Determining the Preferred Order of Materials Safety Data Sheets (MSDS): A User-Centered Approach

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ABSTRACT

Although the Hazard Communication Standard (OSHA, 1994) provides recommendations for the type of information contained in materials safety data sheets (MSDSs), there are no regulations for the order in which information should be presented. Research and theory suggest that information displays that are constructed to match the user's mental model facilitate visual search efficiency and accuracy. The present research was designed to determine whether there is a preferred ordering of MSDS information that novices expect, presumably based on their cognitive expectations. Sixty participants were given MSDS section information on separate sheets and asked to arrange them in an order they considered most usable. The results showed differences in the placement of certain components within different MSDSs and the consistent placement of other components (e.g., Health Hazards Data, Physical Data) at the beginning or the end. Results showed support for common mental models among novices relating to the order in which safety information should be displayed. Implications for the design of MSDSs and safety material are discussed.

INTRODUCTION

The presentation of safety information is a critical research area, particularly as the increasingly literate workforce becomes less tolerant of workplace injuries and fatalities occurring in the context of unusable or unavailable preventive information. Numerous occupations require workers to directly interact with or work around dangerous chemicals. Human factors researchers have been using empirical approaches for a number of years to provide feedback to industry and government groups to aid in design of usable safety information (Frantz, 1993).

The Hazard Communication Standard (HCS) was developed to prevent or reduce the number of accidents and injuries related to chemical hazards (OSHA, 1994). During development of the HCS, OSHA estimated that within one year, between 40 and 50 thousand employees experienced illnesses or injuries related to chemical handling or exposure. OSHA (1994) noted that this estimate is probably much lower than the actual number.

The HCS was developed with a recognition that every employee has the right to know critical information regarding chemical dangers and appropriate actions to take to prevent injury or reduce the extent of injury if exposure occurs. In addition, the standard communicates requirements for the use of Materials Safety Data Sheets (MSDSs). MSDSs typically contain information that describes the chemical, identifies associated hazards, provides preventive actions and, if exposure occurs, actions to reduce damage. MSDSs are required to be available and accessible to all employees working with hazardous substances.

MSDSs are not only critical to the safety of employees, but also for health care workers who may intervene when exposure occurs. The HCS (OSHA, 1994) provides information on the content and recommended formats of MSDSs. The HCS provides a suggested order, shown in Table 1, but no specific ordering is required.

Employer surveys conducted in 1991 by OSHA indicated that 55% of moderate to large-sized construction, personal services, and manufacturing industry employers reported that MSDS information was too technical for employees to understand. Thirty-eight percent of respondents reported that too much information was contained in MSDSs and 25% reported that specific information was difficult to locate when searching through MSDSs. Survey respondents expressed a strong need for uniform terminology and consistent formats (OSHA, 1991).

The format including the order in which MSDS information is presented in practice can vary considerably. The lack of consistency can reduce employees' ability to efficiently find critical information. With consistent formats, visual search is facilitated (Tullis, 1983). When formats

TABLE 1
Sample Order of MSDS Headings/Sections
(Hazard Communication Standard, OSHA, 1994)

Order of 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

vary, individuals' search behaviors and strategies become less efficient (Schneider & Shiffren, 1977).

Employees may not be adequately trained to use MSDSs before being required to work with hazardous chemicals. In addition, the language skills of employees who handle bulk chemicals and those of novices in general may be exceeded by the complexity of the language used in typical MSDSs. Previous research has demonstrated that users will avoid searching through MSDSs containing large amounts of highly complex information; and when such searches are attempted, they are inefficient (Lehto, 1998). The guiding principles of MSDS design should be to reduce the difficulties that these groups may experience in searching and understanding the content.

An awareness of users' pre-existing mental models or schemata could be used to establish a standard order of information to assist employees in locating and using the information. Consistent topic headings can act as cues to facilitate the development of a productive mental model that can later help structure visual search behavior (Elkind, Card, Hochberg, & Huey, 1990). In addition, working memory load is decreased when a mental model for a particular display organization is established (Eberts & Schneider, 1985). Thus, a consistent order across all MSDSs could potentially decrease search time and reduce working memory load, which is particularly important in contexts where critical decisions must be made while under stress and within the context of high information load.

It should be noted that any single random order could be established as the standard. However, first time and less experienced users would have difficulty locating information initially. Nevertheless, with sufficient experience and training, users could learn the order and eventually move to a high level of efficiency. Random orders are, in general, more difficult to learn than orders based on previous expectations. If instead the order that is established as the standard is based on users' expectations, novices' assumptions about the location of critical information will be matched by the actual location, and consequently, the usability of the material will be facilitated.

