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Application of a mental models approach to MSDS design

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In the U.S.A., Material Safety Data Sheets (MSDSs) are required by the Occupational Safety and Health Administration (OSHA). Mental model theories of cognitive processing predict that information format inconsistencies can undermine usability and thereby worker safety and compliance.

The present study explored whether information presentation priorities are dependent upon the population tested. Ninety participants were sampled from three populations (undergraduates, community volunteers, and firefighters). Participants sorted cards containing chunks of information comprised of MSDS headings and text. Mean rank analyses showed that health-related information was given higher priority than other information, such as reactivity or chemical make-up. While there were similarities for the different subgroups, the firefighters differed from the other two groups in several respects. Results were consistent with previous research on schema differences between groups based upon experience and expectations. Implications for MSDS design and application of usability and mental model approaches to improve safety communications are discussed.

Keywords: Material safety data sheets; Mental models; Information design; Communication ergonomics

1. Introduction

1.1. *MSDS content order and user expectations*

Materials Safety Data Sheets (MSDSs) are printed documentation providing information about chemicals used in the workplace by workers and emergency personnel. The information provided typically includes physical characteristics, health hazards, precautionary recommendations, and first aid procedures.

In the United States, the Occupational Safety and Health Administration (OSHA) through its Hazard Communication Standard (HAZCOM; 29 CFR 1910.1200, 1994) states the minimum content of the MSDS. This includes sections on chemical name, physical and health hazards, and emergency and first aid procedures. The Standard also provides a sample layout to be used in a MSDS (Sample MSDS Headings shown in table 1).

HAZCOM also communicates requirements for safety information in workplaces where workers may be exposed to chemical hazards. One requirement is that MSDSs must be made available to all employees.

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Table 1. Sample MSDS headings from HAZCOM (OSHA Regulation, Standards—29 CFR 1910.1200).

Headings
Substance Identification
Health Hazard Data
Emergency First Aid Procedures
Respirators, Protective Clothing, and Eye Protection
Housekeeping and Hygiene Facilities
Precautions for Safe Use, Handling, and Storage
Medical Requirements
Monitoring and Measurement Procedures

Although example MSDS headings are given in the regulation, no specific regulation or recommendations are made regarding the order in which the contents should be presented. MSDSs developed by chemical manufacturers and distributors tend to conform to the example(s) given in the HAZCOM regulation with regard to content but not order. Thus, the order of the contents may vary by chemical manufacturer. This variability leads to inconsistencies in format across MSDSs.

Even if chemical MSDSs follow the sample HAZCOM format in the regulation (29 CFR 1910.1200), the content orders of MSDSs are often based upon the type of chemical featured. For instance, some MSDS content orders present fire and explosion information near the front of the MSDS, while others included fire and explosion data at or near the end. This variability is due to the absence of specifications for MSDS formats.

No empirical research has examined user needs and information processing styles to determine the most appropriate content order. At present, MSDS content orders are not designed to account for the cognitive demands placed upon a worker and the workplace conditions under which consultation may occur. From a task-analytic perspective, an MSDS may be consulted under less demanding conditions such as worker training sessions, or in more demanding conditions such as spills or other chemical accidents involving accidental ingestions or exposures. Because an MSDS may be consulted under conditions in which the worker has other competing demands, it is important to make the materials as easy to use as possible to aid information acquisition. One possible way to accomplish ease-of-use is to order information according to preferences. Schema theory suggests that user preferences for external stimuli are based on compatibility with pre-existing schemas (e.g. Matlin 1998). If users have a schema for information order, then this schema can be expressed through preferences for order, since preferences commonly match expectations about the world. Consequently, developing a common order of presentation across MSDSs on the basis of preference could be a useful way to enhance the usability of information.

Safety information such as MSDSs is generally presented on hard-copy displays. Like other written decision-making tools, the structure of the information, such as how it is ordered, can affect user comprehension, search time, decision-making quality, and, ultimately, response selection (Schneider and Shiffren 1977; Wickens, 1984). The structure of information can influence the manner in which information is processed and could facilitate or undermine user decision-making. For example, users tend to employ heuristics or cognitive short cuts that require less cognitive processing resources than detailed, systematic resources (Tversky and Kahneman 1982). They are biased towards expending the least amount of effort to process information and draw inferences. Trumbo (1999) examined how individuals make judgements about risk and explored how the tendency to conserve cognitive resources might affect risk judgements. This researcher found that risk judgements are made through systematic or heuristic processing. If systematic processing is applied, individuals will use effortful processing. Heuristic processing reflects the use of short cuts such as cues to make a decision. Given a situation where printed information is searched and examined, users within a work system are more likely to use heuristic processing and quickly search and extract the smallest amount of relevant information to make a decision. This approach, however, may undermine decision effectiveness in an occupational safety context.

