	2.5	5.5	8	2.5	5.5	7	1
77	Uncertified SP	2	2	8	6.5	2	4	5	6.5	9
78	Uncertified SP	8.5	2	8.5	5	2	4	6.5	2	6.5
79	Uncertified SP	8.5	1.5	6	8.5	1.5	4	7	5	3
80	Uncertified SP	7.5	6	9	4	5	2	2	2	7.5
81	Uncertified SP	9	4.5	7	2.5	8	1	6	2.5	4.5
82	Uncertified SP	9	2.5	8	7	6	1	5	4	2.5
83	Uncertified SP	8.5	1	6	3	8.5	4	5	2	7
84	Uncertified SP	7.5	2	1	7.5	7.5	3	4	7.5	5
85	Uncertified SP	5	1.5	5	7	8.5	3	5	1.5	8.5
86	Uncertified SP	8	3	5	3	8	6	8	3	1
87	Uncertified SP	8	2.5	9	2.5	5	1	6	4	7
88	Uncertified SP	7.5	1	5	9	6	2	7.5	4	3
89	Uncertified SP	9	4	7.5	4	6	1.5	7.5	1.5	4
90	Uncertified SP	6	4.5	8.5	1.5	3	4.5	8.5	7	1.5
91	University	8.5	3	3	7	8.5	1	6	3	5
92	University	3.5	1.5	6	6	3.5	1.5	9	8	6
93	University	3.5	6.5	3.5	8.5	1.5	6.5	5	8.5	1.5
94	University	3.5	1	2	7	7	7	3.5	5	9
95	University	6	2	7	8	4.5	1	9	3	4.5
96	University	9	4.5	1	3	6.5	8	2	6.5	4.5
97	University	4.5	6	7	1	8.5	3	8.5	2	4.5
98	University	8.5	1.5	6.5	6.5	5	4	8.5	3	1.5
99	University	9	1	2	7	6	5	8	3.5	3.5
100	University	8.5	1.5	4	8.5	6	1.5	6	6	3
101	University	8.5	2	5.5	8.5	2	5.5	7	4	2
102	University	1.5	4	3	8	1.5	8	6	5	8
103	University	7	1.5	3.5	8.5	5	1.5	8.5	6	3.5
104	University	7.5	2.5	7.5	4	2.5	5	9	6	1
105	University	8.5	1.5	3	7	5.5	5.5	8.5	4	1.5
106	University	6.5	1.5	8.5	4	3	6.5	5	1.5	8.5
107	University	8	2.5	7	5.5	2.5	5.5	9	4	1
108	University	8.5	4	8.5	7	1.5	3	6	1.5	5
109	University	4	1	4	7	2	7	7	4	9
110	University	8.5	1	3.5	6.5	6.5	3.5	8.5	3.5	3.5
111	University	9	4	1	8	7	2	4	6	4
112	University	1.5	6	8.5	1.5	7	4.5	8.5	3	4.5
113	University	4.5	1.5	9	3	7	4.5	7	1.5	7
114	University	9	1.5	5	7.5	6	1.5	7.5	4	3
115	University	8.5	2.5	6	8.5	1	4.5	7	2.5	4.5
116	University	8.5	2	8.5	4.5	6.5	2	4.5	2	6.5
117	University	2	5.5	2	5.5	2	9	4	7	8
118	University	8	1.5	3.5	8	5.5	3.5	8	1.5	5.5
119	University	9	5	5	2	5	3	7.5	7.5	1
120	University	8.5	3	5	6.5	8.5	1	6.5	3	3
121	University	8.5	1	4	8.5	2.5	5	6.5	2.5	6.5
122	University	8	1.5	7	4	6	5	9	3	1.5
123	University	8.5	1	3	8.5	7	2	5.5	5.5	4
124	University	7	3.5	3.5	8.5	8.5	1.5	5.5	5.5	1.5
125	University	4	1.5	1.5	8	7	5	3	9	6
126	University	8	1.5	3	4.5	8	6	8	1.5	4.5
127	University	9	2.5	6.5	5	6.5	1	8	4	2.5
128	University	8.5	1	6.5	8.5	2.5	2.5	6.5	4	5
129	University	7	1.5	9	6	3	1.5	8	4	5

Participant	Stratum	Referent Ranks								
		Stairs	Implants	Steel-toes	Disconnect	No Reaching	Wet Hands	Exhaust	Flooring	Confined Space
130	University	1	9	7	3	2	5	5	5	8
131	University	8.5	4	6.5	2	8.5	2	5	2	6.5
132	University	1.5	5	7.5	6	1.5	7.5	4	3	9
133	University	4.5	1	2	8	6.5	6.5	9	3	4.5
134	University	9	5	6	1.5	7.5	3.5	7.5	3.5	1.5
135	University	8.5	2.5	5	6.5	8.5	1	6.5	2.5	4
136	University	8.5	1.5	8.5	3.5	7	3.5	1.5	5.5	5.5
137	University	6.5	2.5	6.5	5	1	8.5	8.5	4	2.5
138	University	4.5	1	2	8	6.5	3	4.5	6.5	9
139	University	8.5	2.5	7	2.5	5	6	8.5	1	4
140	University	3	6	7.5	3	1	7.5	9	3	5
141	University	8.5	1.5	1.5	6.5	8.5	3.5	6.5	5	3.5
142	University	8.5	1.5	1.5	6.5	8.5	5	6.5	4	3
143	University	8.5	1.5	4	6	6	6	8.5	1.5	3
144	University	7	2	1	8.5	6	3	8.5	4.5	4.5
145	University	3	6	8.5	6	6	1	8.5	2	4

APPENDIX 4.1

Information letter for Phase 1 – Symbol Proto-Drawings participants.

Auburn University

Auburn University, Alabama 36849-5346

Samuel Ginn College of Engineering

Department of
Industrial and Systems Engineering
3301 Shelby Center
Fax: (334) 844-1381

Principal Investigator: Adam Piper
(334) 844-1415 – piperak@auburn.edu
Faculty Advisor: Dr. Jerry Davis
(334) 844-1411 – davisga@auburn.edu

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMATION LETTER
for a Research Study entitled
"Hand Drawing Safety Symbols to Determine Their Pictorial Attributes"

You are invited to participate in a research study to determine the pictorial attributes preferred in the construction of safety symbols. The study is being conducted by Adam Piper, under the direction of Dr. Jerry Davis in the Auburn University Department of Industrial and Systems Engineering. You were selected as a possible participant because you are an Auburn University undergraduate or graduate student and you are age 19 or older.

What will be involved if you participate? If you decide to participate in this research study, you will be produce three simple drawings by hand that portray a safety message using a digital whiteboard. Your total time commitment will be approximately one hour.

Are there any risks or discomforts? Since you will be providing information regarding your age, gender, birth country, etc., there is always some risk of a breach of confidentiality which could allow you to be indirectly identified from this information. Therefore, security measures will be maintained to ensure that only Mr. Piper and Dr. Davis have access to the information you provide, and that this information will be destroyed at the conclusion of this research. No names or direct identification information will ever be attached to the symbol drawings you produce, and these drawings will only be displayed completely anonymously in any publications or presentations resulting from this research. It is also possible that you could experience slight fatigue in your hands and arms or in your eyes during the time spent drawing on the digital whiteboard. Therefore, you will be encouraged to take breaks at least every 15 minutes, more often if necessary.

.

Are there any benefits to yourself or others? You may increase your familiarity with safety warning messages which could increase your comprehension of important safety warning signs encountered in the future.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University or the Department of Industrial and Systems Engineering.

Any data obtained in connection with this study will be evaluated and stored anonymously. We will protect your privacy and the data you provide by ensuring that the symbol drawings are not linked to your identifiable information. Information collected through your participation may be used to fulfill a requirement for a doctoral dissertation, published in a professional journal and/or presented at a professional meeting.

If you have questions about this study contact Adam Piper at (334) 844-1415 or piperak@auburn.edu , or Dr. Jerry Davis at (334) 844-1411 or davisga@auburn.edu.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE IF YOU WANT TO PARTICIPATE IN THIS RESEARCH PROJECT. IF YOU DECIDE TO PARTICIPATE, THE DATA YOU PROVIDE WILL SERVE AS YOUR AGREEMENT TO DO SO. THIS LETTER IS YOURS TO KEEP.

____
Investigator's signature Date

Adam Piper

APPENDIX 4.2

Instructions and Data Collection form for participants in the Symbol Proto-drawing experiment.

The purpose of this research is to understand the kinds of symbols you prefer to see on a safety sign. Safety signs are placed near the location of a hazard to communicate the risk to all see it.

Your role in this study will be to draw a simple picture, or a symbol, that could be added to a sign to communicate a safety message without using any text at all. This picture you draw should communicate each safety message I will give you as clearly and completely as possible. However, do not worry about making a pretty or high-quality drawing. Artistic skill or well-drawn pictures are not important to this research. As long as you can explain what you picture means, then it is just fine.

You will be drawing your picture using a SmartBoard system, which includes four special marker pens (black, red, green and blue) and a special eraser. Please do not use any other marker pens but the ones provided. To erase your drawing, simply pick up the eraser and wipe away the marks you want to remove. Remember, though, in order to draw with the markers again, the eraser must be returned to its home.

You will be given three different safety messages to draw, one at a time. To help you, you will be given a description of the hazards and locations where symbols like your drawing may be needed. You may take up to 15 minutes to draw each picture, and the researchers will not be able to see your drawing until you are ready. The researchers will remind you periodically of the time remaining on each picture, although you may have more time if you need it. Whenever you are satisfied with your drawing, inform the researcher that it is complete. After you have completed three symbols in this manner, the exercise will be finished.

Please avoid discussing the details of your drawing ideas with anyone who you think might participate in this study to ensure that their results remain unbiased.

Thank you for your cooperation! Please complete the information below before you begin the activity.

Age _________ Gender (circle one): M / F
In what country were you born? ____________________________
For how many years did you live in your birth country? __________________________
What country do you consider to be your home country? _________________________
What language do you speak in your home most often? __________________________
Do you consider yourself to speak English fluently? (circle one) Yes / No
At what age did you first begin reading or speaking English fluently? ________________

APPENDIX 4.3

To create the semantic annotation matrix for a referent, each panelist followed the following procedure.

1. Determine whether newly revealed symbol exhibits critical confusion or is completely non-relevant (Egregious Error)
    a. Determine by majority opinion
    b. If true, set symbol aside and skip to Step 4. If false, continue to Step 2.
2. Which attributes already contained within the matrix are present in this symbol?
    a. Individually and privately recorded on data collection form.
3. Does this symbol add new attributes to the matrix for this referent?
    a. Determine by majority opinion.
    b. If none, skip to Step 4.
    c. Presence of new attributes are individually and privately recorded on data collection forms
4. Move to next symbol in this referent
5. When all symbols are complete, move to new referent.
6. When all referents are complete, end process.

APPENDIX 4.4

Data collection form used by panelists to perform semantic annotation of drawings.

Panelist:	Referent:								Date:					Page #:		
Image Name / Attributes																
1.																
2.																
3.																
4.																
5.																
6.																
7.																
8.																
9.																
10.																
11.																
12.																
13.																
14.																
15.																
16.																
17.																
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24.																
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26.																
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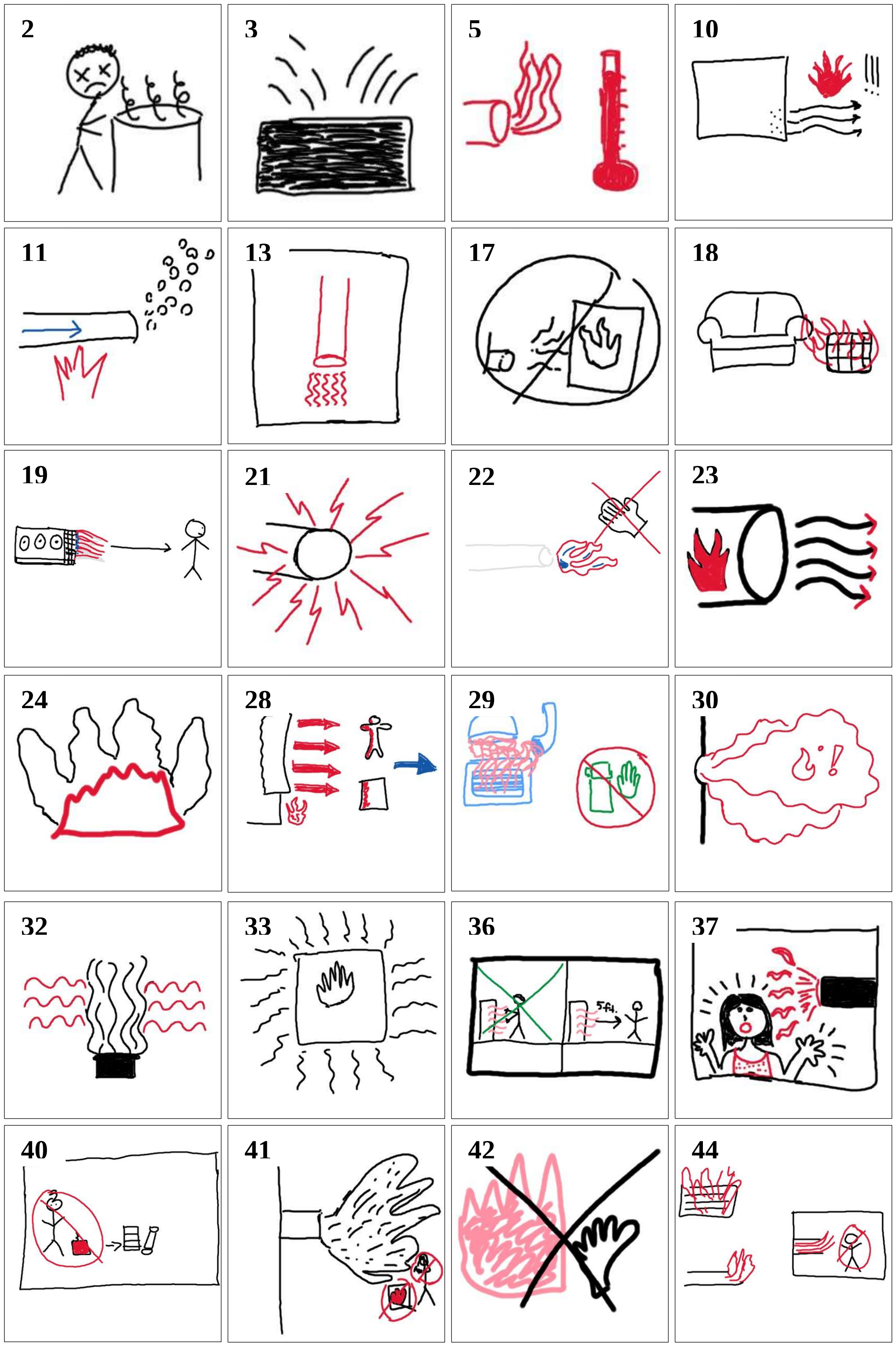
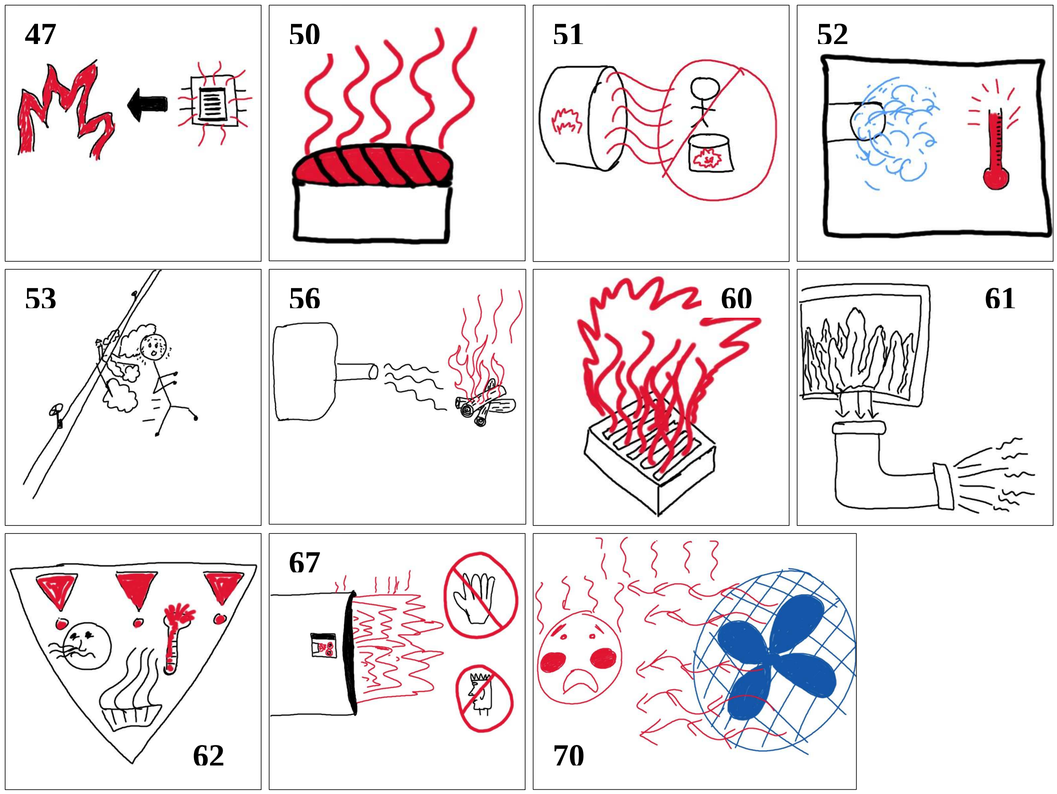
31.																
32.																
33.																
34.																
35.																
36.																
37.																
38.																
39.																
40.																