Frantz (1993) found that safety information was more likely to be attended to and complied with when it is compatible with users' information processing tendencies. If a standard order for MSDSs were to be required or established, it would make sense to base the order on novice users' expectations which would simplify visual search. One way to determine which order might be beneficial in this regard is to examine novice users' preferences. Preferences for the order of safety information have been documented. For example, a study (Vigilante & Wogalter, 1996) involving the ordering of safety information in power tool product manuals indicated that users preferred that the most important information and information related to severe or probable injuries be presented first. Vigilante and Wogalter (1997) also found that consumers had consistent expectations about the ordering of headings on package labels for over-the-counter pharmaceutical products. Presumably, these consistent expectations are based on common mental models.

The present study was designed to employ a user-centered approach to identify preferred orders of major sections of MSDSs. A user-centered approach involves collecting and analyzing data from potential users and using this information as the basis of design. In this particular application, it involves the determination of the user's schema and applying this information to the design of the MSDS. It is hypothesized that users share a common schema-based expectation of the order of safety information. If so, this schema can be used to order safety information for future use. If no pre-existing schemas exist, then the orders indicated by a sample of participants will be random and will not show a consistent, reliable pattern.

METHOD

Participants

Sixty individuals participated. Half were undergraduates (12 females, 18 males), taking Introductory Psychology courses at North Carolina State University who were participating for course credit. The other half were community volunteers (16 females, 14 males) from the Research Triangle region of North Carolina. The undergraduates' age range was 18 to 23, with an average age of 20.4. The community volunteers ranged in age from 18 to 80, with an average age of 33.39 ($n = 29$).

Twenty-nine undergraduate participants reported having some college, while one undergraduate participant had a 2-year degree. The highest educational levels reported by the community volunteers were as follows (n = 29): High school, 7; some college, 9; 2 year degree, 6; Baccalaureate degree 7.

Sixty-seven percent of the undergraduates had no previous experience working with MSDSs, while 33% reported previous experience with MSDSs in various fields. Of the experienced participants, 1 had between 7 and 10 years of experience, 2 had 4 to 6 years of experience, 3 had 1 to 3 years of experience, and 4 had less than 1 year of experience.

Forty-seven percent of the community volunteers had no previous experience working with MSDSs. Of the 53% reporting experience with MSDSs, 11 had between 7 and 10 years of experience; 1 had 4 to 6 years of experience; 2 had 1 to 3 years of experience; and 2 had less than 1 year of experience.

Materials and Procedure

Participants were given an informed consent document and after reading it, signatures were obtained followed by a questionnaire requesting demographic information. This survey contained questions relating to gender, age, educational level, and experience using safety information.

Six MSDSs containing information for 6 different hazardous chemicals were selected from various sources and represented different kinds of chemicals and their usage. The MSDSs were divided by section headings and were presented on individual cards measuring 27.9 cm x 17.8 cm (11-x 7 inch) and containing the topic and its accompanying information. Fonts (16 pt.) and black lettering on a white background were uniform across all card sets. The number of topics (and cards) within each card set ranged from 8 and 12. The original orders of the topic/section headings of the MSDSs are listed in Table 2.

Two of the six card sets were randomly assigned to each participant. Participants were told that each card set consisted of several components of a MSDS. They were also told that MSDSs contained safety-related information on particular hazardous chemicals with which employees may work. Each participant was given a set of cards (which had been shuffled), and was asked to arrange the cards in an order that seemed most logical and useful to them. Participants were given an open-ended questionnaire to report the logic they used to sort the cards and their thoughts about the information contained on the cards. When the first questionnaire had been completed, participants were given the second set of cards and asked to repeat the sorting task. A second questionnaire, like the first, was completed concerning the second ordering task. The researcher recorded the order of each card set. Participants were later debriefed.

RESULTS

Table 3 contains the original order and the participants mean rank orders for each of the 6 MSDSs for both groups combined (All), as well as separately, for the undergraduates (UG) and community volunteers (CV).

A nonparametric between groups analysis of variance (ANOVA) was conducted on the mean ranks for the students and the community volunteers. No between-group or card set differences were found ($ps < .05$). The heading ranks for each MSDS sheet combining both groups of participants were analyzed using a repeated measures nonparametric ANOVA (Freidman test). All were significant at $ps < .0001$. A variant of the Wilcoxon Signed Rank test, the van Der Waerden test, was used to make paired comparisons between headings. The mean ranks and significance test results are shown in Table 3. The subscripts that differ between headings are significant at $p < .05$. Headings with the same subscript are not significantly different.