One way to aid the reader of an MSDS is to provide information in separate labelled chunks as recommended in HAZCOM and to order the information based on people's expectations for the relative placement of information. Relative placement of headings establishes a top–down framework to assist users in assigning overall meaning to the written information. Users process information in written text in the context of information gained from previous text (Cohen 1989, Kinstsch 1993, Matlin 1999); therefore, documents that are not organized in a manner that facilitates sequential comprehension may impair overall comprehension. This reading pattern is applicable to MSDSs since the headings are scanned or read in sequence. In addition, because users must use working memory resources to locate, decode and process what they are reading, information-dense documents that are arbitrarily organized may increase search costs, consume cognitive resources, and ultimately impair a user's ability to comprehend and apply the information (Schneider & Shiffren 1977, Beatty 1982, Baird 1984, Baddeley 1986, Bishu and Drury 1988).

In research on the display of information on computer screens, information that is compatible with user expectations and experiences will facilitate the speed and quality of decision-making by allowing efficient application of top–down processing (Sanders and McCormick 1993). Besides leading to accurate response selection, safety information that is compatible with user information processing tendencies facilitates information processing and compliance (Frantz 1993, Leonard *et al.* 1999, Wogalter 1999). Most studies examining the ordering of safety information have shown that users have at least some expectations of order (Vigilante and Wogalter 1996, 1997) and users perform better and comprehend more when the order of the information is compatible with expectations or cognitive processing styles (Bradshaw *et al.* 1975, Frantz 1993, Adelman *et al.* 1996, Vigilante and Wogalter 1998, Wogalter 1999). Another study has shown that participants reported that simple information employing an outline format was more preferred than complex prose and paragraph layout (Desaulniers 1987), presumably because the outline format decreases task load, and consequently increases search speed. The degree to which the outline format reduced complexity may differ on the basis of worker experience.

MSDSs are used in work environments that consist of workers with different skill levels. Consequently, the search strategy, schemas, and mental models of users with different skill levels may differ. Previous cognitive research has supported differences in schema organization and memory strategies between experts and novices (Matlin 1998). Thus, this difference may be manifested in differences between preferred orders.

1.2. *Previous research on MSDSs*

Only a few studies have examined MSDS usability, and these studies identified comprehension and usability problems. Comprehension and usability problems are due to several factors related to content and format (information order). An OSHA-administered survey (OSHA 1991 as cited in Hazard Communication, 1994) of workers in construction, manufacturing and personal services found that 55% believed MSDSs to be too technical to understand, and 38% reported that there was too much information. The same survey revealed that 25% of workers had problems locating information in MSDSs. Although the employer's right-to-know requirement was satisfied, based upon observations of worker performance, Samways (1988) concluded that MSDSs were difficult to comprehend. In addition, Samways concluded that the complexity of MSDSs placed additional demands on workers with limited reading and comprehension abilities. Kolp *et al*. (1993) tested the comprehension of workers in manufacturing environments by using an 'open-book' test that focused on information contained in several MSDSs. Comprehension rates were around 30%, which indicates the limited effectiveness of this particular hazard communication.

Lehto (1998) found that although workers could reasonably interpret information in MSDSs, when given opportunities to use an MSDS to locate critical information, 36% chose not to consult the MSDS. Workers with less experience were less willing to consult the MSDS, and preferred to rely on guessing or past knowledge. From Lehto's study, it seems that users prefer to conserve cognitive resources by avoiding safety information that is too complex (or organized in a manner that does not match pre-existing schemas). Even if MSDSs are carefully examined, there is no guarantee that the information will be understood. In a study examining readability and comprehensibility of MSDSs among unionized workers in 18 different job specialty areas, Phillips *et al*. (1999) found that employees comprehended only two-thirds of the information contained in MSDSs (based on knowledge tests) and almost 40% reported that MSDSs were difficult to understand. Despite problems with comprehension, workers gave very high satisfaction ratings.

The studies on MSDSs have identified problems with ease-of-use, mainly in terms of comprehensibility and readability. Comprehensibility and readability are intimately tied to the degree to which information is consistent with user expectations.