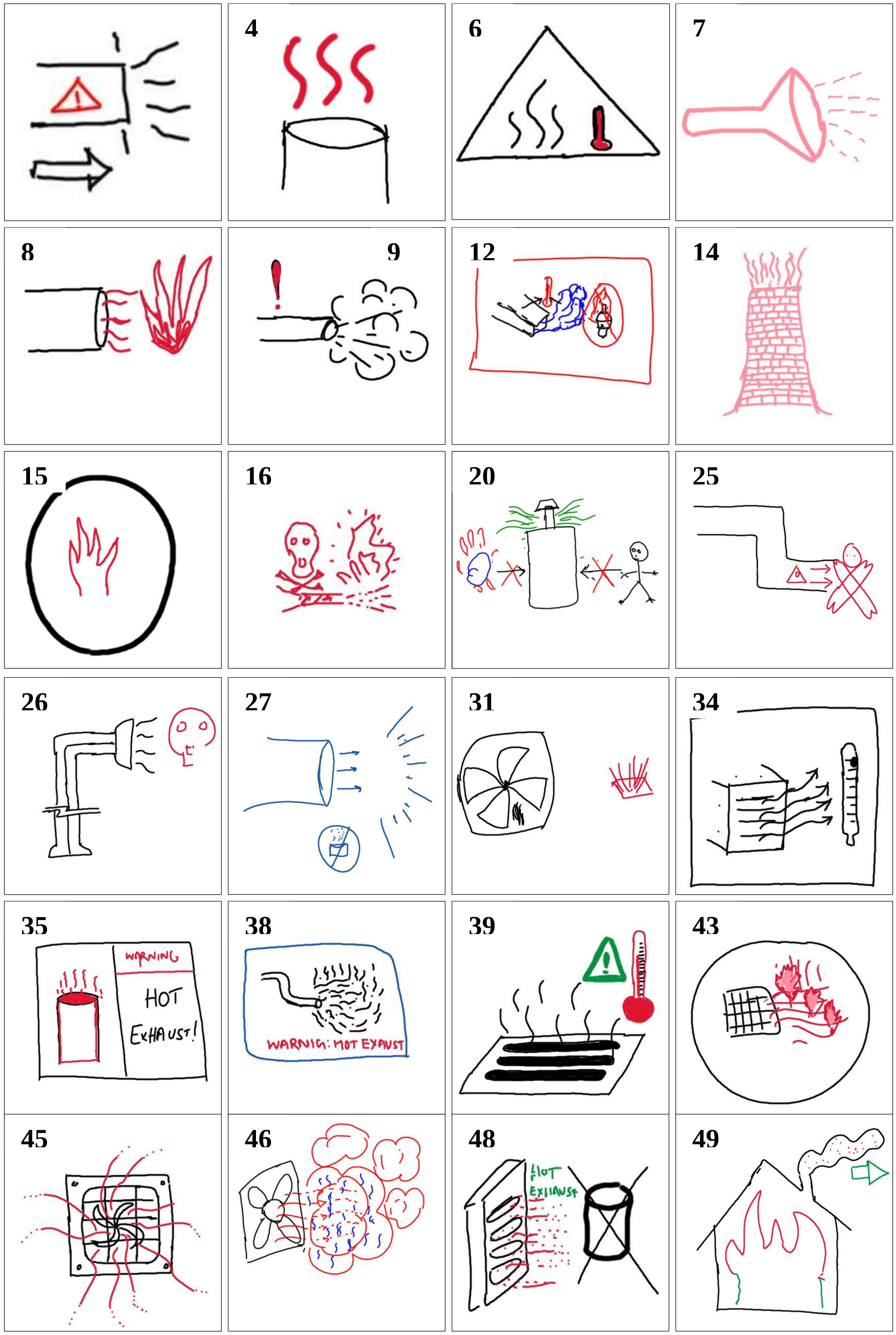
APPENDIX 4.5

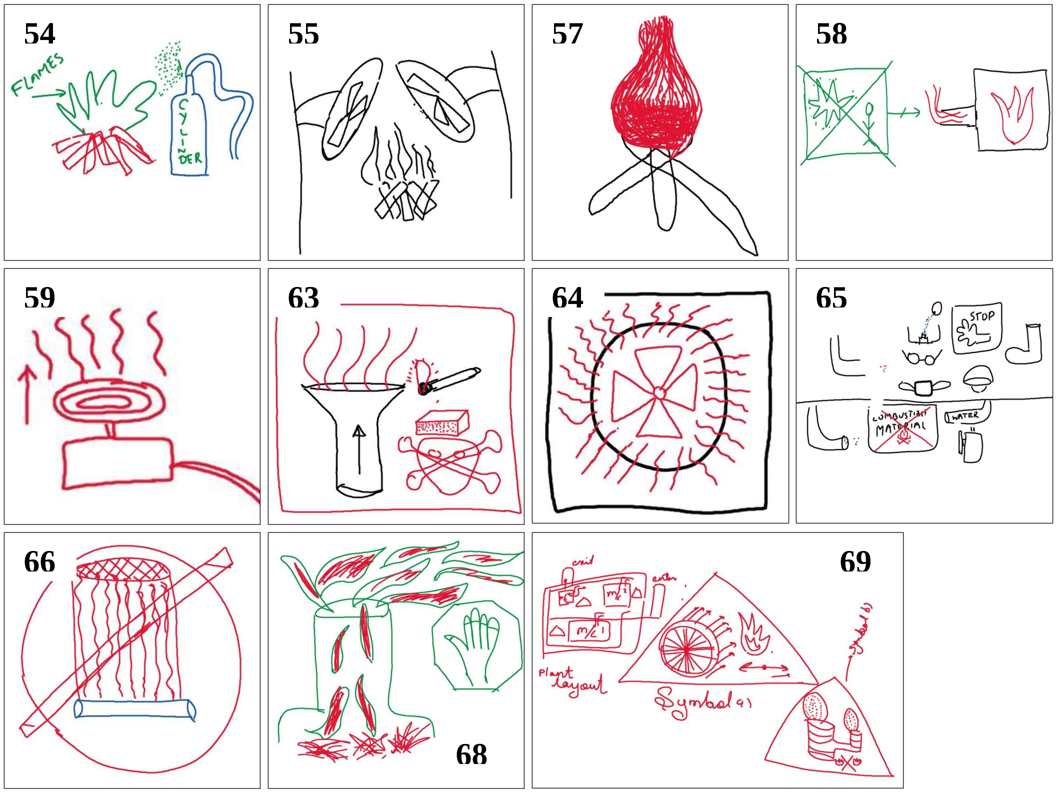
Symbol proto-drawings produced by the U.S. stratum for "Hot Exhaust"



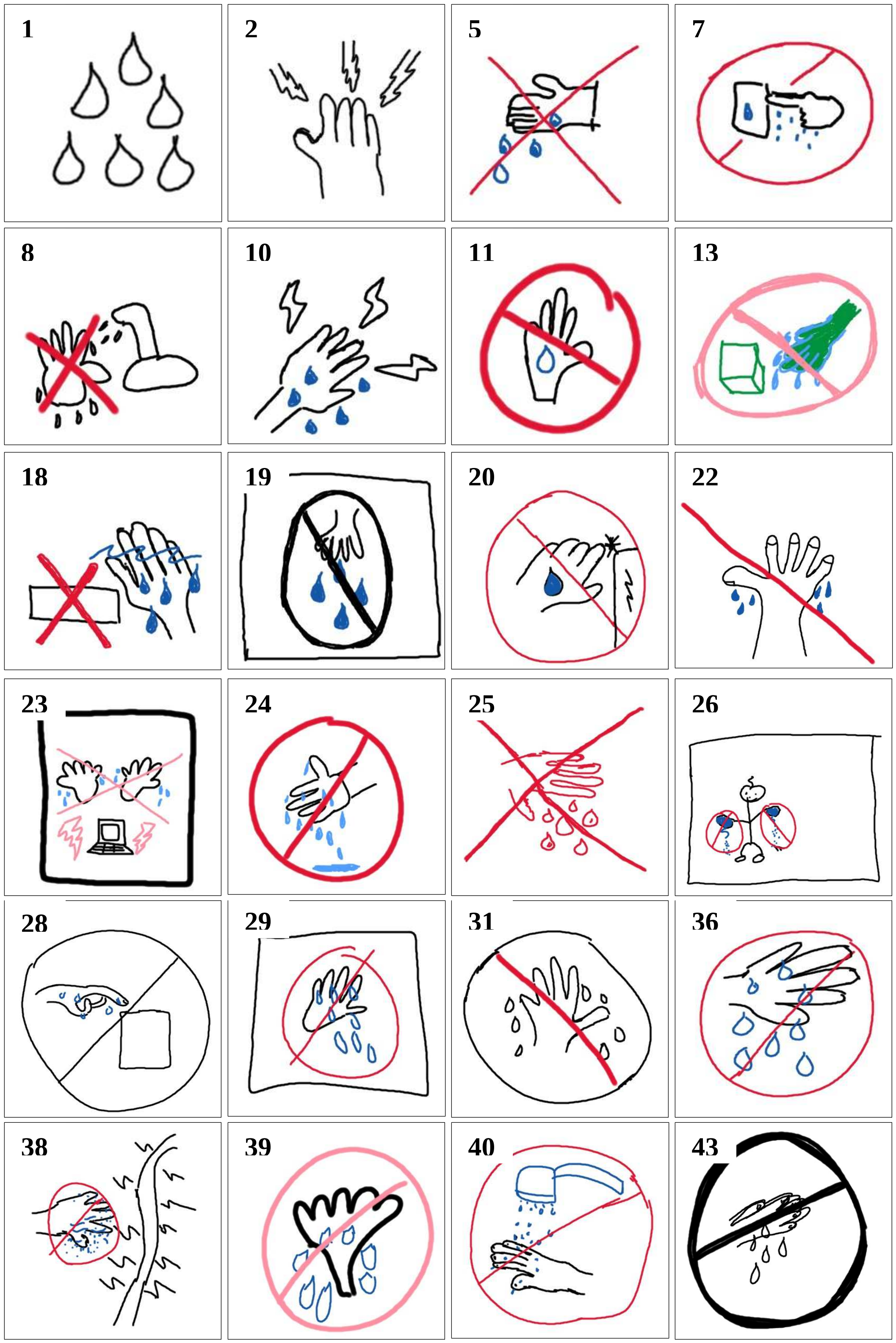

47
50
51
52
53
56
60
61
62
67
70

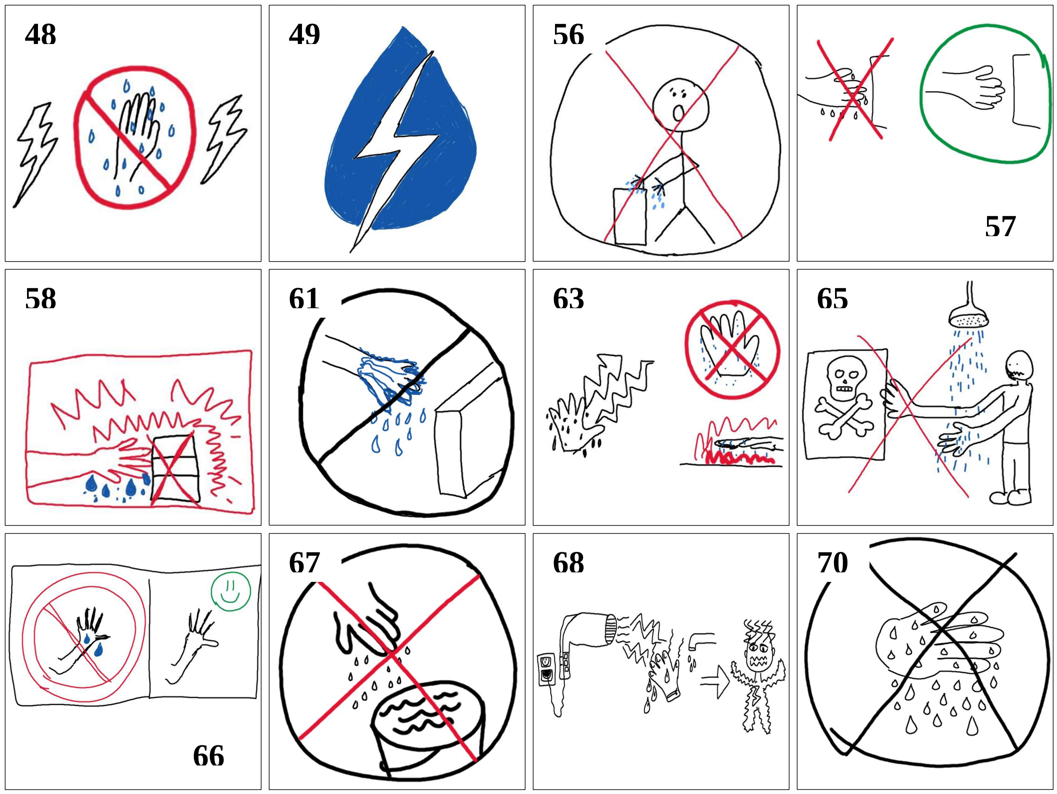
Symbol proto-drawings produced by the Indian stratum for “Hot Exhaust”



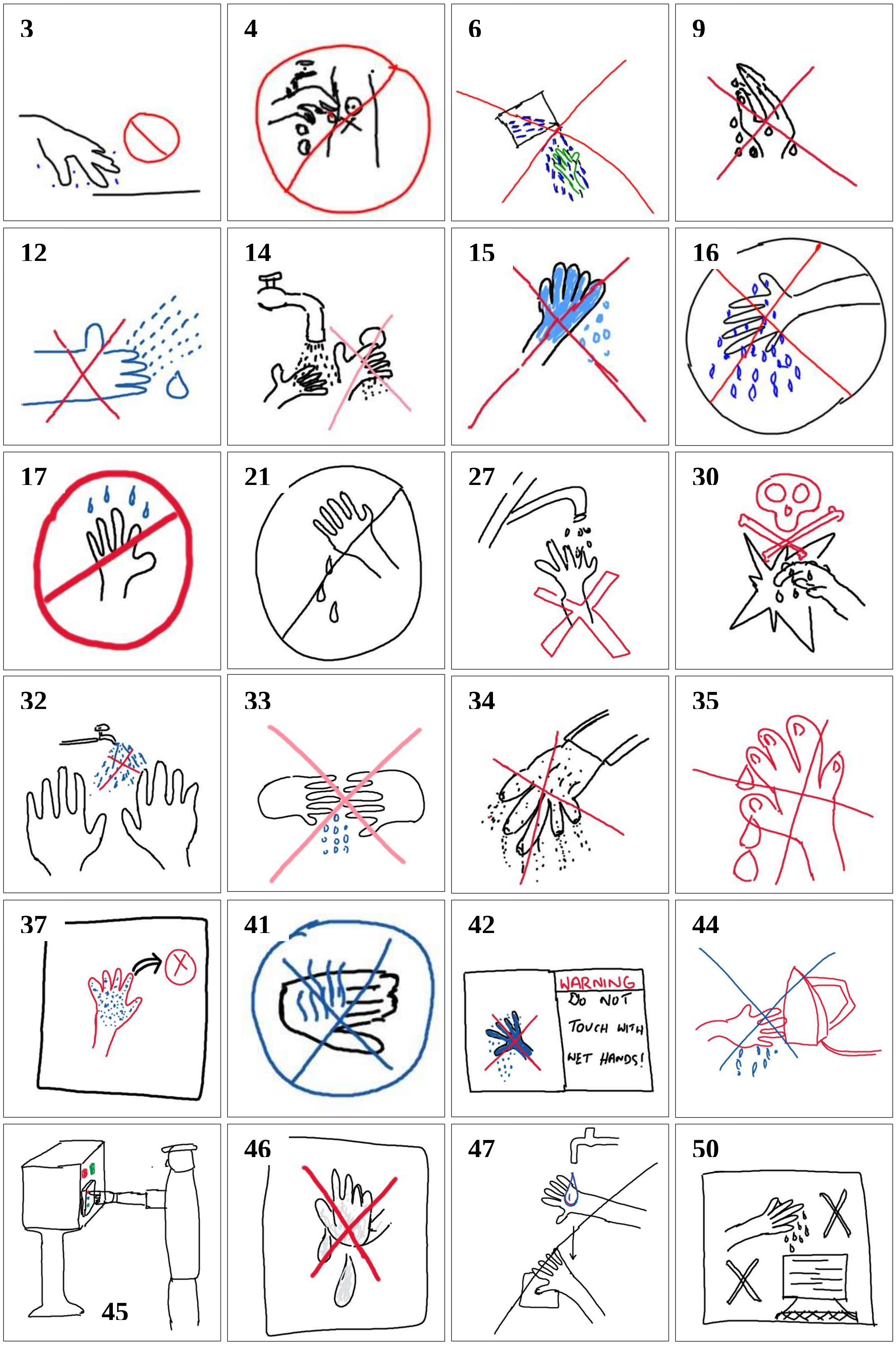

54
FLAMES
CYLINDER
55
57
58
59
63
64
65
STOP
WATER
66
68
69
plant layout

Symbol proto-drawings produced by the U.S. stratum for “Do Not Touch with Wet Hands”

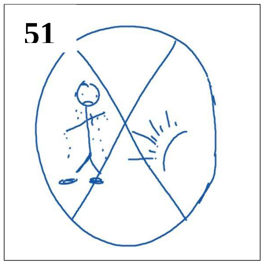



48
49
56
57
58
61
63
65
66
67
68
70

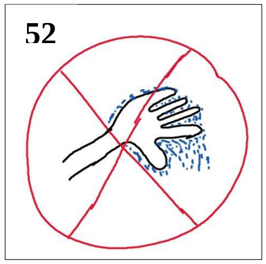
Symbol proto-drawings produced by the Indian stratum for “Do Not Touch with Wet Hands”



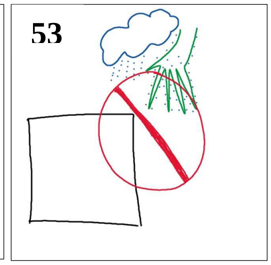
51



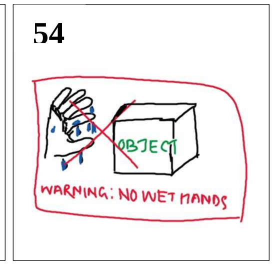
52



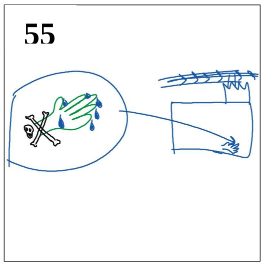
53



54

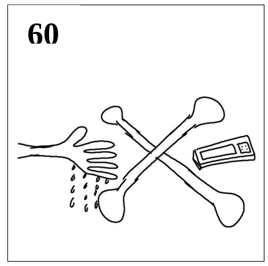


55



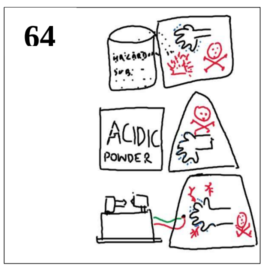
59

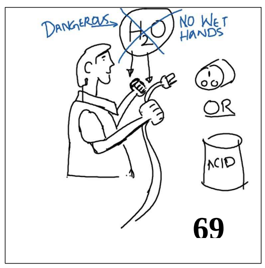
60



62

64





69

APPENDIX 4.6

Consensus attribute matrix produced by summing the three individual panelists' attribute matrices for "Do Not Touch with Wet Hands".