Data from the post-task questionnaire items were collated into response categories. A summary of these data are shown in Table 4. The majority of respondents used a sorting method based on a priority of communicating information

TABLE 2
Original Order of MSDSs Provided to Participants

Chemical	Original Order of Headings
ISOPROPYL ALCOHOL	Product Identification Hazardous Ingredients Physical Data Fire and Explosion Hazard Health Hazards Data Reactivity Data Spill or Leak Procedures Special Protection Information
METHYL ALCOHOL	Product Identification Hazardous Ingredients Physical Data Fire and Explosion Data Health Hazards Data Reactivity Data Spill or Leak Procedures Special Protection Equipment Special Precautions
TOLUENE	Product Identification Hazardous Ingredients Physical Data Fire and Explosion Hazard Health Hazards Data Reactivity Data Spill or Leak Procedures Special Protection Information Special Precautions
STYRENE-ACRYLATE	Product Identification Composition Hazardous Ingredients First Aid Measures Fire Fighting Measures Accidental Release Measures Exposure Controls Physical and Chemical Properties Stability and Reactivity Toxicological Information Ecological Information Regulatory Information
BUTYL ALCOHOL	Product Identification Hazardous Components Physical Data Fire and Explosion Hazard Data Health Hazard Data Reactivity Data Spill and Disposal Procedures Protective Equipment Storage and Handling Procedures
PHENANTHROLINE	Product Identification Precautionary Labeling Hazardous Components Physical Data Fire and Explosion Hazard Data Health Hazards Data Reactivity Data Spill and Disposal Procedures Protective Equipment Transportation Data Storage and Handling Precautions

TABLE 3
Mean Rank Orders of Headings for MSDSs

Heading	Original Rank	All	UG	CV
ISOPROPYL ALCOHOL				
Health Hazards Data	5	3.5a	4.0	3.0
Spill or Leak Procedures	7	3.9b	3.4	4.4
Product Identification	1	4.1b	4.1	4.1
Fire and Explosion Hazard	4	4.3b,c	3.8	4.8
Special Protection Information	8	4.3b,c	4.2	4.4
Reactivity Data	6	5.0d	5.7	4.4
Hazardous Ingredients	2	5.1d	4.8	5.4
Physical Data	3	5.8e	6.0	5.5
METHYL ALCOHOL				
Health Hazards Data	5	4.2a	3.8	4.5
Product Identification	1	4.3a,b	4.3	4.3
Special Precautions	9	4.4b	4.1	4.1
Fire and Explosion Data	4	4.8b	4.8	4.8
Spill or Leak Procedures	7	4.8b	4.7	5.0
Special Protection Equipment	8	5.1c	5.0	5.2
Hazardous Ingredients	2	5.2c	5.9	4.6
Physical Data	3	6.0d	6.7	5.3
Reactivity Data	6	6.2e	5.7	6.6
TOLUENE				
Health Hazards Data	5	3.5a	3.8	3.2
Special Precautions	9	3.6a	3.0	4.2
Fire and Explosion Hazard	4	4.2b	4.7	3.8
Special Protection Information	8	4.2b	3.7	4.8
Spill or Leak Procedures	7	4.4b,c	4.2	4.6
Product Identification	1	6.0d	6.3	5.8
Physical Data	3	6.0d	6.3	5.8
Hazardous Ingredients	2	6.2d	6.3	6.2
Reactivity Data	6	6.6e	6.7	4.2
STYRENE-CRYLATE				
First Aid Measures	4	3.6a	3.4	3.8
Toxicological Information	10	4.6a,b	4.2	5.0
Accidental Release Measures	6	4.8b	4.1	5.4
Exposure Controls	7	4.8b	4.0	5.5
Fire Fighting Measures	5	5.2c	4.6	5.8
Hazardous Ingredients	3	6.4d	7.4	5.5
Stability and Reactivity	9	6.8d	7.3	6.2
Physical & Chemical Prop.	8	8.0e	7.9	8.0
Composition	2	8.0e	8.2	8.4
Ecological Information	11	8.2e	8.8	7.6
Regulatory Information	12	8.3e	8.7	7.4
Product Identification	1	9.4f	9.4	9.4
BUTYL ALCOHOL				
Product Identification	1	3.6a	3.7	3.4
Protective Equipment	8	4.5a,b	5.1	3.9
Health Hazard Data	5	4.8b	3.8	5.9
Spill and Disposal Procedures	7	4.9b,c	6.1	3.7
Hazardous Components	2	5.0b,c	4.9	5.0
Fire & Explosion Hazard Data	4	5.3b,c	5.5	5.1
Reactivity Data	6	5.5b,c	4.6	6.4
Physical Data	3	5.6c,d	4.5	6.7
Storage & Handling Proc.	9	5.8c,d	6.8	4.9
PHENANTHROLINE				
Health Hazards Data	6	3.1a	3.1	3.1
Product Identification	1	3.8a	5.5	2.0
Precautionary Labeling	2	3.9a	3.0	4.8
Protective Equipment	9	3.9a	3.6	4.2
Fire & Explosion Hazard Data	5	6.0a,b	6.2	5.9
Spill and Disposal Procedures	8	6.2b	5.7	6.7
Hazardous Components	3	6.8b	5.2	8.5
Storage & Handling Prec.	11	7.3b	7.8	6.8
Physical Data	4	7.4b	7.6	7.1
Reactivity Data	7	8.0b,c	7.8	8.1
Transportation Data	10	9.6c,d	10.5	8.8

Note: Order in list is based on mean ranks of ALL participants. Different subscripts within the same heading are significantly different ($p < .05$).