1.3. *Goals of present study*

The purpose of the present study was to determine user preferences for the order of MSDS headings and to examine population-based differences that may be influenced by experience. This study applied a mental models approach through the use of a sorting and ranking method to examine user schemas and preferences (Gentner and Stevens 1983, Bostrom *et al*. 1992, Fischoff *et al*. 1998, Seemster *et al*. 1997). Preferences for information order may reflect users' attempts to impose a structure that would make the information more meaningful. Meaningful information is information that is consistent with pre-existing schemas or expectations and, consequently, is tied to the structure of mental models. Thus, preferences for a specific order may well indicate how similar information is organized in users' schemas.

Since schemas are developed based on experiences, the structure of mental models of novices, intermediates and experts may differ. Instructional System and Training Design (ISTD) research and the field of Knowledge Acquisition (KA) have found strong support for differences in the manner in which information is organized and processed by novices versus experts, and in preferences for the presentation of information to facilitate learning and application (Schneiderman 1992, Gordon 1994, Wickens *et al*. 1997). Another major goal of the present study was to examine the degree to which population groups might differ in their preferences for information order. Three groups were used to approximate three levels of expertise. Firefighters were selected to represent an 'expert' group due to their frequent use of MSDSs, while students and community volunteers were selected as approximate representations of 'novice-to-intermediate' users.

2. Method

2.1. *Participants*

A total of 90 individuals participated, 30 undergraduates (12 females, 18 males) who were taking Introduction to Psychology courses at North Carolina State University, 30 community volunteers (16 females, 14 males) from Raleigh, Durham, and Chapel Hill, North Carolina, and 30 firefighters (1 female, 29 males) from two different counties in central North Carolina. The mean ages of the undergraduates, community volunteers, and firefighters were 20.4 ($SD = 4.2$), 33.39 ($SD = 9.24$), and 37.73 ($SD = 8.17$) years, respectively.

Table 2 provides descriptive data on experience and education for each group. All firefighters and almost half of the community volunteers had previous MSDS experience, and one-third of the undergraduates had previous experience with MSDSs, thus 60% of the sample had previous experience with MSDSs. Twenty-two percent of the sample had 4-year college degrees.

2.2. *Materials*

Six MSDSs representing various hazardous chemicals similar in number and types of headings were selected. These MSDSs were based upon actual MSDSs distributed by manufacturers. The six chemicals were:

- butyl alcohol,
- isopropyl alcohol,
- methyl alcohol,
- phenanthroline,
- styrene-acrylate,
- toluene.

Each MSDS was divided into sections according to headings and accompanying text and were placed on separate cards measuring 27.9 cm × 17.8 cm (11 × 7 inch). All cards were uniformly constructed using 16-point font in black lettering on a white background. The number of cards within each set ranged from 8 to 12, which replicated the number of different headings used by manufacturers.

Table 2. Participant group MSDS experience and education levels in percentages.

Participant group category	Previous MSDS experience (%)	Education category (%)		
		4-year	2-year	High school
Undergraduates ($n=30$)	33	0	3	97
Community volunteers ($n=30$)	47	27	20	53
Firefighters ($n=30$)	100	40	20	40

2.3. *Procedure*

Participants were first given informed consent documents which they were asked to read and sign. After signing, participants completed a demographic questionnaire, containing questions regarding age, gender, education and previous experience with MSDS.

Participants were randomly assigned two of the six card sets. Pairs of card sets were presented an equal number of times across the sample. The cards within each set were randomized for each participant and participants were told that each card set contained a chemical name and relevant hazard-related information on chemicals with which employees may work. They were asked to 'sort the cards in an order that was most meaningful to you', and no instruction was given on how they should determine meaningfulness. Participants were given as much time as needed to complete the sorting task.

After sorting each card set, participants answered several questions designed to elicit their sorting strategy. Participants also answered questions related to ease of understanding the information on the MSDS, and any opinions on whether the MSDS needed improvement and how they should be improved. This information was gained using an open-ended questionnaire format.

3. Results

Participant groups varied in the amount of experience with MSDSs. This study used the selected populations to represent the wide range of users that could be found in the industrial workplace. Experience levels ranged from none to several years of experience. Sixty-six percent of the undergraduates had no previous experience using MSDSs. Thirteen percent of the undergraduates reported having 4–6 years of MSDS experience, 10% reporting having 1–3 years of MSDS experience, and 10% reported having less than one year of MSDS experience. Fifty-three percent of the community volunteers reported having no previous MSDS experience. Twenty percent of the community volunteers reported 7 or more years of experience, 17% reported 1–3 years of experience, and 10% reported less than a year of MSDS experience. As expected, 100% of the firefighters reported having MSDS experience, with 37% reporting 7 or more years of MSDS experience, 47% with 4–6 years of MSDS experience, 10% with 1–3 years of MSDS experience, and 6% with less than 1 year of MSDS experience.