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Attribute	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**	**Indian**
A	Single Hand	EE	EE	3	3	3	3	3	3	3	3	3	3	3	3	3
B	1-D Surface	EE	EE	3	2	0	0	2	0	0	0	0	0	0	0	0
C	Multiple Water Drops	EE	EE	3	3	3	3	3	3	3	3	0	1	3	3	3
D	Prohibition Symbol	EE	EE	3	3	0	0	3	0	0	0	3	0	3	0	0
E	2nd Color	EE	EE	3	3	3	3	3	3	3	3	3	3	2	3	2
F	Skull/Crossbones	EE	EE	0	3	0	0	0	0	0	0	0	0	0	0	0
G	Faucet	EE	EE	0	3	0	0	0	3	0	0	0	0	0	3	0
H	Prohibition X	EE	EE	0	0	3	3	0	3	3	0	0	3	0	3	3
I	Liquid Container	EE	EE	0	0	0	3	0	0	0	0	0	0	0	0	0
J	2-D Panel	EE	EE	0	0	0	0	3	0	0	0	0	1	0	3	0
K	Lightning Bolts	EE	EE	0	0	0	0	0	0	0	3	0	1	0	0	0
L	Single Water Drop	EE	EE	0	0	0	0	0	0	0	0	3	3	0	0	0
M	3-D Object	EE	EE	0	0	0	0	0	0	0	0	0	0	3	0	0
N	Multi-Panel	EE	EE	0	0	0	0	0	0	0	0	0	0	0	3	0
O	Water Ripple	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
P	Spark	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
Q	Single Lightning Bolt	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
R	Energized Equipment	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Two Hands	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
T	Puddle	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
U	Person	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
V	Sequence Arrow	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
W	Rain Cloud	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
X	Surprised Face	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
Y	Permissable Circle	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
Z	Happy Face	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
AA	Mr. Sparky	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0
BB	Heat Waves	EE	EE	0	0	0	0	0	0	0	0	0	0	0	0	0

		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	Attribute	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**Indian**
A	Single Hand	3	3	3	3	3	3	3	1	3	3	0	3	3	3	3
B	1-D Surface	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
C	Multiple Water Drops	3	3	3	3	0	3	3	3	3	3	2	3	3	3	3
D	Prohibition Symbol	1	2	0	3	3	3	3	0	3	0	3	0	3	3	0
E	2nd Color	2	3	3	3	3	0	3	3	3	0	3	3	2	3	3
F	Skull/Crossbones	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
G	Faucet	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
H	Prohibition X	2	0	3	0	0	0	0	3	0	3	0	3	0	0	0
I	Liquid Container	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J	2-D Panel	0	0	3	0	3	0	0	0	0	0	0	0	3	0	0
K	Lightning Bolts	0	0	0	0	1	0	0	3	0	0	0	0	0	0	0
L	Single Water Drop	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
M	3-D Object	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N	Multi-Panel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	Water Ripple	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
P	Spark	0	0	0	0	3	0	0	0	0	0	0	0	0	0	3
Q	Single Lightning Bolt	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
R	Energized Equipment	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
S	Two Hands	0	0	0	0	0	0	0	3	0	0	2	0	0	0	0
T	Puddle	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
U	Person	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
V	Sequence Arrow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	Rain Cloud	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
X	Surprised Face	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Y	Permissable Circle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z	Happy Face	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AA	Mr. Sparky	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BB	Heat Waves	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
	Attribute	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**Indian**	**Indian**
A	Single Hand	3	0	0	3	3	3	CC	3	3	3	3	3	1	3	CC
B	1-D Surface	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
C	Multiple Water Drops	3	3	3	3	3	3	CC	3	3	3	3	3	3	3	CC
D	Prohibition Symbol	3	0	0	0	0	3	CC	3	3	3	0	0	3	0	CC
E	2nd Color	3	3	3	3	0	3	CC	3	3	3	3	3	0	3	CC
F	Skull/Crossbones	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
G	Faucet	0	3	0	0	0	0	CC	0	0	3	0	0	0	0	CC
H	Prohibition X	0	3	3	3	3	0	CC	0	0	0	3	3	0	3	CC
I	Liquid Container	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
J	2-D Panel	0	0	0	0	0	0	CC	3	0	0	0	0	0	0	CC
K	Lightning Bolts	0	0	0	0	0	0	CC	3	0	0	0	0	0	0	CC
L	Single Water Drop	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
M	3-D Object	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
N	Multi-Panel	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
O	Water Ripple	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
P	Spark	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
Q	Single Lightning Bolt	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
R	Energized Equipment	0	0	0	0	0	0	CC	0	0	0	0	0	0	3	CC
S	Two Hands	0	2	2	0	0	0	CC	0	0	0	0	0	2	0	CC
T	Puddle	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
U	Person	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
V	Sequence Arrow	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
W	Rain Cloud	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
X	Surprised Face	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
Y	Permissable Circle	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
Z	Happy Face	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
AA	Mr. Sparky	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC
BB	Heat Waves	0	0	0	0	0	0	CC	0	0	0	0	0	0	0	CC

		46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	Attribute	**Indian**	**Indian**	**U.S.**	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**
A	Single Hand	3	3	3	EE	3	0	3	3	3	3	1	3	3	CC	EE
B	1-D Surface	0	0	0	EE	0	3	0	0	0	0	0	0	0	CC	EE
C	Multiple Water Drops	3	0	3	EE	3	3	3	3	3	3	3	3	3	CC	EE
D	Prohibition Symbol	0	2	3	EE	0	1	1	3	1	0	1	0	0	CC	EE
E	2nd Color	3	3	3	EE	1	0	3	3	3	0	3	3	3	CC	EE
F	Skull/Crossbones	0	0	0	EE	0	0	0	0	0	0	0	0	0	CC	EE
G	Faucet	0	3	0	EE	0	0	0	0	0	0	0	0	0	CC	EE
H	Prohibition X	3	1	0	EE	3	2	2	0	3	3	2	3	3	CC	EE
I	Liquid Container	0	0	0	EE	0	0	0	0	0	0	0	0	0	CC	EE
J	2-D Panel	0	3	0	EE	0	0	0	3	0	0	3	3	2	CC	EE
K	Lightning Bolts	0	0	3	EE	0	1	0	0	0	0	0	0	0	CC	EE
L	Single Water Drop	0	2	0	EE	0	0	0	0	0	0	0	0	0	CC	EE
M	3-D Object	0	0	0	EE	0	0	0	0	3	0	0	0	0	CC	EE
N	Multi-Panel	0	3	0	EE	0	0	0	0	0	0	0	3	0	CC	EE
O	Water Ripple	0	0	0	EE	0	0	0	0	0	0	0	0	0	CC	EE
P	Spark	0	0	0	EE	0	2	0	0	0	0	0	0	3	CC	EE
Q	Single Lightning Bolt	0	0	0	EE	0	0	0	0	0	0	0	0	0	CC	EE
R	Energized Equipment	0	0	0	EE	3	0	0	0	0	3	0	0	1	CC	EE
S	Two Hands	0	0	0	EE	0	0	0	0	0	0	0	0	0	CC	EE
T	Puddle	0	0	0	EE	0	1	0	0	0	0	0	0	0	CC	EE
U	Person	0	0	0	EE	0	2	0	0	0	0	3	0	0	CC	EE
V	Sequence Arrow	0	3	0	EE	0	0	0	0	0	0	0	0	0	CC	EE
W	Rain Cloud	0	0	0	EE	0	0	0	3	0	0	0	0	0	CC	EE
X	Surprised Face	0	0	0	EE	0	0	0	0	0	0	3	0	0	CC	EE
Y	Permissable Circle	0	0	0	EE	0	0	0	0	0	0	0	2	0	CC	EE
Z	Happy Face	0	0	0	EE	0	0	0	0	0	0	0	0	0	CC	EE
AA	Mr. Sparky	0	0	0	EE	0	0	0	0	0	0	0	0	0	CC	EE
BB	Heat Waves	0	0	0	EE	0	0	0	0	0	0	0	0	0	CC	EE

		61	62	63	64	65	66	67	68	69	70
	Attribute	**U.S.**	**Indian**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**
A	Single Hand	3	2	EE	3	0	3	3	3	CC	3
B	1-D Surface	0	0	EE	0	0	0	0	0	CC	0
C	Multiple Water Drops	3	3	EE	3	3	3	3	2	CC	3
D	Prohibition Symbol	3	3	EE	0	0	3	1	0	CC	1
E	2nd Color	3	3	EE	3	3	3	3	0	CC	0
F	Skull/Crossbones	0	1	EE	3	2	0	0	0	CC	0
G	Faucet	0	2	EE	0	3	0	0	2	CC	0
H	Prohibition X	0	0	EE	0	3	0	2	0	CC	2
I	Liquid Container	0	0	EE	2	0	0	3	0	CC	0
J	2-D Panel	0	3	EE	2	3	0	0	0	CC	0
K	Lightning Bolts	0	0	EE	2	0	0	0	1	CC	0
L	Single Water Drop	0	0	EE	0	0	0	0	0	CC	0
M	3-D Object	3	0	EE	0	0	0	0	0	CC	0
N	Multi-Panel	0	3	EE	3	0	3	0	3	CC	0
O	Water Ripple	0	0	EE	0	0	0	3	0	CC	0
P	Spark	0	0	EE	3	0	0	0	2	CC	0
Q	Single Lightning Bolt	0	3	EE	0	0	0	0	0	CC	0
R	Energized Equipment	0	0	EE	3	0	0	0	3	CC	0
S	Two Hands	0	3	EE	0	0	0	0	0	CC	0
T	Puddle	0	0	EE	0	0	0	0	0	CC	0
U	Person	0	0	EE	0	1	0	0	0	CC	0
V	Sequence Arrow	0	0	EE	0	0	0	0	3	CC	0
W	Rain Cloud	0	0	EE	0	0	0	0	0	CC	0
X	Surprised Face	0	0	EE	0	0	0	0	0	CC	0
Y	Permissable Circle	0	0	EE	0	0	0	0	0	CC	0
Z	Happy Face	0	0	EE	0	0	3	0	0	CC	0
AA	Mr. Sparky	0	0	EE	0	0	0	0	3	CC	0
BB	Heat Waves	0	0	EE	0	0	0	0	2	CC	0

Attribute matrix produced by Panelist #1 for “Do Not Touch with Wet Hands”.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Attribute	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**	**Indian**
A	Single Hand	**EE**	**EE**	1	1	1	1	1	1	1	1	1	1	1	1	1
B	1-D Surface	**EE**	**EE**	1	1			1								
C	Multiple Water Drops	**EE**	**EE**	1	1	1	1	1	1	1	1			1	1	1
D	Prohibition Symbol	**EE**	**EE**	1	1			1				1		1		
E	2nd Color	**EE**	**EE**	1	1	1	1	1	1	1	1	1	1	1	1	1
F	Skull/Crossbones	**EE**	**EE**		1											
G	Faucet	**EE**	**EE**		1				1						1	
H	Prohibition X	**EE**	**EE**			1	1		1	1			1		1	1
I	Liquid Container	**EE**	**EE**				1									
J	2-D Panel	**EE**	**EE**					1							1	
K	Lightning Bolts	**EE**	**EE**								1		1			
L	Single Water Drop	**EE**	**EE**									1	1			
M	3-D Object	**EE**	**EE**											1		
N	Multi-Panel	**EE**	**EE**												1	
O	Water Ripple	**EE**	**EE**													
P	Spark	**EE**	**EE**													
Q	Single Lightning Bolt	**EE**	**EE**													
R	Energized Equipment	**EE**	**EE**													
S	Two Hands	**EE**	**EE**													
T	Puddle	**EE**	**EE**													
U	Person	**EE**	**EE**													
V	Sequence Arrow	**EE**	**EE**													
W	Rain Cloud	**EE**	**EE**													
X	Surprised Face	**EE**	**EE**													
Y	Permissable Circle	**EE**	**EE**													
Z	Happy Face	**EE**	**EE**													
AA	Mr. Sparky	**EE**	**EE**													
BB	Heat Waves	**EE**	**EE**													

		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	Attribute	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**Indian**
A	Single Hand	1	1	1	1	1	1	1	1	1	1		1	1	1	1
B	1-D Surface															
C	Multiple Water Drops	1	1	1	1		1	1	1	1	1	1	1	1	1	1
D	Prohibition Symbol	1	1		1	1	1	1		1		1		1	1	
E	2nd Color	1	1	1	1	1		1	1	1		1	1	1	1	1
F	Skull/Crossbones															1
G	Faucet												1			
H	Prohibition X			1					1		1		1			
I	Liquid Container															
J	2-D Panel			1		1								1		
K	Lightning Bolts								1							
L	Single Water Drop					1										
M	3-D Object															
N	Multi-Panel															
O	Water Ripple			1												
P	Spark					1										1
Q	Single Lightning Bolt					1										
R	Energized Equipment								1							
S	Two Hands								1			1				
T	Puddle									1						
U	Person											1				
V	Sequence Arrow															
W	Rain Cloud															
X	Surprised Face															
Y	Permissable Circle															
Z	Happy Face															
AA	Mr. Sparky															
BB	Heat Waves															

		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
	Attribute	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**Indian**	**Indian**
A	Single Hand	1			1	1	1	**CC**	1	1	1	1	1		1	**EE**
B	1-D Surface							**CC**								**EE**
C	Multiple Water Drops	1	1	1	1	1	1	**CC**	1	1	1	1	1	1	1	**EE**
D	Prohibition Symbol	1					1	**CC**	1	1	1			1		**EE**
E	2nd Color	1	1	1	1		1	**CC**	1	1	1	1	1		1	**EE**
F	Skull/Crossbones							**CC**								**EE**
G	Faucet		1					**CC**			1					**EE**
H	Prohibition X		1	1	1	1		**CC**				1	1		1	**EE**
I	Liquid Container							**CC**								**EE**
J	2-D Panel							**CC**	1							**EE**
K	Lightning Bolts							**CC**	1							**EE**
L	Single Water Drop							**CC**								**EE**
M	3-D Object							**CC**								**EE**
N	Multi-Panel							**CC**								**EE**
O	Water Ripple							**CC**								**EE**
P	Spark							**CC**								**EE**
Q	Single Lightning Bolt							**CC**								**EE**
R	Energized Equipment							**CC**							1	**EE**
S	Two Hands							**CC**						1		**EE**
T	Puddle							**CC**								**EE**
U	Person							**CC**								**EE**
V	Sequence Arrow							**CC**								**EE**
W	Rain Cloud							**CC**								**EE**
X	Surprised Face							**CC**								**EE**
Y	Permissable Circle							**CC**								**EE**
Z	Happy Face							**CC**								**EE**
AA	Mr. Sparky							**CC**								**EE**
BB	Heat Waves							**CC**								**EE**

		46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	Attribute	**Indian**	**Indian**	**U.S.**	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**
A	Single Hand	1	1	1	**EE**	1		1	1	1	1	1	1	1	**CC**	**EE**
B	1-D Surface				**EE**		1								**CC**	**EE**
C	Multiple Water Drops	1		1	**EE**	1	1	1	1	1	1	1	1	1	**CC**	**EE**
D	Prohibition Symbol			1	**EE**		1	1	1			1			**CC**	**EE**
E	2nd Color	1	1	1	**EE**			1	1	1		1	1	1	**CC**	**EE**
F	Skull/Crossbones				**EE**										**CC**	**EE**
G	Faucet		1		**EE**										**CC**	**EE**
H	Prohibition X	1	1		**EE**	1				1	1		1	1	**CC**	**EE**
I	Liquid Container				**EE**										**CC**	**EE**
J	2-D Panel		1		**EE**				1			1	1	1	**CC**	**EE**
K	Lightning Bolts			1	**EE**										**CC**	**EE**
L	Single Water Drop		1		**EE**										**CC**	**EE**
M	3-D Object				**EE**					1					**CC**	**EE**
N	Multi-Panel		1		**EE**								1		**CC**	**EE**
O	Water Ripple				**EE**										**CC**	**EE**
P	Spark				**EE**		1							1	**CC**	**EE**
Q	Single Lightning Bolt				**EE**										**CC**	**EE**
R	Energized Equipment				**EE**	1					1				**CC**	**EE**
S	Two Hands				**EE**										**CC**	**EE**
T	Puddle				**EE**		1								**CC**	**EE**
U	Person				**EE**		1					1			**CC**	**EE**
V	Sequence Arrow		1		**EE**										**CC**	**EE**
W	Rain Cloud				**EE**				1						**CC**	**EE**
X	Surprised Face				**EE**							1			**CC**	**EE**
Y	Permissable Circle				**EE**										**CC**	**EE**
Z	Happy Face				**EE**										**CC**	**EE**
AA	Mr. Sparky				**EE**										**CC**	**EE**
BB	Heat Waves				**EE**										**CC**	**EE**

	61	62	63	64	65	66	67	68	69	70
Attribute	**U.S.**	**Indian**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**
Single Hand	1	1	**EE**	1		1	1	1	**CC**	1
1-D Surface			**EE**						**CC**	
Multiple Water Drops	1	1	**EE**	1	1	1	1	1	**CC**	1
Prohibition Symbol	1	1	**EE**			1	1		**CC**	1
2nd Color	1	1	**EE**	1	1	1	1		**CC**	
Skull/Crossbones			**EE**	1	1				**CC**	
Faucet		1	**EE**		1				**CC**	
Prohibition X			**EE**		1				**CC**	
Liquid Container			**EE**				1		**CC**	
2-D Panel		1	**EE**	1	1				**CC**	
Lightning Bolts			**EE**						**CC**	
Single Water Drop			**EE**						**CC**	
3-D Object	1		**EE**						**CC**	
Multi-Panel		1	**EE**	1		1		1	**CC**	
Water Ripple			**EE**				1		**CC**	
Spark			**EE**	1				1	**CC**	
Single Lightning Bolt		1	**EE**						**CC**	
Energized Equipment			**EE**	1				1	**CC**	
Two Hands		1	**EE**						**CC**	
Puddle			**EE**						**CC**	
Person			**EE**						**CC**	
Sequence Arrow			**EE**					1	**CC**	
Rain Cloud			**EE**						**CC**	
Surprised Face			**EE**						**CC**	
Permissable Circle			**EE**						**CC**	
Happy Face			**EE**			1			**CC**	
Mr. Sparky			**EE**					1	**CC**	
Heat Waves			**EE**						**CC**	

Attribute matrix produced by Panelist #2 for "Do Not Touch with Wet Hands".

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Attribute	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**	**Indian**
A	Single Hand	**EE**	**EE**	1	1	1	1	1	1	1	1	1	1	1	1	1
B	1-D Surface	**EE**	**EE**	1	1											
C	Multiple Water Drops	**EE**	**EE**	1	1	1	1	1	1	1	1		1	1	1	1
D	Prohibition Symbol	**EE**	**EE**	1	1			1				1		1		
E	2nd Color	**EE**	**EE**	1	1	1	1	1	1	1	1	1	1	1	1	1
F	Skull/Crossbones	**EE**	**EE**		1											
G	Faucet	**EE**	**EE**		1				1						1	
H	Prohibition X	**EE**	**EE**			1	1		1	1			1		1	1
I	Liquid Container	**EE**	**EE**				1									
J	2-D Panel	**EE**	**EE**					1							1	
K	Lightning Bolts	**EE**	**EE**								1					
L	Single Water Drop	**EE**	**EE**									1	1			
M	3-D Object	**EE**	**EE**											1		
N	Multi-Panel	**EE**	**EE**												1	
O	Water Ripple	**EE**	**EE**													
P	Spark	**EE**	**EE**													
Q	Single Lightning Bolt	**EE**	**EE**													
R	Energized Equipment	**EE**	**EE**													
S	Two Hands	**EE**	**EE**													
T	Puddle	**EE**	**EE**													
U	Person	**EE**	**EE**													
V	Sequence Arrow	**EE**	**EE**													
W	Rain Cloud	**EE**	**EE**													
X	Surprised Face	**EE**	**EE**													
Y	Permissable Circle	**EE**	**EE**													
Z	Happy Face	**EE**	**EE**													
AA	Mr. Sparky	**EE**	**EE**													
BB	Heat Waves	**EE**	**EE**													

	Attribute	16 Indian	17 Indian	18 U.S.	19 U.S.	20 U.S.	21 Indian	22 U.S.	23 U.S.	24 U.S.	25 U.S.	26 U.S.	27 Indian	28 U.S.	29 U.S.	30 Indian
A	Single Hand	1	1	1	1	1	1	1		1	1		1	1	1	1
B	1-D Surface															
C	Multiple Water Drops	1	1	1	1		1	1	1	1	1		1	1	1	1
D	Prohibition Symbol		1		1	1	1	1		1		1		1	1	
E	2nd Color	1	1	1	1	1		1	1	1		1	1		1	1
F	Skull/Crossbones															1
G	Faucet												1			
H	Prohibition X	1		1					1		1		1			
I	Liquid Container															
J	2-D Panel			1		1								1		
K	Lightning Bolts					1			1							
L	Single Water Drop					1										
M	3-D Object															
N	Multi-Panel															
O	Water Ripple			1												
P	Spark					1										1
Q	Single Lightning Bolt					1										
R	Energized Equipment								1							
S	Two Hands								1			1				
T	Puddle									1						
U	Person											1				
V	Sequence Arrow															
W	Rain Cloud															
X	Surprised Face															
Y	Permissable Circle															
Z	Happy Face															
AA	Mr. Sparky															
BB	Heat Waves															