TABLE 4
Descriptive Summary of Subjective Reports (n = 60)

Question	General Response Category (%)
Describe what you thought about when arranging the cards.	• Hazard info. first (53%) • Most important to least important (35%) • Identifying info. first (1%) • Frequency of use (7%)
Do you think the information on the cards was easy to understand?	• Yes (43%) • No (42%) • Only scientists, experts, or very experienced could understand (15%)
How would you improve the safety information on the cards?	• Add graphics (43%) • Summarize the info. (18%) • Simplify the language (17%) • Add more detail. More descriptions. (13%) • Leave as is (5%) • Provide training (3%)

related to hazards, similar to that found in the Vigilante and Wogalter study (1996) with power tool manual warnings. In addition, 57 % of the respondents in the present study reported that the safety information in the MSDSs was not easy to understand or that it was understandable only by users familiar with scientific or technical language.

DISCUSSION

Since the content of each of the MSDSs varied, the results are complex. There were significant differences in the placement of headings within each of the card sets. If participants had no consistent mental model of the location of the headings within each MSDS, the orders generated by the sorting tasks would be random, resulting in no significant differences among the headings. In fact, significant differences between section headings were found, although, most of the differences were not large. These results support the existence of a common expectancy among novice users on the ordering of MSDS components. No statistical differences were found between the two population groups, providing support for a general mental model among lay individuals.

Several examples of consistent placement are apparent in the data. Information about Health Hazards, Protective Equipment, and Fire and Explosion Data tended to be placed toward the beginning, while Physical and Reactivity Data tended to be placed at the end. Spill or Leak Procedures tended to be ranked near the beginning or the middle of each set, indicating that this information may be dependent upon the type of chemical.

Several additional points are noteworthy. None of the participant arrangements (Table 3) matched the original orders of the MSDSs (Table 2), all of which were arranged similar to the example provided in OSHA's (1994) HCS (Table 1). The incompatibility between the participants' preferences and the currently recommended order can lead to the same problems that occur when information displays do not match user expectations — confusion, frustration, errors, or avoidance (Wickens, 1992). When information is presented in a manner that matches user's models, these problems are reduced, producing faster information acquisition. Another major difference between the HCS sample order and the original MSDS order is in the location of Health Hazard data. Four of the six MSDS mean rank orders produced by participants placed Health Hazard data at a higher priority than that given by the HCS regulation example. Similarly, five of the six MSDS orders produced by participants placed Health Hazard data at a higher priority than the original MSDS orders.

Product Identification (i.e., Product name, Formula, Trade names, Synonyms, Manufacturer) was also assigned high priority for all chemicals except Styrene Acrylate, whose product identification section was ranked last. The Product Identification for this chemical contained a well-known company brand name and the chemical's use in camera film; therefore, the lower rank might be due to the presence of this familiar information. The actual chemical name, Styrene Acrylate, does not appear in the Product Identification section but in the Composition section, which interestingly, was also placed towards the end.

The orders derived in this research may be useful as an initial starting point to establish a standard order. Although the current data cannot address issues related to search speed, it is expected that an order based on existing mental models would lead to faster search time and higher hit rates during the learning process. A user-driven order should also lead to faster initial searches and reduce the amount of time a novice user needs to reach an efficient level of use.

The post-test questionnaire responses supported current observations of the lack of usability of MSDSs (Lehto, 1998; Frantz, 1993). Most respondents found the information in MSDSs difficult to understand, and it was believed it would be difficult for non-technical users. Using simple language, reducing the amount of text, and including graphics such as icons and color-coding were common suggestions given by participants to improve usability of MSDSs.

This study provides empirical data on which to build a useful and user-centered design of MSDS information. Further research is needed to determine whether other factors affect users' perceptions of logical order. The present data indicate that the preferred orders are highly dependent upon the type of substance described in a particular MSDS. Although a variety of substances were used in this study, further research is needed to determine whether the chemical's hazard level affects user preference for the location of certain types of information. It is also necessary to examine whether the order of MSDSs is occupation-dependent. Subsequent studies using performance-based methodologies using individuals from various occupations will be helpful to determine the most usable MSDS format.

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