The original orders of the MSDSs and the mean rank orders provided by all participants (ALL) and by group (undergraduates, community volunteers, and firefighters) are included in table 3. Lower mean ranks indicate higher priority.

The following discussion first presents results of analyses of general preferences for information order across all groups for each card set, followed by analyses of consistency of relative placement of cards within each card set.

These results are followed by analyses of differences between groups among rankings of individual cards. Lastly, a summary of descriptive statistics for responses to a post-task questionnaire to elicit explanations of order preferences is presented.

3.1. *General preferences for information order*

The Freidman Test (nonparametric repeated measures ANOVA) was conducted on each card set to determine whether ranks between cards within a card set differed significantly across all participants. All card ranks were significant at $p < 0.05$ and lower, with the exception of the methyl alcohol MSDS, $F\ (8,\ 216) = 1.52$, $p = 0.15$. The non-significant *p*-value indicated that there were several instances within the card set in which cards were ranked in a highly variable order and very little consistency in rankings of cards occurred. Paired comparisons were conducted using the Wilcoxon Signed Rank Test (probability of *T*-values), and significant differences are indicated by subscript in table 3 (ALL column).

3.2. *Relative placement consistency*

Correlational analyses utilizing Kendall's Tau (τ) correlation coefficients were used to determine the degree of placement consistency within bivariate rankings across all participants. For example, two card sets may be consistently ranked in the same order, hence yielding a high positive correlation. A strong correlation would indicate strong agreement across all participants regarding the placement of any two cards with respect to each other. Tau values that are significant indicate the probability that repeated rankings would yield the same relative orders for any given card pair (Lehman 1991). Weaker correlations indicate several reversals or random patterns between any two cards, thereby indicating no strong agreement between participants in relative placement. Table 4 includes Kendall's Tau correlations within each card set that were found to have strong agreement in relative placement across participants, as indicated by p-values less than or equal to 0.01.

Significant relative orders commonly occurred for headings such as Product Identification, Health Hazards or Hazard-related information, and Special Precautions and Spill/Disposal Procedures. The recurring significant correlations between these variables indicated general agreement among all participants regarding their relative positions within the card set compared to other cards.

3.3. *Between-group differences within card sets*

The mean ranks of each heading for each group are shown in table 3. Table 5 is a summary table of the between group differences. A one-way nonparametric ANOVA (Kruskal–Wallis Test) was conducted on the mean ranks for all three groups.

Table 3. Mean rank orders of headings for chemical product MSDS.

Chemical product heading	Original rank	All	Significance	Undergraduates	Community volunteers	Firefighters
ISOPROPYL ALCOHOL						
Health Hazards Data	5	3.6	a	4.0	3.0	3.9
Product Identification	1	3.8	a, b	4.1	4.1	3.1
Spill or Leak Procedures	7	4.1	b	3.4	4.4	4.4
Fire and Explosion Hazard	4	4.1	b, c	3.8	4.8	3.9
Special Protection Information	8	4.3	b, c	4.2	4.4	4.2
Hazardous Ingredients	2	5.3	d	4.8	5.4	5.6
Physical Data	3	5.4	d	6.0	5.5	4.2
Reactivity Data	6	5.5	d	5.7	4.4	6.3
METHYL ALCOHOL						
Product Identification	1	3.8	a	4.3	4.3	2.7
Health Hazards Data	5	4.5	b	3.8	4.5	5.3
Fire and Explosion Data	4	4.6	b	4.8	4.8	4.3
Special Protection Equipment	8	5.0	c	5.0	5.2	4.8
Spill or Leak Procedures	7	5.1	c	4.7	5.0	5.7
Special Precautions	9	5.2	c	4.1	4.1	6.7
Hazardous Ingredients	2	5.5	d	5.9	4.6	6.0
Physical Data	3	5.6	d	6.7	5.3	4.7
Reactivity Data	6	5.7	d	5.7	6.6	4.8
TOLUENE						
Health Hazards Data	5	3.5	a	3.8	3.2	3.6
Fire and Explosion Hazard	4	4.1	b	4.7	3.8	3.7
Special Precautions	9	4.4	b, c	3.0	4.2	5.9
Special Protection Information	8	4.4	b, c	3.7	4.8	4.7
Spill or Leak Procedures	7	4.6	b, c	4.2	4.6	5.0
Hazardous Ingredients	2	5.4	d	6.3	6.2	3.8
Product Identification	1	5.5	d	6.3	5.8	4.5
Physical Data	3	6.1	e	6.3	5.8	6.3
Reactivity Data	6	6.9	f	6.7	4.2	7.5
STYRENE-ACRYLATE						
Exposure Controls	7	4.3	a	4.0	5.5	3.5
First Aid Measures	4	4.4	a	3.4	3.8	6.1