	Attribute	31 U.S.	32 Indian	33 Indian	34 Indian	35 Indian	36 U.S.	37 Indian	38 U.S.	39 U.S.	40 U.S.	41 Indian	42 Indian	43 U.S.	44 Indian	45 Indian
A	Single Hand	1			1	1	1	**CC**	1	1	1	1	1		1	**CC**
B	1-D Surface							**CC**								**CC**
C	Multiple Water Drops	1	1	1	1	1	1	**CC**	1	1	1	1	1	1	1	**CC**
D	Prohibition Symbol	1					1	**CC**	1	1	1			1		**CC**
E	2nd Color	1	1	1	1		1	**CC**	1	1	1	1	1		1	**CC**
F	Skull/Crossbones							**CC**								**CC**
G	Faucet		1					**CC**			1					**CC**
H	Prohibition X		1	1	1	1		**CC**				1	1		1	**CC**
I	Liquid Container							**CC**								**CC**
J	2-D Panel							**CC**	1							**CC**
K	Lightning Bolts							**CC**	1							**CC**
L	Single Water Drop							**CC**								**CC**
M	3-D Object							**CC**								**CC**
N	Multi-Panel							**CC**								**CC**
O	Water Ripple							**CC**								**CC**
P	Spark							**CC**								**CC**
Q	Single Lightning Bolt							**CC**								**CC**
R	Energized Equipment							**CC**							1	**CC**
S	Two Hands		1	1				**CC**						1		**CC**
T	Puddle							**CC**								**CC**
U	Person							**CC**								**CC**
V	Sequence Arrow							**CC**								**CC**
W	Rain Cloud							**CC**								**CC**
X	Surprised Face							**CC**								**CC**
Y	Permissable Circle							**CC**								**CC**
Z	Happy Face							**CC**								**CC**
AA	Mr. Sparky							**CC**								**CC**
BB	Heat Waves							**CC**								**CC**

		46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	Attribute	**Indian**	**Indian**	**U.S.**	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**
A	Single Hand	1	1	1	**EE**	1		1	1	1	1		1	1	**EE**	**EE**
B	1-D Surface				**EE**		1								**EE**	**EE**
C	Multiple Water Drops	1		1	**EE**	1	1	1	1	1	1	1	1	1	**EE**	**EE**
D	Prohibition Symbol		1	1	**EE**				1	1					**EE**	**EE**
E	2nd Color	1	1	1	**EE**			1	1	1		1	1	1	**EE**	**EE**
F	Skull/Crossbones				**EE**										**EE**	**EE**
G	Faucet		1		**EE**										**EE**	**EE**
H	Prohibition X	1			**EE**	1	1	1		1	1	1	1	1	**EE**	**EE**
I	Liquid Container				**EE**										**EE**	**EE**
J	2-D Panel		1		**EE**				1			1	1	1	**EE**	**EE**
K	Lightning Bolts			1	**EE**										**EE**	**EE**
L	Single Water Drop				**EE**										**EE**	**EE**
M	3-D Object				**EE**					1					**EE**	**EE**
N	Multi-Panel		1		**EE**								1		**EE**	**EE**
O	Water Ripple				**EE**										**EE**	**EE**
P	Spark				**EE**		1							1	**EE**	**EE**
Q	Single Lightning Bolt				**EE**										**EE**	**EE**
R	Energized Equipment				**EE**	1					1				**EE**	**EE**
S	Two Hands				**EE**										**EE**	**EE**
T	Puddle				**EE**										**EE**	**EE**
U	Person				**EE**							1			**EE**	**EE**
V	Sequence Arrow		1		**EE**										**EE**	**EE**
W	Rain Cloud				**EE**				1						**EE**	**EE**
X	Surprised Face				**EE**							1			**EE**	**EE**
Y	Permissable Circle				**EE**								1		**EE**	**EE**
Z	Happy Face				**EE**										**EE**	**EE**
AA	Mr. Sparky				**EE**										**EE**	**EE**
BB	Heat Waves				**EE**										**CC**	**EE**

		61	62	63	64	65	66	67	68	69	70
	Attribute	**U.S.**	**Indian**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**
A	Single Hand	1		**EE**	1		1	1	1	**CC**	1
B	1-D Surface			**EE**						**CC**	
C	Multiple Water Drops	1	1	**EE**	1	1	1	1		**CC**	1
D	Prohibition Symbol	1	1	**EE**			1			**CC**	
E	2nd Color	1	1	**EE**	1	1	1	1		**CC**	
F	Skull/Crossbones			**EE**	1					**CC**	
G	Faucet		1	**EE**		1			1	**CC**	
H	Prohibition X			**EE**		1		1		**CC**	1
I	Liquid Container			**EE**	1			1		**CC**	
J	2-D Panel		1	**EE**		1				**CC**	
K	Lightning Bolts			**EE**	1					**CC**	
L	Single Water Drop			**EE**						**CC**	
M	3-D Object	1		**EE**						**CC**	
N	Multi-Panel		1	**EE**	1		1		1	**CC**	
O	Water Ripple			**EE**				1		**CC**	
P	Spark			**EE**	1				1	**CC**	
Q	Single Lightning Bolt		1	**EE**						**CC**	
R	Energized Equipment			**EE**	1				1	**CC**	
S	Two Hands		1	**EE**						**CC**	
T	Puddle			**EE**						**CC**	
U	Person			**EE**		1				**CC**	
V	Sequence Arrow			**EE**					1	**CC**	
W	Rain Cloud			**EE**						**CC**	
X	Surprised Face			**EE**						**CC**	
Y	Permissable Circle			**EE**						**CC**	
Z	Happy Face			**EE**			1			**CC**	
AA	Mr. Sparky			**EE**					1	**CC**	
BB	Heat Waves			**EE**					1	**CC**	

Attribute matrix produced by Panelist #3 for “Do Not Touch with Wet Hands”.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Attribute	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**	**Indian**
A	Single Hand	**EE**	**EE**	1	1	1	1	1	1	1	1	1	1	1	1	1
B	1-D Surface	**EE**	**EE**	1				1								
C	Multiple Water Drops	**EE**	**EE**	1	1	1	1	1	1	1	1			1	1	1
D	Prohibition Symbol	**EE**	**EE**	1	1			1				1		1		
E	2nd Color	**EE**	**EE**	1	1	1	1	1	1	1	1	1	1		1	
F	Skull/Crossbones	**EE**	**EE**		1											
G	Faucet	**EE**	**EE**		1				1						1	
H	Prohibition X	**EE**	**EE**			1	1		1	1			1		1	1
I	Liquid Container	**EE**	**EE**				1									
J	2-D Panel	**EE**	**EE**					1					1		1	
K	Lightning Bolts	**EE**	**EE**								1					
L	Single Water Drop	**EE**	**EE**									1	1			
M	3-D Object	**EE**	**EE**											1		
N	Multi-Panel	**EE**	**EE**												1	
O	Water Ripple	**EE**	**EE**													
P	Spark	**EE**	**EE**													
Q	Single Lightning Bolt	**EE**	**EE**													
R	Energized Equipment	**EE**	**EE**													
S	Two Hands	**EE**	**EE**													
T	Puddle	**EE**	**EE**													
U	Person	**EE**	**EE**													
V	Sequence Arrow	**EE**	**EE**													
W	Rain Cloud	**EE**	**EE**													
X	Surprised Face	**EE**	**EE**													
Y	Permissable Circle	**EE**	**EE**													
Z	Happy Face	**EE**	**EE**													
AA	Mr. Sparky	**EE**	**EE**													
BB	Heat Waves	**EE**	**EE**													

		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	Attribute	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**Indian**
A	Single Hand	1	1	1	1	1	1	1		1	1		1	1	1	1
B	1-D Surface		1													
C	Multiple Water Drops	1	1	1	1		1	1	1	1	1	1	1	1	1	1
D	Prohibition Symbol				1	1	1	1		1		1		1	1	
E	2nd Color		1	1	1	1		1	1	1		1	1	1	1	1
F	Skull/Crossbones															1
G	Faucet												1			
H	Prohibition X	1		1					1		1		1			
I	Liquid Container															
J	2-D Panel			1		1								1		
K	Lightning Bolts								1							
L	Single Water Drop					1										
M	3-D Object															
N	Multi-Panel															
O	Water Ripple			1												
P	Spark					1										1
Q	Single Lightning Bolt					1										
R	Energized Equipment								1							
S	Two Hands								1							
T	Puddle									1						
U	Person											1				
V	Sequence Arrow															
W	Rain Cloud															
X	Surprised Face															
Y	Permissable Circle															
Z	Happy Face															
AA	Mr. Sparky															
BB	Heat Waves															

		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
	Attribute	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**Indian**	**Indian**
A	Single Hand	1			1	1	1	**CC**	1	1	1	1	1	1	1	**CC**
B	1-D Surface							**CC**								**CC**
C	Multiple Water Drops	1	1	1	1	1	1	**CC**	1	1	1	1	1	1	1	**CC**
D	Prohibition Symbol	1					1	**CC**	1	1	1			1		**CC**
E	2nd Color	1	1	1	1		1	**CC**	1	1	1	1	1		1	**CC**
F	Skull/Crossbones							**CC**								**CC**
G	Faucet		1					**CC**			1					**CC**
H	Prohibition X		1	1	1	1		**CC**				1	1		1	**CC**
I	Liquid Container							**CC**								**CC**
J	2-D Panel							**CC**	1							**CC**
K	Lightning Bolts							**CC**	1							**CC**
L	Single Water Drop							**CC**								**CC**
M	3-D Object							**CC**								**CC**
N	Multi-Panel							**CC**								**CC**
O	Water Ripple							**CC**								**CC**
P	Spark							**CC**								**CC**
Q	Single Lightning Bolt							**CC**								**CC**
R	Energized Equipment							**CC**							1	**CC**
S	Two Hands		1	1				**CC**								**CC**
T	Puddle							**CC**								**CC**
U	Person							**CC**								**CC**
V	Sequence Arrow							**CC**								**CC**
W	Rain Cloud							**CC**								**CC**
X	Surprised Face							**CC**								**CC**
Y	Permissable Circle							**CC**								**CC**
Z	Happy Face							**CC**								**CC**
AA	Mr. Sparky							**CC**								**CC**
BB	Heat Waves							**CC**								**CC**

		46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	Attribute	**Indian**	**Indian**	**U.S.**	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**
A	Single Hand	1	1	1	**EE**	1		1	1	1	1		1	1	**CC**	**EE**
B	1-D Surface				**EE**		1								**CC**	**EE**
C	Multiple Water Drops	1		1	**EE**	1	1	1	1	1	1	1	1	1	**CC**	**EE**
D	Prohibition Symbol		1	1	**EE**				1						**CC**	**EE**
E	2nd Color	1	1	1	**EE**	1		1	1	1		1	1	1	**CC**	**EE**
F	Skull/Crossbones				**EE**										**CC**	**EE**
G	Faucet		1		**EE**										**CC**	**EE**
H	Prohibition X	1			**EE**	1	1	1		1	1	1	1	1	**CC**	**EE**
I	Liquid Container				**EE**										**CC**	**EE**
J	2-D Panel		1		**EE**				1			1	1		**CC**	**EE**
K	Lightning Bolts			1	**EE**		1								**CC**	**EE**
L	Single Water Drop		1		**EE**										**CC**	**EE**
M	3-D Object				**EE**					1					**CC**	**EE**
N	Multi-Panel		1		**EE**								1		**CC**	**EE**
O	Water Ripple				**EE**										**CC**	**EE**
P	Spark				**EE**									1	**CC**	**EE**
Q	Single Lightning Bolt				**EE**										**CC**	**EE**
R	Energized Equipment				**EE**	1					1			1	**CC**	**EE**
S	Two Hands				**EE**										**CC**	**EE**
T	Puddle				**EE**										**CC**	**EE**
U	Person				**EE**		1					1			**CC**	**EE**
V	Sequence Arrow		1		**EE**										**CC**	**EE**
W	Rain Cloud				**EE**				1						**CC**	**EE**
X	Surprised Face				**EE**							1			**CC**	**EE**
Y	Permissable Circle				**EE**								1		**CC**	**EE**
Z	Happy Face				**EE**										**CC**	**EE**
AA	Mr. Sparky				**EE**										**CC**	**EE**
BB	Heat Waves				**EE**										**CC**	**EE**

		61	62	63	64	65	66	67	68	69	70
	Attribute	**U.S.**	**Indian**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**
A	Single Hand	1	1	**EE**	1		1	1	1	**CC**	1
B	1-D Surface			**EE**						**CC**	
C	Multiple Water Drops	1	1	**EE**	1	1	1	1	1	**CC**	1
D	Prohibition Symbol	1	1	**EE**			1			**CC**	
E	2nd Color	1	1	**EE**	1	1	1	1		**CC**	
F	Skull/Crossbones		1	**EE**	1	1				**CC**	
G	Faucet			**EE**		1			1	**CC**	
H	Prohibition X			**EE**		1		1		**CC**	1
I	Liquid Container			**EE**	1			1		**CC**	
J	2-D Panel		1	**EE**	1	1				**CC**	
K	Lightning Bolts			**EE**	1				1	**CC**	
L	Single Water Drop			**EE**						**CC**	
M	3-D Object	1		**EE**						**CC**	
N	Multi-Panel		1	**EE**	1		1		1	**CC**	
O	Water Ripple			**EE**				1		**CC**	
P	Spark			**EE**	1					**CC**	
Q	Single Lightning Bolt		1	**EE**						**CC**	
R	Energized Equipment			**EE**	1				1	**CC**	
S	Two Hands		1	**EE**						**CC**	
T	Puddle			**EE**						**CC**	
U	Person			**EE**						**CC**	
V	Sequence Arrow			**EE**					1	**CC**	
W	Rain Cloud			**EE**						**CC**	
X	Surprised Face			**EE**						**CC**	
Y	Permissable Circle			**EE**						**CC**	
Z	Happy Face			**EE**			1			**CC**	
AA	Mr. Sparky			**EE**					1	**CC**	
BB	Heat Waves			**EE**					1	**CC**	

Consensus attribute matrix produced by summing the three individual panelists' attribute matrices for "Hot Exhaust".

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Attributes	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**	**Indian**
A	Directional Arrow	3	0	0	0	0	0	0	0	0	1	3	0	0	0	0
B	Safety Alert Symbol	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0
C	Emmission Lines	3	3	3	3	3	3	3	2	3	3	1	2	3	3	0
D	Pipe or Stack	3	1	1	1	3	0	3	3	3	0	3	3	3	3	1
E	2nd Color	3	0	0	2	0	2	0	3	3	3	3	3	2	0	2
F	Negative Face	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
G	Person	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
H	Vat	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0
I	Thermometer	0	0	0	0	3	3	0	0	0	0	0	3	0	0	0
J	Flame	0	0	0	0	0	0	0	3	0	3	3	3	0	0	3
K	Cloud	0	0	0	0	0	0	0	0	3	0	0	3	0	0	0
L	Exclamation Point	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0
M	Vented Object	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0
N	Particulates	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
O	Prohibition Symbol	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
P	Emphasis Arrows	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Q	Structure	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
R	Skull/Crossbones	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Vulnerable Object	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
T	Vent Grate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U	Positive Face	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
V	Vector	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	Prohibited X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
X	Hand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Y	Thermos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z	Hood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AA	Degree Symbol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BB	Fan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CC	Surface	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DD	Radiant Heat Lines	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EE	Multi-Panel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FF	Ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GG	Surprise Face	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HH	Relief Valve	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
II	Movement Lines	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	Attributes	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**
A	Directional Arrow	1	0	0	0	0	0	0	0	0	2	0	3	2	0	0
B	Safety Alert Symbol	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
C	Emmission Lines	3	3	0	3	3	3	2	3	0	1	3	3	1	2	0
D	Pipe or Stack	3	3	0	2	3	3	0	3	0	3	3	3	3	0	3
E	2nd Color	0	0	3	3	3	2	3	3	2	3	2	0	3	3	2
F	Negative Face	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	Person	0	0	0	3	3	0	0	0	0	0	0	0	2	0	0
H	Vat	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
I	Thermometer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J	Flame	3	3	3	0	0	0	2	3	3	0	0	0	3	1	3
K	Cloud	1	0	1	0	0	0	1	0	3	0	0	0	0	0	3
L	Exclamation Point	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
M	Vented Object	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
N	Particulates	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	Prohibition Symbol	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0
P	Emphasis Arrows	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Q	Structure	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
R	Skull/Crossbones	3	0	0	0	0	0	0	0	0	3	3	0	0	0	0
S	Vulnerable Object	0	3	3	1	0	0	0	0	0	0	0	0	3	0	0
T	Vent Grate	0	0	3	3	0	0	0	0	0	0	0	0	0	3	0
U	Positive Face	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
V	Vector	0	0	0	2	2	0	0	0	0	0	0	0	2	0	0
W	Prohibited X	0	0	0	0	3	0	3	0	0	0	0	0	0	0	0
X	Hand	0	0	0	0	0	0	3	0	0	0	0	0	0	2	0
Y	Thermos	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Z	Hood	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
AA	Degree Symbol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
BB	Fan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CC	Surface	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DD	Radiant Heat Lines	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EE	Multi-Panel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FF	Ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GG	Surprise Face	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HH	Relief Valve	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
II	Movement Lines	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
	Attributes	**Indian**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**
A	Directional Arrow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	Safety Alert Symbol	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
C	Emmission Lines	3	3	2	3	3	3	3	3	3	0	2	0	3	3	3
D	Pipe or Stack	0	3	0	2	1	0	3	3	0	1	3	0	0	3	0
E	2nd Color	3	3	0	0	3	3	3	2	3	3	3	2	2	2	3
F	Negative Face	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	Person	0	0	0	0	0	3	2	0	0	3	3	0	0	3	0
H	Vat	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
I	Thermometer	0	0	0	3	0	0	0	0	3	0	0	0	0	0	0
J	Flame	0	0	3	0	0	0	1	0	0	1	2	2	3	0	0
K	Cloud	0	0	0	0	0	0	1	1	0	0	3	1	0	0	0
L	Exclamation Point	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M	Vented Object	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
N	Particulates	0	0	0	0	0	0	0	2	0	0	2	0	0	0	2
O	Prohibition Symbol	0	0	0	0	0	0	0	0	0	3	3	0	0	3	0
P	Emphasis Arrows	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Q	Structure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	Skull/Crossbones	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Vulnerable Object	0	0	2	0	0	0	0	0	0	3	2	0	0	0	0
T	Vent Grate	1	0	0	3	0	0	0	0	3	1	0	0	3	0	0
U	Positive Face	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
V	Vector	0	0	0	0	0	3	0	0	0	1	0	0	0	0	0
W	Prohibited X	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0
X	Hand	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Y	Thermos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z	Hood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AA	Degree Symbol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BB	Fan	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3
CC	Surface	2	0	1	0	0	2	0	0	1	0	0	0	0	0	0
DD	Radiant Heat Lines	0	3	1	0	0	0	0	1	0	0	0	0	2	0	0
EE	Multi-Panel	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
FF	Ground	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
GG	Surprise Face	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
HH	Relief Valve	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
II	Movement Lines	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	Attributes	**Indian**	**U.S.**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**Indian**	**Indian**	**Indian**	**U.S.**
A	Directional Arrow	1	1	0	2	0	0	0	0	**EE**	**EE**	0	**EE**	1	3	0
B	Safety Alert Symbol	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
C	Emmission Lines	2	3	3	0	2	3	3	1	**EE**	**EE**	3	**EE**	3	2	3
D	Pipe or Stack	1	1	0	3	1	3	3	2	**EE**	**EE**	3	**EE**	3	1	0
E	2nd Color	2	3	3	3	3	3	3	0	**EE**	**EE**	3	**EE**	2	0	2
F	Negative Face	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
G	Person	0	0	0	0	0	2	0	3	**EE**	**EE**	0	**EE**	3	0	0
H	Vat	0	0	0	0	2	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
I	Thermometer	0	0	0	0	0	0	3	0	**EE**	**EE**	0	**EE**	0	0	0
J	Flame	0	3	0	3	0	3	0	0	**EE**	**EE**	3	**EE**	3	0	2
K	Cloud	3	0	0	3	0	0	3	3	**EE**	**EE**	0	**EE**	0	0	2
L	Exclamation Point	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
M	Vented Object	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
N	Particulates	2	0	3	3	0	0	2	0	**EE**	**EE**	0	**EE**	0	0	0
O	Prohibition Symbol	0	1	0	0	0	3	0	0	**EE**	**EE**	0	**EE**	0	0	0
P	Emphasis Arrows	0	1	0	1	0	0	0	0	**EE**	**EE**	0	**EE**	1	0	0
Q	Structure	0	0	0	3	0	0	0	0	**EE**	**EE**	0	**EE**	1	0	0
R	Skull/Crossbones	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
S	Vulnerable Object	0	0	2	0	0	3	0	0	**EE**	**EE**	3	**EE**	3	0	0
T	Vent Grate	0	3	3	0	2	0	0	0	**EE**	**EE**	0	**EE**	0	0	3
U	Positive Face	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
V	Vector	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
W	Prohibited X	0	0	3	0	0	0	0	0	**EE**	**EE**	0	**EE**	3	0	0
X	Hand	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
Y	Thermos	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
Z	Hood	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
AA	Degree Symbol	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
BB	Fan	3	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
CC	Surface	0	0	1	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	3	0
DD	Radiant Heat Lines	1	1	0	0	1	0	1	0	**EE**	**EE**	3	**EE**	0	1	1
EE	Multi-Panel	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
FF	Ground	0	0	0	0	0	0	0	0	**EE**	**EE**	0	**EE**	0	0	0
GG	Surprise Face	0	0	0	0	0	0	0	3	**EE**	**EE**	0	**EE**	0	0	0
HH	Relief Valve	0	0	0	0	0	0	0	3	**EE**	**EE**	0	**EE**	0	0	0
II	Movement Lines	0	0	0	0	0	0	0	3	**EE**	**EE**	0	**EE**	0	0	0