Accidental Release Measures	6	4.7	b	4.1	5.4	4.6
Fire Fighting Measures	5	4.8	b	4.6	5.8	4.1
Toxicological Information	10	5.1	b, c	4.2	5.0	6.2
Stability and Reactivity	9	7.1	d	7.3	6.2	7.9
Hazardous Ingredients	3	7.3	d	7.4	5.5	9.0
Physical & Chemical Prop.	8	7.7	e	7.9	8.0	7.1
Product Identification	1	7.9	f	9.4	9.4	5.1
Composition	2	8.0	f	8.2	8.4	7.5
Regulatory Information	12	8.1	g	8.7	7.4	8.2
Ecological Information	11	8.3	g	8.8	7.6	8.6
BUTYL ALCOHOL						
Product Identification	1	3.6	a	3.7	3.4	3.8
Spill and Disposal Procedures	7	4.6	b	6.1	3.7	4.0
Health Hazard Data	5	4.7	b	3.8	5.9	4.4
Fire & Explosion Hazard Data	4	4.7	b	5.5	5.1	3.4
Protective Equipment	8	4.8	b	5.1	3.9	5.3
Hazardous Components	2	5.2	c	4.9	5.0	5.7
Reactivity Data	6	5.4	c, d	4.6	6.4	5.4
Physical Data	3	5.6	d	4.5	6.7	5.7
Storage & Handling Proc.	9	6.3	e	6.8	4.9	7.3
PHENANTHROLINE						
Product Identification	1	3.4	a	5.5	2.0	2.8
Health Hazards Data	6	3.7	b	3.1	3.1	4.8
Precautionary Labeling	2	4.2	c	3.0	4.8	4.7
Protective Equipment	9	4.4	c	3.6	4.2	5.4
Fire & Explosion Hazard Data	5	5.4	d	6.2	5.9	4.0
Spill and Disposal Procedures	8	6.3	e	5.7	6.7	6.4
Hazardous Components	3	6.4	e	5.2	8.5	5.4
Physical Data	4	7.3	f	7.6	7.1	7.3
Reactivity Data	7	7.4	f, g	7.8	8.1	6.3
Storage & Handling Proc.	11	7.6	g	7.8	6.8	8.1
Transportation Data	10	10.0	h	10.5	8.8	10.8

Note: Order in list is based on mean ranks of ALL participants. Letters that differ between headings indicate significant differences in mean ranks at $p < 0.05$ or lower.

Table 4. Relative placement consistency of headings within card sets.

Chemical MSDS	Heading	Tau coefficients and degrees of freedom
Isopropyl alcohol	1. Hazardous Ingredients & Health Hazards Data	1. τ (28) = 0.48***
	2. Physical Data & Spill/Leak Procedures	2. τ (28) = 0.43**
Methyl alcohol	1. Product Identification & Special Protection Equip.	1. τ (28) = 0.38**
	2. Product Identification & Special Precautions	2. τ (28) = 0.43**
	3. Physical Data & Health Hazards Data	3. τ (28) = 0.37**
	4. Physical Data & Reactivity Data	4. τ (28) = 0.40**
	5. Physical Data & Spill/Leak Procedures	5. τ (28) = 0.44**
	6. Reactivity Data & Spill/Leak Procedures	6. τ (28) = 0.44**
Toluene	1. Product Identification & Spill/Leak Procedures	1. τ (28) = 0.37**
	2. Hazardous Ingredients & Fire/Explosion Hazard	2. τ (28) = 0.36**
	3. Hazardous Ingredients & Special Protection Info.	3. τ (28) = 0.51***
	4. Hazardous Ingredients & Special Precautions	4. τ (28) = 0.51***
	5. Physical Data & Special Protection Info.	5. τ (28) = 0.27**
	6. Physical Data & Special Precautions	6. τ (28) = 0.35**
	7. Special Protection Info. & Special Precautions	7. τ (28) = 0.53***
Styrene-acrylate	1. Product Identification & Toxicological Information	1. τ (28) = 0.36**
	2. Accidental Release Measures & Stability/Reactivity	2. τ (28) = 0.36**
	3. Stability/Reactivity & Ecological Information	3. τ (28) = 0.41**
Butyl alcohol	1. Product Identification & Spill/Disposal Procedures	1. τ (28) = 0.47**
	2. Hazardous Components & Fire/Explosion Hazards	2. τ (28) = 0.48**
	3. Physical Data & Protective Equipment	3. τ (28) = 0.40**
	4. Fire/Explosion Hazards & Spill/Disposal Procedures	4. τ (28) = 0.43**
	5. Health Hazard Data & Spill/Disposal Procedures	5. τ (28) = 0.37**
Phenanthroline	1. Product Identification & Physical Data	1. τ (28) = 0.41**
	2. Product Identification & Fire/Explosion Hazards	2. τ (28) = 0.45**
	3. Product Identification & Spill/Disposal Procedures	3. τ (28) = 0.38**
	4. Physical Data & Spill/Disposal Procedures	4. τ (28) = 0.35**

Table 5. Means, standard deviations, and significant between-group differences.*

MSDS (Heading)	Undergraduates	Community volunteers	Firefighters	X^2 value and significance level
Isopropyl alcohol (Reactivity Data)		$M = 4.40$, $SD = 1.90$	$M = 6.30$, SD $= 0.95$	X^2 (2) $= 6.28$, $p < 0.05$
Methyl alcohol (Special Precautions)	$M = 4.10$, $SD = 2.02$		$M = 6.70$, SD $= 1.95$	X^2 (2) $= 6.46$, $p < 0.05$
Toluene (Special Precautions)	$M = 3.00$, $SD = 1.83$		$M = 5.90$, $SD = 2.77$	X^2 (2) $= 5.98$, $p < 0.05$
Butyl alcohol (Storage and Handling Procedures)		$M = 4.90$, $SD = 2.47$	$M = 7.30$, $SD = 2.71$	X^2 (2) $= 6.31$, $p < 0.05$
Phenanthroline (Hazardous Ingredients)	$M = 5.20$, $SD = 2.35$	$M = 8.50$, $SD = 2.63$	$M = 5.40$, $SD = 0.42$	X^2 (2) $= 7.77$, $p < 0.05$
(Health Hazards)	$M = 3.10$, $SD = 1.45$	$M = 3.10$, $SD = 1.60$	$M = 4.80$, $SD = 1.69$	X^2 (2) $= 8.07$, $p < 0.05$
(Transportation Data)	$M = 10.50$, $SD = 1.08$	$M = 8.80$, $SD = 2.35$	$M = 10.80$, $SD = .46$	X^2 (2) $= 7.95$, $p < 0.05$

*Only groups yielding significant differences in pairwise comparisons are included in the table. Cells left blank indicate that the group in that column did not differ significantly from the other 2 groups or the X^2 value was not significant for that card set.

Between-group differences in the mean ranks were found for headings within the following MSDSs: isopropyl alcohol, methyl alcohol, toluene, butyl alcohol and phenanthroline. Card headings found to differ significantly between groups included Reactivity Data, Special Precautions, Storage and Handling Procedures, Hazardous Ingredients, Health Hazards, and Transportation Data. No other between-group differences were found.

3.4. *General agreement between groups*

A Spearman Rho rank order correlation coefficient was calculated to determine the agreement between groups (Firefighters, Students, and Community Volunteers) on ranks assigned to all cards across card sets (58 total) and a second correlation coefficient was calculated to determine between group agreements within card sets (table 6). This analysis was used to identify population-based differences of preferences for information order.

The overall Spearman Rho correlations across card sets between students and community volunteers were r_s $(56) = 0.65$, $p < 0.0001$; between students and firefighters, r_s $(56) = 0.50$, $p < 0.0001$; and between firefighters and community volunteers, r_s $(56) = 0.46$, $p < 0.0005$. These descriptive results indicated higher agreement among students and community volunteers (novice/intermediates)

Table 6. Spearman Rho correlation coefficients within card sets.