		61	62	63	64	65	66	67	68	69	70
	Attributes	**U.S.**	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**Indian**	**Indian**	**U.S.**
A	Directional Arrow	3	0	3	0	**EE**	0	0	0	1	0
B	Safety Alert Symbol	0	3	0	0	**EE**	0	0	0	2	0
C	Emmission Lines	3	3	3	3	**EE**	2	3	2	2	3
D	Pipe or Stack	2	0	3	0	**EE**	3	3	3	0	0
E	2nd Color	0	3	3	3	**EE**	3	3	3	0	1
F	Negative Face	0	3	0	0	**EE**	0	0	0	0	3
G	Person	0	0	0	0	**EE**	0	3	0	0	1
H	Vat	0	0	0	0	**EE**	0	0	0	0	0
I	Thermometer	0	3	0	0	**EE**	0	0	0	0	0
J	Flame	3	0	2	0	**EE**	0	0	3	3	0
K	Cloud	0	0	0	0	**EE**	0	1	3	0	0
L	Exclamation Point	0	3	0	0	**EE**	0	0	0	0	0
M	Vented Object	0	0	0	0	**EE**	1	0	0	0	0
N	Particulates	0	0	0	0	**EE**	0	0	0	0	0
O	Prohibition Symbol	0	0	0	0	**EE**	1	2	1	0	0
P	Emphasis Arrows	0	0	0	0	**EE**	0	0	0	0	0
Q	Structure	0	0	0	0	**EE**	0	0	0	0	0
R	Skull/Crossbones	0	0	3	0	**EE**	0	0	0	0	0
S	Vulnerable Object	0	0	3	0	**EE**	0	0	0	0	0
T	Vent Grate	0	3	0	0	**EE**	3	0	0	0	1
U	Positive Face	0	0	0	0	**EE**	0	0	0	0	0
V	Vector	0	0	0	0	**EE**	0	0	0	2	0
W	Prohibited X	0	0	0	0	**EE**	0	0	0	0	0
X	Hand	0	0	0	0	**EE**	0	2	3	0	0
Y	Thermos	0	0	0	0	**EE**	0	0	0	0	0
Z	Hood	0	0	0	0	**EE**	0	0	0	0	0
AA	Degree Symbol	0	0	0	0	**EE**	0	0	0	0	0
BB	Fan	0	0	0	3	**EE**	0	0	0	3	3
CC	Surface	2	0	0	0	**EE**	0	0	0	0	0
DD	Radiant Heat Lines	2	0	0	0	**EE**	0	3	0	0	3
EE	Multi-Panel	0	0	0	0	**EE**	0	0	0	0	0
FF	Ground	0	0	0	0	**EE**	0	0	0	0	0
GG	Surprise Face	0	0	0	0	**EE**	0	0	0	0	0
HH	Relief Valve	0	0	0	0	**EE**	0	0	0	0	0
II	Movement Lines	0	0	0	0	**EE**	0	0	0	0	0

Attribute matrix produced by Panelist #1 for “Hot Exhaust”.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Attributes	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**	**Indian**
A	Directional Arrow	1										1				
B	Safety Alert Symbol	1					1									
C	Emmission Lines	1	1	1	1	1	1	1	1	1	1			1	1	
D	Pipe or Stack	1				1		1	1	1		1	1	1	1	1
E	2nd Color	1			1		1		1	1	1	1	1	1		1
F	Negative Face		1													
G	Person		1													
H	Vat		1	1	1											
I	Thermometer					1	1						1			
J	Flame								1		1	1	1			1
K	Cloud									1			1			
L	Exclamation Point									1	1					
M	Vented Object										1		1			
N	Particulates											1				
O	Prohibition Symbol												1			
P	Emphasis Arrows												1			
Q	Structure															
R	Skull/Crossbones															
S	Vulnerable Object												1			
T	Vent Grate															
U	Positive Face															
V	Vector															
W	Prohibited X															
X	Hand															
Y	Thermos															
Z	Hood															
AA	Degree Symbol															
BB	Fan															
CC	Surface															
DD	Radiant Heat Lines															
EE	Multi-Panel															
FF	Ground															
GG	Surprise Face															
HH	Relief Valve															
II	Movement Lines															

		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	Attributes	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**
A	Directional Arrow										1		1			
B	Safety Alert Symbol										1					
C	Emmission Lines	1	1		1	1	1	1	1			1	1	1	1	
D	Pipe or Stack	1	1		1	1	1		1		1	1	1	1		1
E	2nd Color			1	1	1	1	1	1	1	1	1		1	1	
F	Negative Face															
G	Person				1	1								1		
H	Vat															
I	Thermometer															
J	Flame	1	1	1				1	1	1				1		1
K	Cloud									1						1
L	Exclamation Point				1											1
M	Vented Object															
N	Particulates															
O	Prohibition Symbol		1												1	
P	Emphasis Arrows															
Q	Structure															
R	Skull/Crossbones	1									1	1				
S	Vulnerable Object		1	1	1									1		
T	Vent Grate			1	1										1	
U	Positive Face				1											
V	Vector					1								1		
W	Prohibited X					1		1								
X	Hand							1								
Y	Thermos														1	
Z	Hood														1	
AA	Degree Symbol															1
BB	Fan															
CC	Surface															
DD	Radiant Heat Lines															
EE	Multi-Panel															
FF	Ground															
GG	Surprise Face															
HH	Relief Valve															
II	Movement Lines															

		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
	Attributes	**Indian**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**
A	Directional Arrow															
B	Safety Alert Symbol									1						
C	Emmission Lines	1	1	1	1	1	1	1	1	1		1		1	1	1
D	Pipe or Stack		1		1			1	1			1			1	
E	2nd Color	1	1			1	1	1	1	1	1	1	1	1	1	1
F	Negative Face															
G	Person						1	1			1	1			1	
H	Vat					1										
I	Thermometer				1					1						
J	Flame			1							1		1	1		
K	Cloud								1			1				
L	Exclamation Point															
M	Vented Object															
N	Particulates								1			1				
O	Prohibition Symbol										1	1			1	
P	Emphasis Arrows															
Q	Structure															
R	Skull/Crossbones															
S	Vulnerable Object			1							1					
T	Vent Grate				1					1				1		
U	Positive Face															
V	Vector						1									
W	Prohibited X						1						1			
X	Hand												1			
Y	Thermos															
Z	Hood															
AA	Degree Symbol															
BB	Fan	1														1
CC	Surface	1					1			1						
DD	Radiant Heat Lines		1													
EE	Multi-Panel						1									
FF	Ground						1									
GG	Surprise Face							1								
HH	Relief Valve															
II	Movement Lines															

		46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	Attributes	**Indian**	**U.S.**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**Indian**	**Indian**	**Indian**	**U.S.**
A	Directional Arrow	1								**EE**	**EE**		**EE**		1	
B	Safety Alert Symbol									**EE**	**EE**		**EE**			
C	Emmission Lines	1	1	1		1	1	1		**EE**	**EE**	1	**EE**	1	1	1
D	Pipe or Stack		1		1		1	1	1	**EE**	**EE**	1	**EE**	1		
E	2nd Color	1	1	1	1	1	1	1		**EE**	**EE**	1	**EE**			1
F	Negative Face									**EE**	**EE**		**EE**			
G	Person						1		1	**EE**	**EE**		**EE**	1		
H	Vat					1				**EE**	**EE**		**EE**			
I	Thermometer							1		**EE**	**EE**		**EE**			
J	Flame		1		1		1			**EE**	**EE**	1	**EE**	1		1
K	Cloud	1			1			1	1	**EE**	**EE**		**EE**			1
L	Exclamation Point									**EE**	**EE**		**EE**			
M	Vented Object									**EE**	**EE**		**EE**			
N	Particulates			1	1			1		**EE**	**EE**		**EE**			
O	Prohibition Symbol		1				1			**EE**	**EE**		**EE**			
P	Emphasis Arrows				1					**EE**	**EE**		**EE**			
Q	Structure				1					**EE**	**EE**		**EE**			
R	Skull/Crossbones									**EE**	**EE**		**EE**			
S	Vulnerable Object			1			1			**EE**	**EE**	1	**EE**	1		
T	Vent Grate		1	1						**EE**	**EE**		**EE**			1
U	Positive Face									**EE**	**EE**		**EE**			
V	Vector									**EE**	**EE**		**EE**			
W	Prohibited X			1						**EE**	**EE**		**EE**	1		
X	Hand									**EE**	**EE**		**EE**			
Y	Thermos									**EE**	**EE**		**EE**			
Z	Hood									**EE**	**EE**		**EE**			
AA	Degree Symbol									**EE**	**EE**		**EE**			
BB	Fan	1								**EE**	**EE**		**EE**			
CC	Surface			1						**EE**	**EE**		**EE**		1	
DD	Radiant Heat Lines									**EE**	**EE**	1	**EE**			
EE	Multi-Panel									**EE**	**EE**		**EE**			
FF	Ground									**EE**	**EE**		**EE**			
GG	Surprise Face								1	**EE**	**EE**		**EE**			
HH	Relief Valve								1	**EE**	**EE**		**EE**			
II	Movement Lines								1	**EE**	**EE**		**EE**			

		61	62	63	64	65	66	67	68	69	70
	Attributes	**U.S.**	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**Indian**	**Indian**	**U.S.**
A	Directional Arrow	1		1		**EE**					
B	Safety Alert Symbol		1			**EE**				1	
C	Emmission Lines	1	1	1	1	**EE**		1	1	1	1
D	Pipe or Stack			1		**EE**	1	1	1		
E	2nd Color		1	1	1	**EE**	1	1	1		1
F	Negative Face		1			**EE**					1
G	Person					**EE**		1			1
H	Vat					**EE**					
I	Thermometer		1			**EE**					
J	Flame	1				**EE**			1	1	
K	Cloud					**EE**			1		
L	Exclamation Point		1			**EE**					
M	Vented Object					**EE**					
N	Particulates					**EE**					
O	Prohibition Symbol					**EE**		1	1		
P	Emphasis Arrows					**EE**					
Q	Structure					**EE**					
R	Skull/Crossbones			1		**EE**					
S	Vulnerable Object			1		**EE**					
T	Vent Grate		1			**EE**	1				
U	Positive Face					**EE**					
V	Vector					**EE**					
W	Prohibited X					**EE**					
X	Hand					**EE**		1	1		
Y	Thermos					**EE**					
Z	Hood					**EE**					
AA	Degree Symbol					**EE**					
BB	Fan				1	**EE**				1	1
CC	Surface	1				**EE**					
DD	Radiant Heat Lines	1				**EE**		1			1
EE	Multi-Panel					**EE**					
FF	Ground					**EE**					
GG	Surprise Face					**EE**					
HH	Relief Valve					**EE**					
II	Movement Lines					**EE**					

Attribute matrix produced by Panelist #2 for "Hot Exhaust".

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Attributes	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**	**Indian**
A	Directional Arrow	1										1				
B	Safety Alert Symbol	1					1									
C	Emmission Lines	1	1	1	1	1	1	1		1	1		1	1	1	
D	Pipe or Stack	1				1		1	1	1		1	1	1	1	
E	2nd Color	1							1	1	1	1	1	1		1
F	Negative Face		1													
G	Person		1													
H	Vat		1	1	1											
I	Thermometer					1	1						1			
J	Flame								1		1	1	1			1
K	Cloud									1			1			
L	Exclamation Point									1	1					
M	Vented Object										1					
N	Particulates											1				
O	Prohibition Symbol												1			
P	Emphasis Arrows												1			
Q	Structure												1			
R	Skull/Crossbones															
S	Vulnerable Object															
T	Vent Grate															
U	Positive Face															
V	Vector															
W	Prohibited X															
X	Hand															
Y	Thermos															
Z	Hood															
AA	Degree Symbol															
BB	Fan															
CC	Surface															
DD	Radiant Heat Lines															
EE	Multi-Panel															
FF	Ground															
GG	Surprise Face															
HH	Relief Valve															
II	Movement Lines															

		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	Attributes	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**
A	Directional Arrow	1											1	1		
B	Safety Alert Symbol										1					
C	Emmission Lines	1	1		1	1	1	1	1		1	1	1			
D	Pipe or Stack	1	1		1	1	1		1		1	1	1	1		1
E	2nd Color			1	1	1	1	1	1	1	1	1		1	1	1
F	Negative Face															
G	Person				1	1										
H	Vat															
I	Thermometer															
J	Flame	1	1	1				1	1	1				1	1	1
K	Cloud	1								1						1
L	Exclamation Point															1
M	Vented Object															
N	Particulates	1														
O	Prohibition Symbol		1												1	
P	Emphasis Arrows															
Q	Structure					1										
R	Skull/Crossbones	1									1	1				
S	Vulnerable Object		1	1										1		
T	Vent Grate			1	1										1	
U	Positive Face				1											
V	Vector				1	1								1		
W	Prohibited X					1		1								
X	Hand							1							1	
Y	Thermos														1	
Z	Hood														1	
AA	Degree Symbol															1
BB	Fan															
CC	Surface															
DD	Radiant Heat Lines															
EE	Multi-Panel															
FF	Ground															
GG	Surprise Face															
HH	Relief Valve															
II	Movement Lines															

		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
	Attributes	**Indian**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**
A	Directional Arrow															
B	Safety Alert Symbol									1						
C	Emmission Lines	1	1		1	1	1	1	1	1		1		1	1	1
D	Pipe or Stack		1					1	1		1	1			1	
E	2nd Color	1	1			1	1	1	1	1	1	1	1	1	1	1
F	Negative Face															
G	Person						1	1			1	1			1	
H	Vat					1										
I	Thermometer				1					1						
J	Flame			1				1				1	1	1		
K	Cloud											1				
L	Exclamation Point															
M	Vented Object															
N	Particulates								1			1				1
O	Prohibition Symbol										1	1			1	
P	Emphasis Arrows															
Q	Structure															
R	Skull/Crossbones															
S	Vulnerable Object										1	1				
T	Vent Grate				1					1				1		
U	Positive Face															
V	Vector						1				1					
W	Prohibited X						1						1			
X	Hand												1			
Y	Thermos															
Z	Hood															
AA	Degree Symbol															
BB	Fan	1														1
CC	Surface	1		1			1									
DD	Radiant Heat Lines		1	1					1					1		
EE	Multi-Panel						1									
FF	Ground						1									
GG	Surprise Face							1								
HH	Relief Valve															
II	Movement Lines															

		46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	Attributes	**Indian**	**U.S.**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**Indian**	**Indian**	**Indian**	**U.S.**
A	Directional Arrow		1		1					**EE**	**EE**		**EE**	1	1	
B	Safety Alert Symbol									**EE**	**EE**		**EE**			
C	Emmission Lines	1	1	1			1	1	1	**EE**	**EE**	1	**EE**	1		1
D	Pipe or Stack				1		1	1	1	**EE**	**EE**	1	**EE**	1	1	
E	2nd Color	1	1	1	1	1	1	1		**EE**	**EE**	1	**EE**	1		1
F	Negative Face									**EE**	**EE**		**EE**			
G	Person						1		1	**EE**	**EE**		**EE**	1		
H	Vat					1				**EE**	**EE**		**EE**			
I	Thermometer							1		**EE**	**EE**		**EE**			
J	Flame		1		1		1			**EE**	**EE**	1	**EE**	1		1
K	Cloud	1			1			1	1	**EE**	**EE**		**EE**			
L	Exclamation Point									**EE**	**EE**		**EE**			
M	Vented Object									**EE**	**EE**		**EE**			
N	Particulates	1		1	1			1		**EE**	**EE**		**EE**			
O	Prohibition Symbol						1			**EE**	**EE**		**EE**			
P	Emphasis Arrows									**EE**	**EE**		**EE**			
Q	Structure				1					**EE**	**EE**		**EE**	1		
R	Skull/Crossbones									**EE**	**EE**		**EE**			
S	Vulnerable Object						1			**EE**	**EE**	1	**EE**	1		
T	Vent Grate		1	1		1				**EE**	**EE**		**EE**			1
U	Positive Face									**EE**	**EE**		**EE**			
V	Vector									**EE**	**EE**		**EE**			
W	Prohibited X			1						**EE**	**EE**		**EE**	1		
X	Hand									**EE**	**EE**		**EE**			
Y	Thermos									**EE**	**EE**		**EE**			
Z	Hood									**EE**	**EE**		**EE**			
AA	Degree Symbol									**EE**	**EE**		**EE**			
BB	Fan	1								**EE**	**EE**		**EE**			
CC	Surface									**EE**	**EE**		**EE**		1	
DD	Radiant Heat Lines					1				**EE**	**EE**	1	**EE**		1	
EE	Multi-Panel									**EE**	**EE**		**EE**			
FF	Ground									**EE**	**EE**		**EE**			
GG	Surprise Face								1	**EE**	**EE**		**EE**			
HH	Relief Valve								1	**EE**	**EE**		**EE**			
II	Movement Lines								1	**EE**	**EE**		**EE**			

		61	62	63	64	65	66	67	68	69	70
	Attributes	**U.S.**	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**Indian**	**Indian**	**U.S.**
A	Directional Arrow	1		1		**EE**					
B	Safety Alert Symbol		1			**EE**				1	
C	Emmission Lines	1	1	1	1	**EE**	1	1		1	1
D	Pipe or Stack	1		1		**EE**	1	1	1		
E	2nd Color		1	1	1	**EE**	1	1	1		
F	Negative Face		1			**EE**					1
G	Person					**EE**		1			
H	Vat					**EE**					
I	Thermometer		1			**EE**					
J	Flame	1		1		**EE**			1	1	
K	Cloud					**EE**			1		
L	Exclamation Point		1			**EE**					
M	Vented Object					**EE**					
N	Particulates					**EE**					
O	Prohibition Symbol					**EE**	1	1			
P	Emphasis Arrows					**EE**					
Q	Structure					**EE**					
R	Skull/Crossbones			1		**EE**					
S	Vulnerable Object			1		**EE**					
T	Vent Grate		1			**EE**	1				1
U	Positive Face					**EE**					
V	Vector					**EE**				1	
W	Prohibited X					**EE**					
X	Hand					**EE**		1	1		
Y	Thermos					**EE**					
Z	Hood					**EE**					
AA	Degree Symbol					**EE**					
BB	Fan				1	**EE**				1	1
CC	Surface	1				**EE**					
DD	Radiant Heat Lines	1				**EE**		1			1
EE	Multi-Panel					**EE**					
FF	Ground					**EE**					
GG	Surprise Face					**EE**					
HH	Relief Valve					**EE**					
II	Movement Lines					**EE**					