Chemical MSDS (N and degrees of freedom)	Students and community volunteers (novice/intermediates)	Students and fire fighters (novice/intermediates and experts)	Community volunteers and firefighters (novice/intermediates and experts)
Isopropyl Alcohol (8, 6)	0.46	0.41	0.41
Methyl alcohol (9, 7)	0.73*	−0.18	−0.27
Toluene (9, 7)	0.39	0.25	0.22
Styrene-acrylate (12, 10)	0.87****	0.54	0.26
Butyl alcohol (9, 7)	−0.23	0.18	0.35
Phenanthroline (12, 10)	0.67*	0.68*	0.73*

Note: Significance indicated as follows: $^{*}p < 0.05$, $^{****}p < 0.0005$.

Table 7. Descriptive summary of post-task questionnaire responses ($n = 90$).

Post-task questionnaire item	General response category (%)
1. Describe what you thought about when arranging the cards.	• Most important to least important (51%) • Hazard information first (41%) • Frequency of use (7%)
2. Do you think the information on the cards was easy to understand?	• Yes (52%) • No (35%) • Only scientists, experts, or very experienced could understand (13%)
3. How would you improve the safety information on the cards?	• Add graphics (42%) • Simplify the language (18%) • Summarize/reduce the information (16%) • Add more detail/more descriptions (11%) • Leave as is (10%) • Provide training (3%)

compared to agreement among firefighters (experts) with either group. These findings parallel expectations regarding group experience levels.

Although agreement varied within card sets, the general pattern supported more agreement between the two novice/intermediate groups than agreement between the novice/intermediate group and the expert group.

3.5. *Post-task questionnaire responses*

Post-task questionnaire responses were tallied for all participants and summarized in table 7. Although 51% of participants reported using a general mental model of most important to least important, 41% reported that they used a hazard-first scheme to arrange cards. Forty-eight percent of participants reported that the information on the MSDS was not easy to understand or could only be understood by scientists/experts. Improvement recommendations revealed that 34% of participants thought the language should be simplified and the information should be summarized or reduced. A large percentage of participants (42%) suggested the addition of graphics such as bold fonts, colors, and pictorials to improve the design of MSDSs.

4. Discussion

4.1. *User expectations*

Users produced consistent orders within card sets and these preferred orders were generally consistent across users. Health hazards data (first aid precautions for styrene-acrylate) were assigned greater importance than many other types of information within each card set. Likewise, information related to physical and reactivity data was placed near the bottom. These patterns demonstrate a shared schema centred on a priority given to health-related information and the relative lower priority given to information related to chemical make-up, characteristics, and reactivity.

Using a systems view of MSDSs, users with schemas regarding the importance of certain types of information may develop a mental model when interacting with the MSDS that leads to an expectation that health-related material is somewhere in the beginning of the MSDS. Schema-consistency and mental model compatibility are both important when designing systems, because human thinking and memory involve active applications of previous knowledge and expectations. The greater the compatibility, the higher the efficiency when using the system and the more accurate their recall for the information contained in the system (Alba and Hasher 1983, Brewer and Treyens 1981).

One primary purpose of this research was to compare population groups presumed to have different mental models due to different experience levels to determine whether these differences would be manifested in preferred information orders and in agreement between groups. This research supported the finding that preferred orders and group agreement were dictated by experience levels of each group. Hence, experience-based mental models were, indeed, related to information order preferences and relative placement.

The Tau coefficients indicating agreement regarding relative placement also provided further support for shared preferences that may be based on survival/health schemas. For example, significant correlations were found between Health Hazards Data or Hazardous Ingredients and Physical Data, Special Precautions, and Spill or Disposal Procedures indicating that given repeated rankings, health-related information will be reliably assigned greater importance than the other information. Although the position of Health Hazards data is close to the top of the HAZCOM sample MSDS arrangement, most of the MSDSs in the present study and many other MSDSs place Health Hazards data in the middle of the MSDS and Physical Data closer to the top.

Repeated measures analyses across cards within MSDSs revealed that 5 of the 6 MSDSs had overall significant differences, indicating a lack of randomness of thought when ordering the information. On the contrary, if individuals were randomly ordering cards, no shared pattern would have emerged and there would be no significant differences revealed between the ranks assigned. Methyl alcohol, however, was the exception to this finding. Schemas based on previous experience may account for the preferred organization of information related to methyl alcohol and these schemas may differ among individuals. Since individual differences are often responsible for large within-groups error when using repeated measures designs, these findings may demonstrate, more so than the other MSDSs, the confounding of familiarity with preferred order. In future studies, familiarity should be measured and incorporated into the analyses.

The consistent placement of cards among individuals and the presence of certain patterns were further supported by user feedback on the post-task questionnaire. Since card sorting was used to elicit schemas, this study supports the existence of shared schemas based upon importance and health protection/injury prevention and very little support for a schema based upon objective task function. The finding that almost half of users thought the information was not easy to understand reveals the need to further examine MSDS content. More firefighters (70%) reported that the information was easy to understand than the other two groups. Other than ease-of-understanding, all distributions of responses on the questionnaire were similar. Users also provided suggestions for modifications that enhance usability by capturing attention and helping to simplify the information (i.e. graphics, simplifying language, and reducing the amount of information).

4.2. *Population-based differences and similarities*

Although between-group differences were found in 5 of the 6 chemical MSDSs, *within* each card set only a single card reflected significantly different group ranks, with the exception of the phenanthroline MSDS. The minimal number of significant differences within most of the card sets supports the use of a shared schema for format across all participants, regardless of group membership. In four different MSDS, Special Precautions, Storage and Handling Procedures and Transportation Data were given less importance (indicated by higher ranks) by firefighters than by the other two groups. The greater relative familiarity of firefighters regarding the handling of potentially toxic materials may account for the differences leading to the assignment of less importance to these sections of the MSDS. The community volunteers and students were likely less familiar with material related to these three headings, which may have led to higher perceived risk and lower ranks (greater importance). Similarly, in the phenanthroline MSDS, firefighters assigned significantly lower importance to Hazardous materials and Health Hazards data. Of the six MSDS, phenanthroline was the least recognized. The greater familiarity among firefighters may again account for the significant differences. To users who were less familiar, the novelty of the name may have contributed to risk perceptions, and consequently the assignment of greater importance.

Although support was found for a shared schema, the overall examination of correlations indicated that more agreement existed between the two novice/intermediate groups (students and community volunteers). Correlations between firefighters and either of the two novice/intermediate groups consistently yielded lower correlations, with the exception of butyl alcohol. The greater relative familiarity of firefighters regarding the handling of potentially toxic materials may account for the differences leading to the assignment of slightly different rank orders to specific sections within MSDS. The community volunteers and students were less familiar with chemicals contained in the test stimuli. This difference can be explained by differences in knowledge and expectations, and therefore preferences, brought about by experience (Gordon 1994, Wickens *et al*. 1997).

To apply what has been found in this research, it would be necessary to further elicit the knowledge and expectations of experts to order information appropriately and to train novices and intermediates. This same approach has been applied to aviation training and training in the use of decision support systems (Wickens *et al*. 1997).

5. Summary

The present study provided support for preferred orders of MSDS information among users, and suggests that common schemas for the importance of and arrangement of health-related information may exist. The preference for particular orders indicated patterns reflecting schemas that are centred on survival or health. Consequently, designing on the basis of these schemas and subsequent mental models could increase compatibility and facilitate usability. Determinations of order preferences may translate to better performance, although performance was not assessed in this study. Most importantly, this study provides empirical support for schema-based patterns and their relationship to expectations and preference regarding information design.

The descriptive data revealed user preferences for the use of color and pictorials/symbols in MSDSs. Features such as colors and pictorials could facilitate attention-capture and search efficiency, as well as enhance retention. Further studies to determine the incremental benefits of these features should be conducted and have the potential to yield useful information to apply to MSDS design.

This study also demonstrated the effectiveness of a knowledge elicitation methodology (concept sorting) to identify user preferences and possible shared schemas for safety information. This approach as well as other knowledge acquisition techniques could yield useful data to develop guidelines for safety information design and the development of training applications.

The consistent use of MSDSs is important for primary or loss prevention (i.e. preventing hazards from occurring) and secondary prevention or loss control (i.e. avoiding accidents and injuries in the context of hazards). However, prevention outcomes will not be achieved unless user-centred approaches are proactively applied. This study attempted to capture information to facilitate development of design principles to enhance usability of MSDSs. The use of empirically based design principles will facilitate information capture, and ultimately, worker safety and health. In addition, the move toward computerized MSDSs can be enhanced by applying user-centred research, such as this study to the design of computerized MSDSs that are displayed in a customized format, based upon user needs and capabilities.

Further studies should examine performance consequences when MSDSs are consistent with user expectations. For example, if given a user-preferred order versus an order determined by a chemical manufacturer, would search times, comprehension, and memory for the material differ? Further performance-based measures would provide stronger arguments for the need to redesign information to better fit user expectations. Performance-based scenarios that manipulate user workload could also be used to determine the degree to which the complexities of format and content contribute to overall workload and interfere with information processing and decision-making. Studies focusing on these areas would yield useful information to simplify the design of MSDSs.

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