Attribute matrix produced by Panelist #3 for “Hot Exhaust”.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Attributes	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**	**Indian**
A	Directional Arrow	1									1	1				
B	Safety Alert Symbol	1														
C	Emmission Lines	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
D	Pipe or Stack	1	1	1	1	1		1	1	1		1	1	1	1	
E	2nd Color	1			1		1		1	1	1	1	1			
F	Negative Face		1													
G	Person		1													
H	Vat															
I	Thermometer					1	1						1			
J	Flame								1		1	1	1			1
K	Cloud									1			1			
L	Exclamation Point									1	1					
M	Vented Object										1					
N	Particulates											1				
O	Prohibition Symbol												1			
P	Emphasis Arrows												1			
Q	Structure												1			
R	Skull/Crossbones															
S	Vulnerable Object															
T	Vent Grate															
U	Positive Face															
V	Vector															
W	Prohibited X															
X	Hand															
Y	Thermos															
Z	Hood															
AA	Degree Symbol															
BB	Fan															
CC	Surface															
DD	Radiant Heat Lines															
EE	Multi-Panel															
FF	Ground															
GG	Surprise Face															
HH	Relief Valve															
II	Movement Lines															

		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	Attributes	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**
A	Directional Arrow										1		1	1		
B	Safety Alert Symbol										1					
C	Emmission Lines	1	1		1	1	1		1			1	1		1	
D	Pipe or Stack	1	1			1	1		1		1	1	1	1		1
E	2nd Color			1	1	1		1	1		1			1	1	1
F	Negative Face															
G	Person				1	1								1		
H	Vat					1										
I	Thermometer															
J	Flame	1	1	1					1	1				1		1
K	Cloud			1				1		1						1
L	Exclamation Point															1
M	Vented Object				1											
N	Particulates															
O	Prohibition Symbol		1												1	
P	Emphasis Arrows					1										
Q	Structure															
R	Skull/Crossbones	1									1	1				
S	Vulnerable Object		1	1										1		
T	Vent Grate			1	1										1	
U	Positive Face				1											
V	Vector				1											
W	Prohibited X					1		1								
X	Hand							1							1	
Y	Thermos														1	
Z	Hood														1	
AA	Degree Symbol															1
BB	Fan															
CC	Surface															
DD	Radiant Heat Lines															
EE	Multi-Panel															
FF	Ground															
GG	Surprise Face															
HH	Relief Valve															
II	Movement Lines															

		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
	Attributes	**Indian**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**U.S.**	**Indian**
A	Directional Arrow															
B	Safety Alert Symbol									1						
C	Emmission Lines	1	1	1	1	1	1	1	1	1				1	1	1
D	Pipe or Stack		1		1	1		1	1			1			1	
E	2nd Color	1	1			1	1	1		1	1	1				1
F	Negative Face															
G	Person						1				1	1			1	
H	Vat															
I	Thermometer				1					1						
J	Flame			1								1		1		
K	Cloud							1				1	1			
L	Exclamation Point															
M	Vented Object						1									
N	Particulates															1
O	Prohibition Symbol										1	1			1	
P	Emphasis Arrows										1					
Q	Structure															
R	Skull/Crossbones															
S	Vulnerable Object			1							1	1				
T	Vent Grate	1			1					1	1			1		
U	Positive Face															
V	Vector						1									
W	Prohibited X						1						1			
X	Hand												1			
Y	Thermos															
Z	Hood															
AA	Degree Symbol															
BB	Fan	1														1
CC	Surface															
DD	Radiant Heat Lines		1											1		
EE	Multi-Panel						1									
FF	Ground						1									
GG	Surprise Face							1								
HH	Relief Valve															
II	Movement Lines															

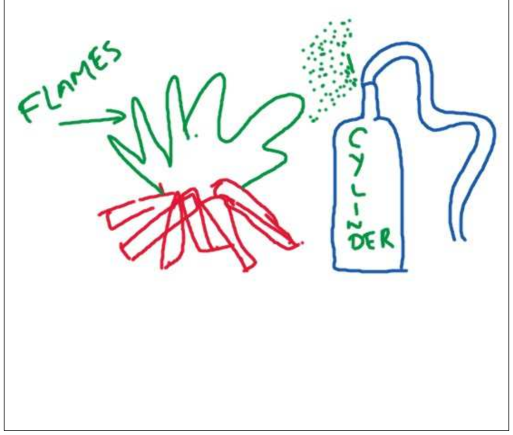
		46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	Attributes	**Indian**	**U.S.**	**Indian**	**Indian**	**U.S.**	**U.S.**	**U.S.**	**U.S.**	**Indian**	**Indian**	**U.S.**	**Indian**	**Indian**	**Indian**	**U.S.**
A	Directional Arrow				1					**EE**	**EE**		**EE**		1	
B	Safety Alert Symbol									**EE**	**EE**		**EE**			
C	Emmission Lines		1	1		1	1	1		**EE**	**EE**	1	**EE**	1	1	1
D	Pipe or Stack	1			1	1	1	1		**EE**	**EE**	1	**EE**	1		
E	2nd Color		1	1	1	1	1	1		**EE**	**EE**	1	**EE**	1		
F	Negative Face									**EE**	**EE**		**EE**			
G	Person								1	**EE**	**EE**		**EE**	1		
H	Vat									**EE**	**EE**		**EE**			
I	Thermometer							1		**EE**	**EE**		**EE**			
J	Flame		1		1		1			**EE**	**EE**	1	**EE**	1		
K	Cloud	1			1			1	1	**EE**	**EE**		**EE**			1
L	Exclamation Point									**EE**	**EE**		**EE**			
M	Vented Object									**EE**	**EE**		**EE**			
N	Particulates	1		1	1					**EE**	**EE**		**EE**			
O	Prohibition Symbol						1			**EE**	**EE**		**EE**			
P	Emphasis Arrows		1							**EE**	**EE**		**EE**	1		
Q	Structure				1					**EE**	**EE**		**EE**			
R	Skull/Crossbones									**EE**	**EE**		**EE**			
S	Vulnerable Object			1			1			**EE**	**EE**	1	**EE**	1		
T	Vent Grate		1	1		1				**EE**	**EE**		**EE**			1
U	Positive Face									**EE**	**EE**		**EE**			
V	Vector									**EE**	**EE**		**EE**			
W	Prohibited X			1						**EE**	**EE**		**EE**	1		
X	Hand									**EE**	**EE**		**EE**			
Y	Thermos									**EE**	**EE**		**EE**			
Z	Hood									**EE**	**EE**		**EE**			
AA	Degree Symbol									**EE**	**EE**		**EE**			
BB	Fan	1								**EE**	**EE**		**EE**			
CC	Surface									**EE**	**EE**		**EE**		1	
DD	Radiant Heat Lines	1	1					1		**EE**	**EE**	1	**EE**			1
EE	Multi-Panel									**EE**	**EE**		**EE**			
FF	Ground									**EE**	**EE**		**EE**			
GG	Surprise Face								1	**EE**	**EE**		**EE**			
HH	Relief Valve								1	**EE**	**EE**		**EE**			
II	Movement Lines								1	**EE**	**EE**		**EE**			

		61	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**
	Attributes	**U.S.**	**U.S.**	**Indian**	**Indian**	**Indian**	**Indian**	**U.S.**	**Indian**	**Indian**	**U.S.**
A	Directional Arrow	1		1		**EE**				1	
B	Safety Alert Symbol		1			**EE**					
C	Emmission Lines	1	1	1	1	**EE**	1	1	1		1
D	Pipe or Stack	1		1		**EE**	1	1	1		
E	2nd Color		1	1	1	**EE**	1	1	1		
F	Negative Face		1			**EE**					1
G	Person					**EE**		1			
H	Vat					**EE**					
I	Thermometer		1			**EE**					
J	Flame	1		1		**EE**			1	1	
K	Cloud					**EE**		1	1		
L	Exclamation Point		1			**EE**					
M	Vented Object					**EE**	1				
N	Particulates					**EE**					
O	Prohibition Symbol					**EE**					
P	Emphasis Arrows					**EE**					
Q	Structure					**EE**					
R	Skull/Crossbones			1		**EE**					
S	Vulnerable Object			1		**EE**					
T	Vent Grate		1			**EE**	1				
U	Positive Face					**EE**					
V	Vector					**EE**				1	
W	Prohibited X					**EE**					
X	Hand					**EE**			1		
Y	Thermos					**EE**					
Z	Hood					**EE**					
AA	Degree Symbol					**EE**					
BB	Fan				1	**EE**				1	1
CC	Surface					**EE**					
DD	Radiant Heat Lines					**EE**		1			1
EE	Multi-Panel					**EE**					
FF	Ground					**EE**					
GG	Surprise Face					**EE**					
HH	Relief Valve					**EE**					
II	Movement Lines					**EE**					

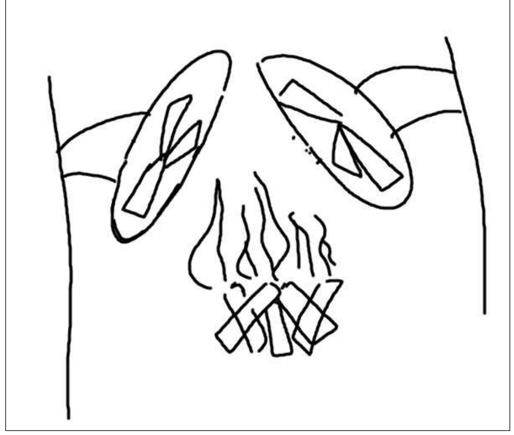
APPENDIX 4.7

"Hot Exhaust" Symbols voted as Egregious Error by expert panel

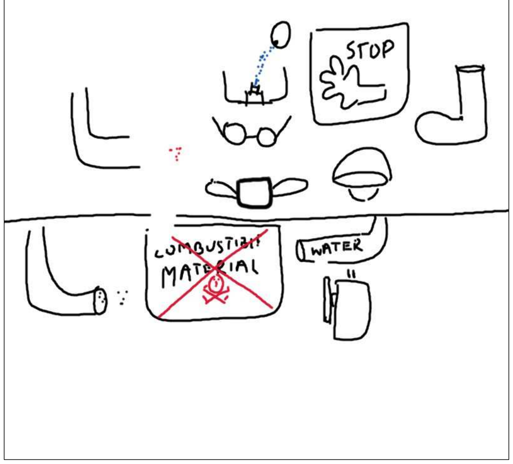
54



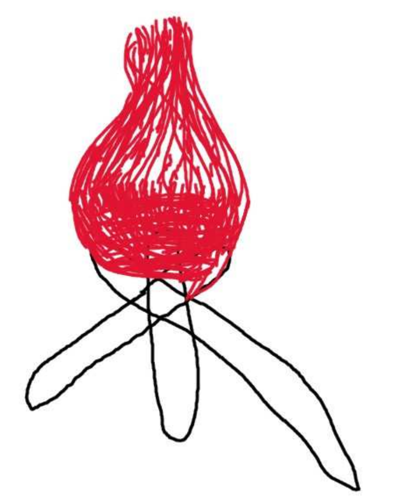
55



65



57



Each of these symbols was drawn for the referent "Hot Exhaust" and was discarded by majority vote of the expert panel. The panel perceived that the artists did not understand the intent of the referent or did not portray the intent in their picture.

These symbols were not included in the clustering process to prevent passing potentially erroneous symbol attributes into the DIGA symbol design tool, perhaps at the expense of attributes contributing to adequate symbol designs.

Note: No symbols were labeled "Critical Confusion" for the "Hot Exhaust" referent.

“Do Not Touch with Wet Hands” Symbols voted as Egregious Error by expert panel

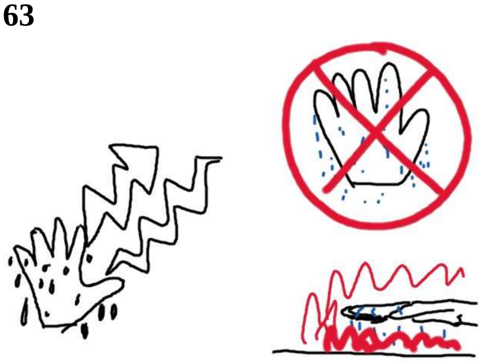
1

2

49

60

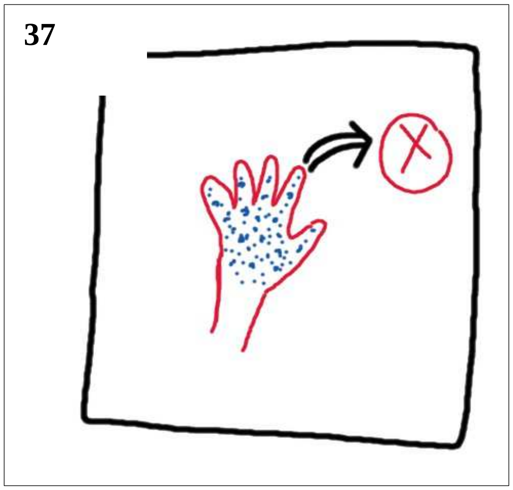
63



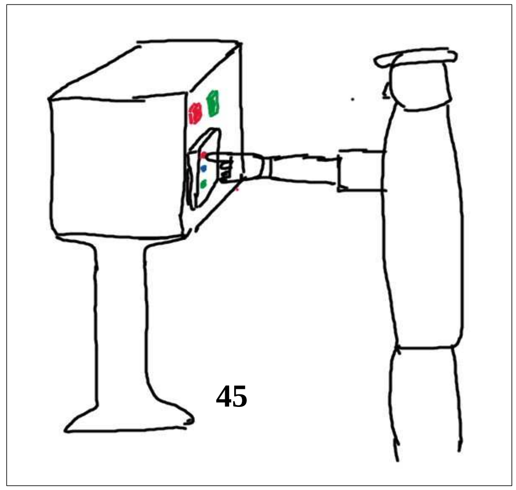
Each of these symbols was drawn for the referent “Do Not Touch with Wet Hands” and was discarded by majority vote of the expert panel. The panel perceived that the artists did not understand the intent of the referent or did not portray the intent in their picture.

These symbols were not included in the clustering process to prevent passing potentially erroneous symbol attributes into the DIGA symbol design tool, perhaps at the expense of attributes contributing to adequate symbol designs.

“Do Not Touch with Wet Hands” Symbols voted as Critical Confusion by expert panel

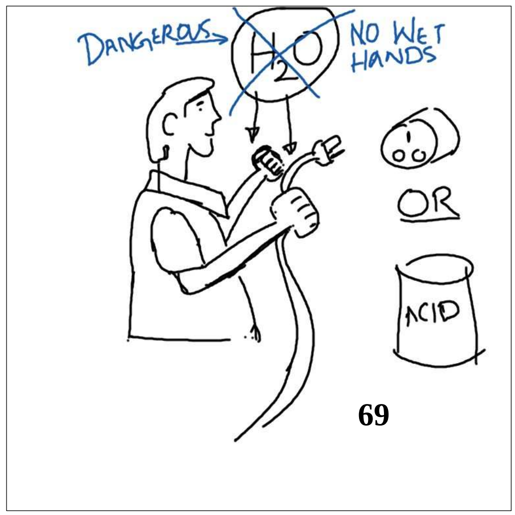


37



45

59



69

Each of these symbols was drawn for the referent “Do Not Touch with Wet Hands” and was discarded by majority vote of the expert panel. The panel perceived that the artists portrayed an opposite meaning to the intent of the referent, or that the symbol encouraged unsafe behavior.

These symbols were not included in the clustering process to prevent passing potentially critically confusing symbol attributes into the DIGA symbol design tool, perhaps at the expense of attributes contributing to adequate symbol designs.

APPENDIX 4.8

K-means clustering results

Referent	Stratum	K	RSS_{min}	r_{min}	d	w_{small}	w_{large}	Attributes		
								Total	Eliminated*	Final
Hot Exhaust	American	3	42	1.1	0.976	31%	34%	35	31	4
	Indian	5	19	1.63	1	16%	26%	35	31	4
	All	5	37	1.41	1	17%	24%	35	32	3
Do Not Touch with Wet Hands	American	3	21	2.94	0.976	16%	47%	28	23	5
	Indian	4	20	2.71	0.949	14%	38%	28	22	6
	All	4	27	3.73	1	11%	41%	28	23	5

* An attribute was eliminated if it did not appear in the centroid of any cluster in the final clustering run reported in this table.

Key to the semantic symbol attributes for "Hot exhaust"

	Attribute Name	Pictorial Description
A	Directional Arrow	An arrow indicating the direction of flow or movement
B	Safety Alert Symbol	A standard triangle with an exclamation point indicating danger or hazard
C	Emmission Lines	Any straight, dotted, wavy or other lines representing pneumatic flow
D	Pipe or Stack	A cylindrical or conical transmission line with an open end
E	2nd Color *	The deliberate use of an additional color to emphasize part of the drawing
F	Negative Face	A facial expression meant to specifically indicate negative feelings
G	Person	All or part of a human body
H	Vat	A tank or wide-mouthed opening that is the source of the exhaust
I	Thermometer	A traditional mercury thermometer intended to indicate high temperatures
J	Flame	A flame or fire intended to indicate high temperatures or combustion
K	Cloud	A fine mist or emission cloud
L	Exclamation Point	An exclamation point symbol found outside of a safety alert symbol
M	Vented Object	A 3-D object with a vent or grate on one side
N	Particulates	A type of emission that is intended to indicate solid particles
O	Prohibition Symbol	The traditional circle/slash intended to indicate "Do Not…"
P	Emphasis Arrows	Arrows drawn to point or call attention to a portion of the symbol
Q	Structure	All of or part of a building, such as a wall or column
R	Skull/Crossbones	The traditional "toxic" or "danger" symbol of a skull and crossbones
S	Vulnerable Object	Any non-specific shape placed in the vulnerable area of the exhaust stream
T	Vent/Grate	A slotted grate or vent which is the source of emissions
U	Positive Face	A facial expression meant to specifically indicate positive or good feelings
V	Vector	An arrow intended to communicate both distance and direction
W	Prohibited X	An "X" or cross used in place of the traditional circle/slash prohibition symbol
X	Hand	A hand or arm without the rest of the human body
Y	Thermos	A classic camping or lunch pail thermos
Z	Hood	A fume hood
AA	Degree Symbol	The " °" symbol intended to indicat e temperature
BB	Fan	A rotating fan affecting the emissions
CC	Surface	A 2-D flat surface
DD	Radiant Heat Lines	Wavy lines intended to communicate "heat" rather than an emission
EE	Multi-Panel	More than one scene is depicted in the symbol to tell a more complete story
FF	Ground	The floor or earth is specifically included
GG	Surprise Face	A facial expression, neither positive nor negative, intended to express surprise
HH	Relief Valve	A valve, switch, or cut-off handle
II	Movement Lines	Lines, either straight or curved, intended to show that objects are in motion

Results of K-means clustering of the consensus attribute matrix for the “Hot exhaust” referent with combined strata. The bolded and underlined **rows** in the table indicate the nearest drawing to the centroid of the cluster.

Drawing Number	Cluster	Stratum	Attribute																																	
			A	B	C	D	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB	CC	DD	EE	FF	GG	HH	II
8	**1**	**Indian**			2	3					3																									
11	1	American	3		1	3					3				3																					
12	1	Indian			2	3				3	3	3		1		3	3	2		1																
15	1	Indian				1					3																									
18	1	American									3	1								3	3															
22	1	American			2						2	1												3	3											
24	1	American									3	3																								
28	1	American	2		1	3		2			3									3			2													
29	1	American			2						1					3					3				2	3	3									
30	1	American				3					3	3	3															3								
33	1	American			2						3									2										1	1					
41	1	American			2	3		3			2	3			2	3				2																
49	1	Indian	2			3					3	3			3		1	3																		
66	1	Indian			2	3								1		1					3															
68	1	Indian			2	3					3	3				1									3											
69	1	Indian	1	2	2						3												2						3							
2	2	American			3	1	3	3	2																											
3	**2**	**American**			3	1			2																											
4	2	Indian			3	1			2																											
19	2	American			3	2		3					1	1						1	3	3	2													
34	2	Indian			3	2				3											3															
35	2	Indian			3	1			2																											
40	2	American				1		3			1					3	1			3	1		1													
46	2	Indian	1		2	1						3			2														3		1					
47	2	American	1		3	1					3					1	1				3										1					
50	2	American			2	1			2												2										1					
53	2	American			1	2		3				3																						3	3	3
59	2	Indian	3		2	1																								3	1					
10	3	American	1		3						3		3	3																						
16	3	Indian	1		3	3					3	1			1				3																	
17	3	American			3	3					3					3				3																
23	**3**	**American**			3	3					3																									
37	3	American			3	3		2			1	1																						3		
43	3	Indian			3						3										3										2					
51	3	American			3	3		2			3					3				3																
56	3	American			3	3					3									3											3					
58	3	Indian	1		3	3		3			3						1	1		3				3												
61	3	American	3		3	2					3																			2	2					
63	3	Indian	3		3	3					2								3	3																
6	**4**	**Indian**		2	3					3																										
31	4	Indian			3																1								3	2						
36	4	American			3			3						1									3	3						2		3	3			
39	4	Indian		3	3					3											3									1						
42	4	American									2	1												3	3											
45	4	Indian			3										2														3							
48	4	Indian			3										3					2	3			3						1						
60	4	American			3						2	2									3										1					
62	4	American		3	3		3			3			3								3															
64	4	Indian			3																								3							
70	4	American			3		3	1													1								3		3					
1	5	Indian	3	3	3	3																														
5	5	American			3	3				3																										
7	5	Indian			3	3																														
9	5	Indian			3	3						3	3																							
13	**5**	**American**			3	3																														
14	5	Indian			3	3																														
20	5	Indian			3	3		3	1								1	1					2	3												
21	5	American			3	3																														
25	5	Indian	2	3	1	3													3																	
26	5	Indian			3	3													3																	
27	5	Indian	3		3	3																														
32	5	American			3	3																									3					
38	5	Indian			3	3						1			2																1					
44	5	American			3	3		3								3																				
52	5	American			3	3				3		3			2																1					
67	5	American			3	3		3				1				2									2						3					

Results of K-means clustering of the consensus attribute matrix for the “Hot exhaust”, U.S. stratum. The bolded and underlined **rows** in the table indicate the nearest drawing to the centroid of the cluster.

Drawing Number	Cluster	Stratum	Attribute																																	
			A	B	C	D	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB	CC	DD	EE	FF	GG	HH	II
2	1	American			3	1	3	3	2																											
19	1	American			3	2		3					1	1						1	3	3	2													
28	1	American	2		1	3		2			3									3			2													
36	1	American			3			3						1									3	3						2		3	3			
37	1	American			3	3		2			1	1																						3		
40	1	American				1		3			1					3	1			3	1		1													
41	1	American			2	3		3			2	3			2	3				2																
<u>44</u>	**<u>1</u>**	**<u>American</u>**			3	3		3								3																				
51	1	American			3	3		2			3					3				3																
53	1	American			1	2		3				3																						3	3	3
67	1	American			3	3		3				1				2									2						3					
70	1	American			3		3	1													1								3		3					
10	2	American	1		3						3		3	3																						
11	2	American	3		1	3					3				3																					
18	2	American									3	1								3	3															
22	2	American			2						2	1												3	3											
<u>24</u>	**<u>2</u>**	**<u>American</u>**									3	3																								
29	2	American			2						1					3					3				2	3	3									
30	2	American				3					3	3	3															3								
33	2	American			2						3									2										1	1					
42	2	American									2	1												3	3											
47	2	American	1		3	1					3					1	1				3										1					
60	2	American			3						2	2									3										1					
61	2	American	3		3	2					3																			2	2					
3	3	American			3	1			2																											
5	3	American			3	3				3																										
<u>13</u>	**<u>3</u>**	**<u>American</u>**			3	3																														
17	3	American			3	3					3					3				3																
21	3	American			3	3																														
23	3	American			3	3					3																									
32	3	American			3	3																									3					
50	3	American			2	1			2												2										1					
52	3	American			3	3				3		3			2																1					
56	3	American			3	3					3									3											3					
62	3	American		3	3		3			3			3								3															

Results of K-means clustering of the consensus attribute matrix for the “Hot exhaust”, Indian stratum. The bolded and underlined **rows** in the table indicate the nearest drawing to the centroid of the cluster.

Drawing Number	Cluster	Stratum	Attribute																																	
			A	B	C	D	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB	CC	DD	EE	FF	GG	HH	II
8	**1**	**Indian**			2	3					3																									
12	1	Indian			2	3				3	3	3		1		3	3	2		1																
25	1	Indian	2	3	1	3													3																	
49	1	Indian	2			3					3	3			3		1	3																		
66	1	Indian			2	3								1		1					3															
68	1	Indian			2	3					3	3				1									3											
69	1	Indian	1	2	2						3												2						3							
6	2	Indian		2	3					3																										
31	2	Indian			3																1								3	2						
34	2	Indian			3	2				3											3															
39	2	Indian		3	3					3											3									1						
43	**2**	**Indian**			3						3										3										2					
45	2	Indian			3										2														3							
48	2	Indian			3										3					2	3			3						1						
64	2	Indian			3																								3							
4	**3**	**Indian**			3	1			2																											
15	3	Indian				1					3																									
35	3	Indian			3	1			2																											
46	3	Indian	1		2	1						3			2														3		1					
59	3	Indian	3		2	1																								3	1					
1	4	Indian	3	3	3	3																														
16	4	Indian	1		3	3					3	1			1				3																	
27	**4**	**Indian**	3		3	3																														
58	4	Indian	1		3	3		3			3						1	1		3				3												
63	4	Indian	3		3	3					2								3	3																
7	5	Indian			3	3																														
9	5	Indian			3	3						3	3																							
14	**5**	**Indian**			3	3																														
20	5	Indian			3	3		3	1								1	1					2	3												
26	5	Indian			3	3													3																	
38	5	Indian			3	3						1			2																1					

Key to the semantic symbol attributes for “Do not touch with wet hands”

	Attribute Name	Pictorial Description
A	Single Hand	One hand or arm without the rest of the human body
B	1-D Surface	A single line indicating a surface
C	Multiple Water Drops	More than one droplet of water
D	Prohibition Symbol	The traditional circle/slash intended to indicate "Do Not…"
E	2nd Color *	The deliberate use of an additional color to emphasize part of the drawing
F	Skull/Crossbones	The traditional "toxic" or "danger" symbol of a skull and crossbones
G	Faucet	A simple kitchen or bathroom faucet serving as a source of water
H	Prohibition X	An "X" or cross used in place of the traditional circle/slash prohibition symbol
I	Liquid Container	An enclosed volumen intended to suggest that liquid is held inside
J	2-D Panel	A 2-D shape representing a surface
K	Lightning Bolts	Several common, jagged lines representing shock or danger
L	Single Water Drop	A single droplet of water
M	3-D Object	A 3-D shape with a volume
N	Multi-Panel	More than one scene is depicted in the symbol to tell a more complete story
O	Water Ripple	Ripples or waves used to portray a liquid
P	Spark	Any small particulate emission intended to indicate shock or danger
Q	Single Lightning Bolt	A lone common, jagged line representing shock or danger
R	Energized Equipment	A generic box or device that is intended to appear electrically sensitive
S	Two Hands	Two hands or arms are present without the rest of the human body
T	Puddle	A small amount of water collected on a surface or the ground
U	Person	A substantial portion of the human body is visible
V	Sequence Arrow	An arrow inserted to show cause and effect
W	Rain Cloud	A cloud drawn to represent a weather phenomenon that is emitting water drops
X	Surprised Face	A facial expression, neither positive nor negative, intended to express surprise
Y	Permissable Circle	A circle without a slash or "X" intended to portray an action that is good
Z	Happy Face	A facial expression meant to specifically indicate positive or good feelings
AA	Mr. Sparky	A specific symbol design of an electric "lightning bolt" inside of a human body
BB	Heat Waves	Wavy lines intended to communicate "heat" rather than an emission

Results of K-means clustering of the consensus attribute matrix for the "Do not touch with wet hands" referent with combined strata. The bolded and underlined **rows** in the table indicate the nearest drawing to the centroid of the cluster.

Drawing Number	Cluster	Stratum	Attribute																										
			A	B	C	D	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
8	**1**	**American**	3		3			3	3																				
14	1	Indian	3		3			3	3		3				3														
27	1	Indian	3		3			3	3																				
32	1	Indian			3			3	3											2									
47	1	Indian	3			2		3	1		3		2		3								3						
65	1	American			3		2	3	3		3											1							
68	1	American	3		2			2				1			3		2		3				3					3	2
5	**2**	**American**	3		3				3																				
6	2	Indian	3		3				3	3																			
9	2	Indian	3		3				3																				
10	2	American	3		3							3																	
12	2	Indian	3		1				3		1	1	3																
15	2	Indian	3		3				3																				
18	2	American	3		3				3		3					3													
23	2	American	1		3				3			3							3	3									
25	2	American	3		3				3																				
30	2	Indian	3		3		3										3												
33	2	Indian			3				3											2									
34	2	Indian	3		3				3																				
35	2	Indian	3		3				3																				
41	2	Indian	3		3				3																				
42	2	Indian	3		3				3																				
44	2	Indian	3		3				3										3										
46	2	Indian	3		3				3																				
50	2	Indian	3		3				3										3										
54	2	Indian	3		3	1			3					3															
55	2	Indian	3		3				3										3										
57	2	American	3		3				3		3				3											2			
58	2	American	3		3				3		2						3		1										
64	2	Indian	3		3		3			2	2	2			3		3		3										
3	3	Indian	3	3	3	3																							
4	3	Indian	3	2	3	3	3	3																					
7	3	American	3	2	3	3					3																		
11	3	American	3			3							3																
13	3	American	3		3	3								3															
17	3	Indian	3	1	3	2																							
19	3	American	3		3	3																							
20	3	American	3			3					3	1	3				3	3											
21	**3**	**Indian**	3		3	3																							
22	3	American	3		3	3																							
24	3	American	3		3	3															3								
26	3	American			2	3														2		3							
28	3	American	3		3	3					3																		
29	3	American	3		3	3																							
31	3	American	3		3	3																							
36	3	American	3		3	3																							
38	3	American	3		3	3					3	3																	
39	3	American	3		3	3																							
40	3	American	3		3	3		3																					
43	3	American	1		3	3														2									
48	3	American	3		3	3						3																	
53	3	Indian	3		3	3					3													3					
61	3	American	3		3	3								3															
62	3	Indian	2		3	3	1	2			3				3			3		3									
66	3	American	3		3	3									3												3		
16	4	Indian	3		3	1			2																				
51	4	Indian		3	3	1			2			1					2				1	2							
52	4	Indian	3		3	1			2																				
56	4	American	1		3	1			2		3											3			3				
67	4	American	3		3	1			2	3						3													
70	**4**	**American**	3		3	1			2																				

Results of K-means clustering of the consensus attribute matrix for the “Do not touch with wet hands” referent, U.S. stratum. The bolded and underlined **rows** in the table indicate the nearest drawing to the centroid of the cluster.

Drawing Number	Cluster	Stratum	Attribute																										
			A	B	C	D	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
5	1	American	3		3				3																				
8	1	American	3		3			3	3																				
10	1	American	3		3							3																	
18	1	American	3		3				3		3					3													
23	1	American	1		3				3			3							3	3									
25	**1**	**American**	3		3				3																				
57	1	American	3		3				3		3				3											2			
58	1	American	3		3				3		2						3		1										
65	1	American			3		2	3	3		3											1							
67	1	American	3		3	1			2	3						3													
68	1	American	3		2			2				1			3		2		3				3					3	2
70	1	American	3		3	1			2																				
7	2	American	3	2	3	3					3																		
20	2	American	3			3					3	1	3				3	3											
28	**2**	**American**	3		3	3					3																		
38	2	American	3		3	3					3	3																	
56	2	American	1		3	1			2		3											3			3				
11	3	American	3			3							3																
13	3	American	3		3	3								3															
19	3	American	3		3	3																							
22	3	American	3		3	3																							
24	3	American	3		3	3															3								
26	3	American			2	3														2		3							
29	**3**	**American**	3		3	3																							
31	3	American	3		3	3																							
36	3	American	3		3	3																							
39	3	American	3		3	3																							
40	3	American	3		3	3		3																					
43	3	American	1		3	3														2									
48	3	American	3		3	3						3																	
61	3	American	3		3	3								3															
66	3	American	3		3	3									3												3		

Results of K-means clustering of the consensus attribute matrix for the “Do not touch with wet hands” referent, Indian stratum. The bolded and underlined **<u>rows</u>** in the table indicate the nearest drawing to the centroid of the cluster.

Drawing Number	Cluster	Stratum	Attribute																										
			A	B	C	D	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
3	1	Indian	3	3	3	3																							
4	1	Indian	3	2	3	3	3	3																					
16	1	Indian	3		3	1			2																				
17	1	Indian	3	1	3	2																							
<u>21</u>	**<u>1</u>**	**<u>Indian</u>**	3		3	3																							
30	1	Indian	3		3		3										3												
51	1	Indian		3	3	1			2			1					2				1	2							
52	1	Indian	3		3	1			2																				
53	1	Indian	3		3	3					3													3					
62	1	Indian	2		3	3	1	2			3				3			3		3									
6	2	Indian	3		3				3	3																			
9	2	Indian	3		3				3																				
12	2	Indian	3		1				3		1	1	3																
15	2	Indian	3		3				3																				
33	2	Indian			3				3											2									
<u>34</u>	**<u>2</u>**	**<u>Indian</u>**	3		3				3																				
35	2	Indian	3		3				3																				
41	2	Indian	3		3				3																				
42	2	Indian	3		3				3																				
46	2	Indian	3		3				3																				
54	2	Indian	3		3	1			3					3															
44	3	Indian	3		3				3										3										
50	3	Indian	3		3				3										3										
<u>55</u>	**<u>3</u>**	**<u>Indian</u>**	3		3				3										3										
64	3	Indian	3		3		3			2	2	2			3		3		3										
14	4	Indian	3		3			3	3		3				3														
<u>27</u>	**<u>4</u>**	**<u>Indian</u>**	3		3			3	3																				
32	4	Indian			3			3	3											2									
47	4	Indian	3			2		3	1		3		2		3								3						

APPENDIX 5.1

Information letter approved by the auburn university institutional review board for designing symbols using interactive evolutionary computation and focus groups.

Auburn University

Auburn University, Alabama 36849-5346

Samuel Ginn College of Engineering

Department of
Industrial and Systems Engineering
3301 Shelby Center
Fax: (334) 844-1381

Principal Investigator: Adam Piper
(334) 844-1415 – piperak@auburn.edu
Faculty Advisor: Dr. Jerry Davis
(334) 844-1411 – davisga@auburn.edu

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMATION LETTER
for a Research Study entitled
"Designing Safety Symbols in Focus Groups with Artificial Intelligence Assistance"

You are invited to participate in a research study to compare the design of safety symbols in traditional focus groups with that from artificial intelligence-assisted groups. The study is being conducted by Adam Piper, under the direction of Dr. Jerry Davis in the Auburn University Department of Industrial and Systems Engineering. You were selected as a possible participant because you are an Auburn University undergraduate or graduate student and you are age 19 or older.

What will be involved if you participate? If you decide to participate in this research study, you will evaluate safety symbol designs produced on a computer using artificial intelligence, or you will produce your own symbol designs by hand and help evaluate the others' designs. A total time commitment of two hours is required in either case.

Are there any risks or discomforts? Since you will be providing information regarding your age, gender, birth country, etc., there is always some risk of a breach of confidentiality which could allow you to be indirectly identified from this information. Therefore, security measures will be maintained to ensure that only Mr. Piper and Dr. Davis have access to the information you provide, and that this information will be destroyed at the conclusion of this research. No names or direct identification information will ever be attached to the symbol drawings you produce, and these drawings will only be displayed completely anonymously in any publications or presentations resulting from this research. It is also possible that you could experience slight fatigue in your hands and arms or in your eyes during the time spent drawing on the digital whiteboard or using the computer mouse. Therefore, you will be encouraged to take breaks at least every few minutes or more often if necessary.

Are there any benefits to yourself or others? You may increase your familiarity with safety warning messages which could increase your comprehension of important safety warning signs encountered in the future.

Will you receive compensation for participating? To thank you for your time, you will be offered $40. To receive this compensation, you need to provide your student banner # and a local mailing address which will be sealed and delivered to the ISE Department confidentially. International students will also need to compete the Alien Tax Information Form if they have not already done so. The investigators will not have access to this information. A check for $40 will be mailed to your address, or $40 will be transmitted to your account via direct deposit if you have previously arranged for this transaction with the university. The student is responsible for all taxes on this amount.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University or the Department of Industrial and Systems Engineering. Withdrawal will not jeopardize your compensation.

Any data obtained in connection with this study will be evaluated and stored anonymously. We will protect your privacy and the data you provide by ensuring that the symbol designs are not linked to your identifiable information. Only the symbol designs produced by your entire focus group will be saved. Information collected through your participation may be used to fulfill a requirement for a doctoral dissertation, published in a professional journal and/or presented at a professional meeting.

If you have questions about this study contact Adam Piper at (334) 844-1415 or piperak@auburn.edu , or Dr. Jerry Davis at (334) 844-1411 or davisga@auburn.edu.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE IF YOU WANT TO PARTICIPATE IN THIS RESEARCH PROJECT. IF YOU DECIDE TO PARTICIPATE, THE DATA YOU PROVIDE WILL SERVE AS YOUR AGREEMENT TO DO SO. THIS LETTER IS YOURS TO KEEP.

____

Investigator's signature Date

Adam Piper

APPENDIX 5.2

Instructions and Data Collection form for participants in the DIGA experiment.

The purpose of this research is to understand the kinds of symbols you prefer to see on a safety sign. Safety signs are placed near the location of a hazard to communicate risk.

Your role in this study will be to evaluate a series of simple pictures, or symbols, that could be added to a sign to communicate a safety message without using any text at all. You will perform this task within a group of approximately 10-20 people. You will evaluate symbols on a computer monitor to determine if they communicate a given safety message simply, clearly and completely. The symbols will be produced by an artificial intelligence system on a computer based on the preferences of all members of the group. Therefore, they will not always be of the highest artistic quality. When you evaluate them, you may assume that the pictures will be redrawn by an artist who will correct any small glitches. Your task will be to anticipate which symbols, if cleaned up and redrawn, would be preferred the most by others like you.

Each participant will be assigned his/her own computer. You will be given a simple safety message as well as a brief example of locations where this hazard might be found. If you have questions about this safety message, feel free to ask the researchers. When the researchers begin the study, you will see nine symbols randomly arranged on your monitor. Select the symbol that most simply, clearly and completely portrays the message. Once you have selected the best symbol, select the next best remaining symbol, continuing in this manner until all nine symbols have been selected. If you make a mistake or would like to change your response, select one of the symbols to unselect it and all symbols selected after it. Reselect the best remaining symbols one at a time until all nine have been selected.

Once you have evaluated all nine symbols in this manner, click the “submit” button and wait until everyone finishes this selection round. When the round is complete, you will receive a new set of nine symbols to evaluate. Please repeat this process until the researchers announce that the trial is finished.

Thank you for your participation! Please complete the information below before you begin the activity.

Age __________ Gender (circle one): M / F

In what country were you born? ______________________________

For how many years did you live in your birth country? ___________________________

What country do you consider to be your home country? ___________________________

What language do you speak in your home most often? ___________________________

Do you consider yourself to speak English fluently? (circle one) Yes / No

At what age do you first remember reading or speaking English fluently? ______________

Instructions and Data Collection form for participants in the Focus Group experiment.

The purpose of this research is to understand the kinds of symbols you prefer to see on a safety sign. Safety signs are placed near the location of a hazard to communicate risk.

Your role in this study will be to design a simple picture, or a symbol, that could be added to a sign to communicate a safety message without using any text at all. You will perform this task within a focus group of approximately 10-20 people. This symbol you design should communicate the safety message I will give clearly and completely. However, do not worry about making a pretty or high-quality drawing. Artistic skill or well-drawn pictures are not important to this research. As long as you or your group members can explain what you picture means, then it will be fine.

You will be drawing your picture on paper at first with no input from others in your focus group. Once each member of your group has created his/her own personal design on paper, each of you will reveal all designs to the group and discuss your favorites. After reviewing each member's designs, the group will determine the best design characteristics and combine them into a new, final group design. This final symbol should be drawn on the SmartBoard system which will be saved by the researchers.

You will be given three different symbols to design in this fashion, one at a time. To help you, you will also be given a description of the hazards and locations where symbols like your drawing may be needed. You may take up to 20 minutes to draw your own symbol, and then the group will have 20 minutes to discuss and create the final group design. The researchers will remind you periodically of the time remaining on each picture, although you may have more time if you need it. After you have completed three symbols in this manner, the exercise will be finished.

Thank you for your cooperation! Please complete the information below before you begin the activity.

Age _________ Gender (circle one): M / F

In what country were you born? ____________________________

For how many years did you live in your birth country? __________________________

What country do you consider to be your home country? _________________________

What language do you speak in your home most often? __________________________

Do you consider yourself to speak English fluently? (circle one) Yes / No

At what age do you first remember reading or speaking English fluently? _____________

APPENDIX 5.3

Blank forms for drawing symbols during the focus group experiment.

"Hot Exhaust."

Description: Many processes and pieces of equipment release heated air or fumes into the working environment.

WARNING

"Do Not Touch with Wet Hands."

Description: Many processes and products can be dangerous when they become wet.

WARNING

APPENDIX 5.4

Sample evaluation survey question for “Do Not Touch with Wet hands”

Symbol Comparison 3

Please look at the safety symbol below. Answer the questions with specific and brief answers.

* **1. Exactly what do you think this symbol means?**

* **2. What action would you take in response to this symbol?**

Symbol Comparison Final 2

Each of the symbols below is trying to communicate the same message:

"Do Not Touch with Wet Hands"

*** 1. Each the symbols above is trying to communicate this message:**

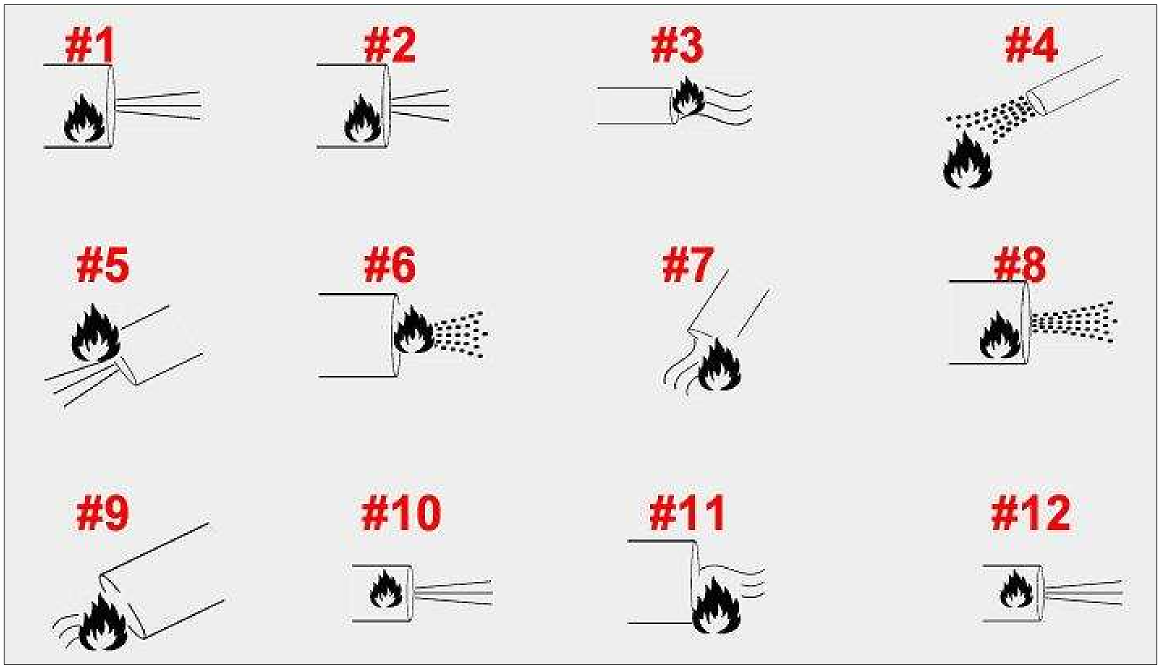
"Do Not Touch with Wet Hands"

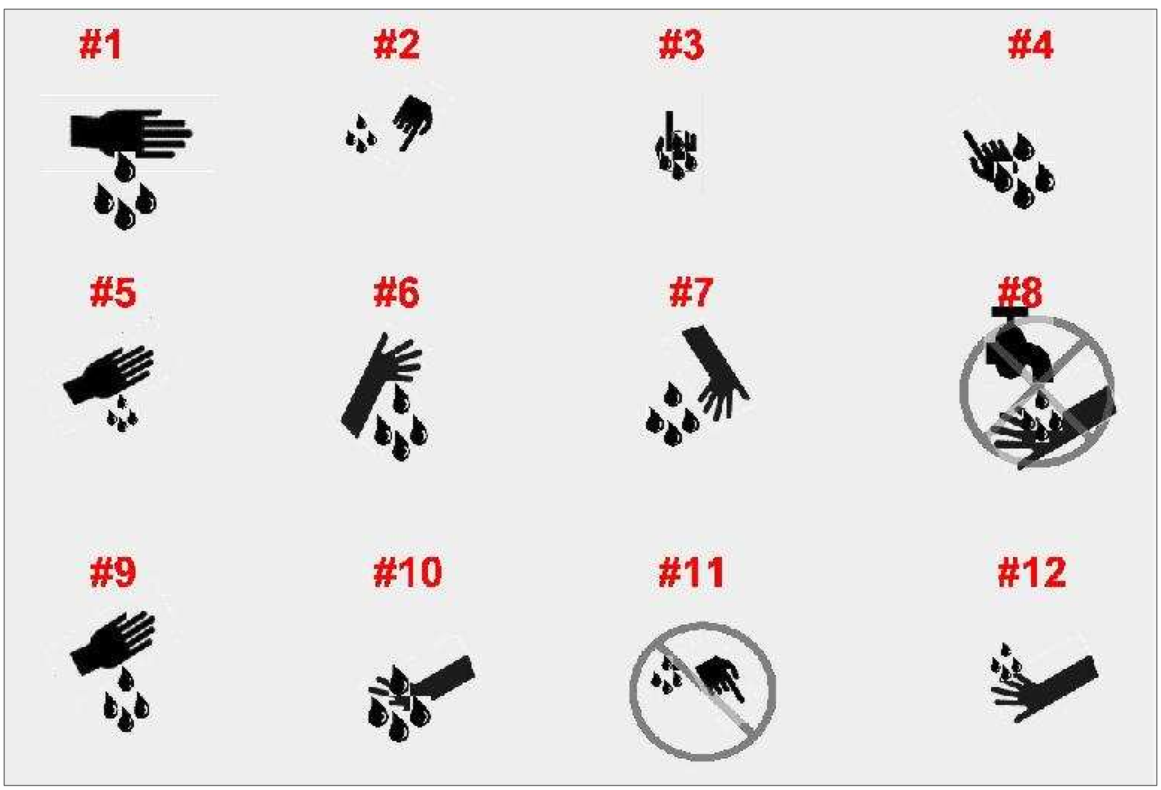
Which one of these symbols do you think would be the easiest for people to understand?

◯ Symbol #1	◯ Symbol #4	◯ Symbol #7
◯ Symbol #2	◯ Symbol #5	◯ Symbol #8
◯ Symbol #3	◯ Symbol #6	◯ Symbol #9

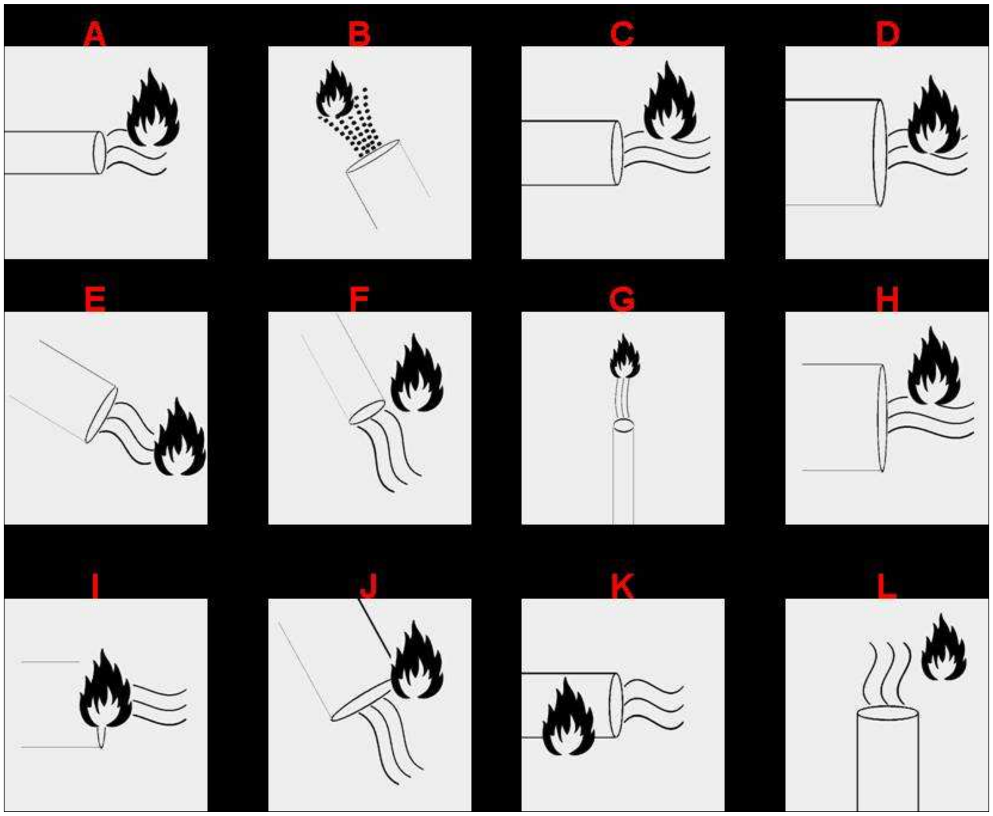
APPENDIX 5.5

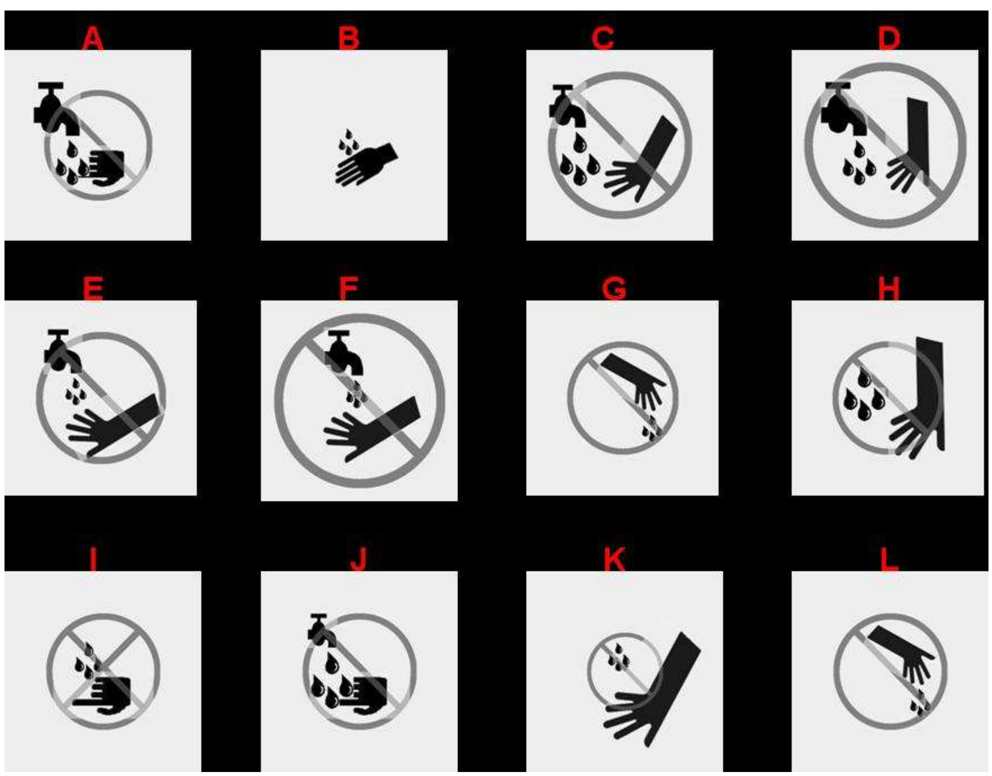
DIGA Group 1 “Hot Exhaust” & “Do Not Touch with Wet Hands” top-ranked symbols



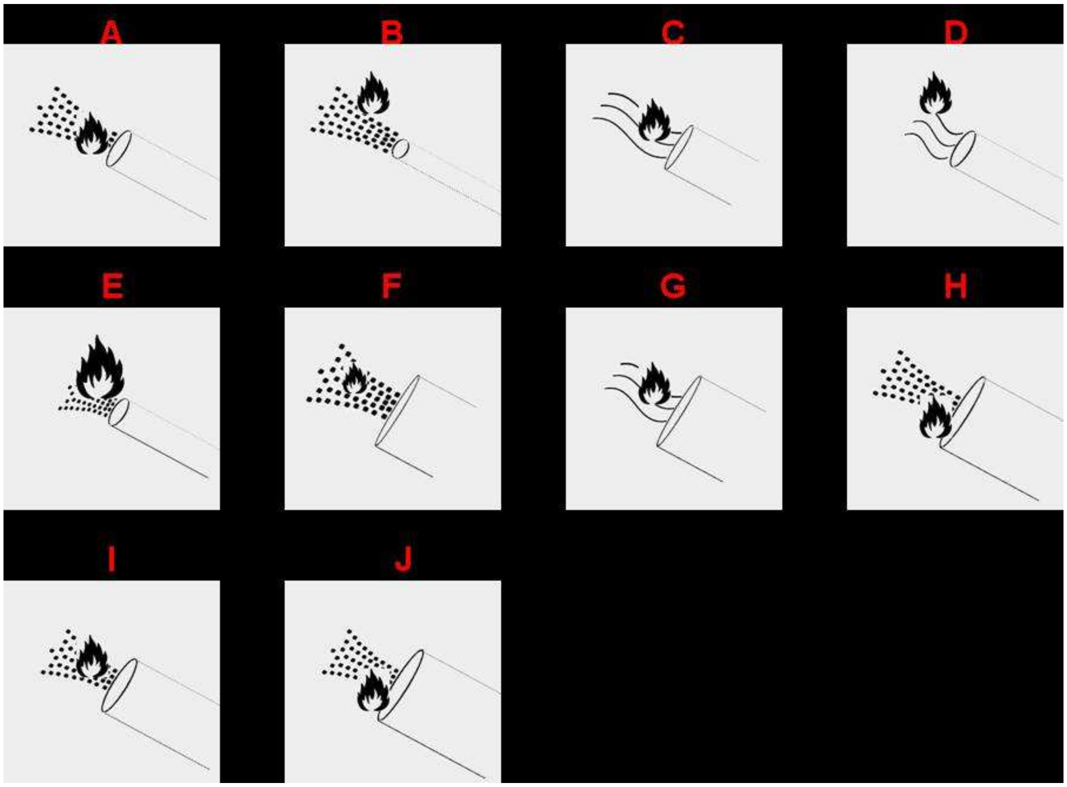


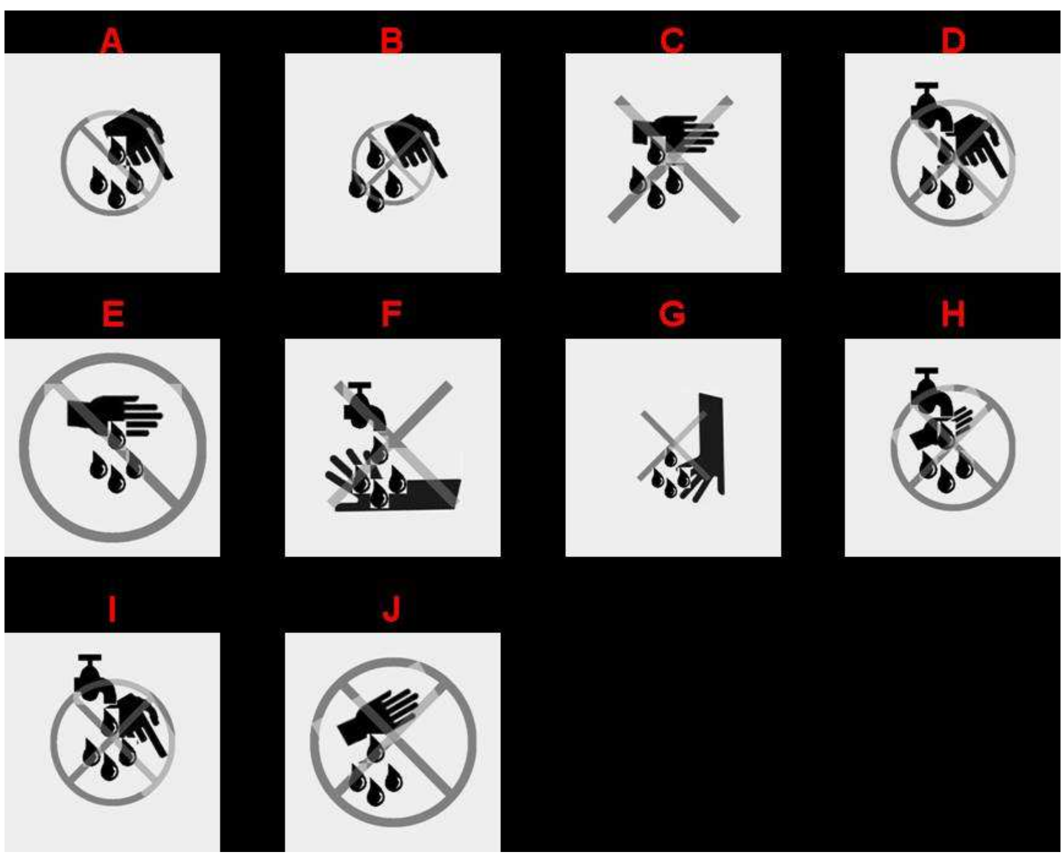
DIGA Group 2 “Hot Exhaust” & “Do Not Touch with Wet Hands” top-ranked symbols





DIGA Group 3 “Hot Exhaust” & “Do Not Touch with Wet Hands” top-ranked symbols.





DIGA Group 4 “Hot Exhaust” & “Do Not Touch with Wet Hands” top-ranked symbols.