

**Final Performance Report  
On-line Ergonomics Solutions for General Industry  
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## **Abstract: On-line Ergonomics Solutions**

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This project created a website knowledgebase of roughly 5000 practical solutions for common causes of workplace Musculoskeletal Disorders (MSDs) in general industry. These disorders constitute the leading type of all workplace injuries and illnesses, and account for about 70% of total workers' compensation costs.

These solutions were adapted from actual improvements in industrial settings based on consulting projects performed in over 1500 individual workplaces. Emphasis is placed on showing low-cost solutions, including items that can be fabricated in-house. Over 3000 photographs of solutions are included, adding practicality and ease-of-use to the website. Descriptions are written in a down-to-earth style, making the site accessible to both non-professionals in small companies and professionals in large organizations.

The solutions are divided into several categories: workstations, material handling, machine operations, hand tools, maintenance, and warehousing. Each of these categories is further divided into topics that contain the specific solutions. Background explanatory material is provided at each level to guide users in proper application.

Nearly all of these solutions provide for better production efficiency as well as prevention of injuries. The solutions are both fundamental to common production operations and are comprehensive. Thus, the website serves as a de facto primer on setting up production operations intelligently.

Several portals are provided. Each of these has a different orientation for different users and purposes, but all are based on and link to the various solutions in the knowledgebase:

1. How to set up production systems
2. How to design equipment to prevent MSDs
3. Principles of human-friendly design
4. Training

Consequently, users have the option of browsing the categories or using the portals to obtain a step-by-step introduction to the solutions.

Usability studies were conducted as part of the project to help optimize ease-of-use in accessing the large knowledgebase and the portals. Results confirmed that the system is understandable and usable. In some cases the feedback led to improvements in the website design. Additionally, new technology became available during the course of this project that enables on-going, semi-automated usability testing. This capability was integrated into the website to conduct studies continuously in the future.

This is unique and marks a milestone in the evolution of workplace ergonomics. The information is expected help employers reduce injuries as well as improve efficiency.

The grant recipients are proceeding with full commercialization, plus are submitting a paper about the project for an international ergonomics conference in 2014.

## Section I — Highlights and Significance

### Key Findings/Results

#### *Product*

This project created a website knowledgebase of roughly 5000 practical solutions for common causes of workplace Musculoskeletal Disorders (MSDs) in manufacturing operations. The knowledgebase contains approximately 3000 photographs of the solutions, which add considerably to the ability to browse and to understand the point of the solutions. Considerable emphasis is placed on showing low-cost, low-tech solutions, including items that can be fabricated in-house. Vendor information is provided in many cases, with either direct links to product websites that are especially useful or general internet search categories and sources for commonly available items.

The solutions are divided into several categories: workstations, material handling, machine operations, hand tools, maintenance, and warehousing. Each of these categories is further divided into topics that contain the specific solutions. Background explanatory material is provided at each level to guide users in proper application.

In addition to this list of categories and topics, several portals are provided:

1. How to set up production systems
2. How to design equipment to prevent MSDs
3. Principles of human-friendly design
4. Training

Each of these has a different orientation for different users and purposes, but all are based on and link to the various solutions in the knowledgebase. Consequently, users have the option of browsing the categories or using the portals to obtain a step-by-step introduction to the solutions.

#### *Website architecture*

The creation of this knowledgebase triggered a complete renovation of the website architecture in order to provide state-of-the-art capability for the knowledgebase and access by users. This upgrading of software was not funded by the grant, but provided a foundation for successful implementation, ongoing continuous improvement functionality, and future management of the project. The choice of the new platform was significantly influenced and tested against the requirements for the grant activity.

#### *Research*

There were two levels of research for this project: Data development and Website Usability.

Data development – The research on effective solutions was conducted over a 30-year period as part of a private consulting practice. The initial database consisted of reports, photographs, and related information from more than 1500 individual workplaces. Results of this research led to the development of the knowledgebase, taxonomy, and descriptive portals described above. This research was not funded by the grant, but was essential to the project.

Website Usability – Several levels of usability testing were incorporated to help optimize ease-of-use in accessing the large knowledgebase and the portals. Note that this research was critical to the success of the project, but results do not lend themselves to statistical summary. The following table summarizes the usability research:

<b>Approach</b>	<b>Summary</b>
Card Sorting	Fifteen subjects conducted a series of tasks to gauge familiarity with terminology, knowledgebase topics, and recognition of the intended content for sample photographs from the knowledgebase. Results showed that (a) there is little or no standardized terminology for the types of equipment in this knowledgebase, and (b) that despite this lack of standardized terminology, the categories and topics of the knowledgebase were understandable.
Heuristic Evaluation	Spot check heuristic evaluations were continuously applied throughout the life of the project, and the heuristic goals were imbedded in site development guidelines.
Focus Groups	Nine separate focus group sessions, with a combined total of 48 participants, were held at client sites during consulting engagements with large corporations. The focus groups were subjective in nature, and feedback was used to gauge commercial viability, emotional responses, and interface and content improvement ideas. The focus groups showed that different individuals search for solutions in widely different ways, which led to the development of the different portals.
Task Analysis and Questionnaires / Surveys	Ten participants were recruited to participate in a detailed task analysis and questionnaire study. Tasks included reviewing content, nomenclature, content presentation and layout, searches for specific information, and site navigation. Results were highly informative and are being incorporated into the web content and design. All subjects were easily able to navigate the site and all stated they or others in their organizations would find the site useful.
Ongoing Studies and Continuous Improvement	New sophisticated web technologies became available during the course of this project and were incorporated. These technologies allow on-going usability studies and iterative improvements through semi-automated methods including user generated open tagging and A/B page testing.

#### **Translation of Findings/Results**

Solutions for the prevention of MSDs have been gathered from real world industrial settings, categorized and described, and published on-line in a way that is easily

accessible by a variety of types of personnel in general industry. This information has been made available on a scope and level of practicality that has previously not existed. Different portals are provided on the website to accommodate different types of users. Since a website of this nature and size can easily become unwieldy and difficult to navigate, usability research helped insure that the site is as user-friendly as possible.

### **Outcomes/Impact**

Work-related Musculoskeletal Disorders (MSDs) are the most prevalent, most expensive and most preventable workplace injuries in the country (OSHA, 1999). The U.S. Bureau of Labor Statistics (BLS) surveys show that MSDs comprise the single largest category of workplace illnesses and injuries, constituting one in three workplace injuries and illnesses. Moreover, days lost related to MSDs are greater than other types of injuries, thus the costs of these disorders are greater than would be expected from the number of recorded cases (BLS, 2007). Workers' compensation costs to employers nationally total over \$87 billion per year, an increase 36% since 2000 (NASI, 2010). Furthermore, the tasks that cause these disorders tend to be inefficient and involve wasted motions, time, and effort (MacLeod, 1995, 2000, 2012).

This solutions knowledgebase and the accompanying "how-to" portals are unique and mark a milestone in the evolution of workplace ergonomics. The solutions are both fundamental to common production operations and are comprehensive. Thus, the website serves as a de facto primer on setting up production operations intelligently.

Documentation of the effectiveness of the solutions was not part of the grant, but the solutions were developed in manufacturing plants where their implementation typically yielded cuts in workers' compensation costs by at least 50% plus increased productivity by roughly 10-15%, occasionally reaching peaks of 200-300% improvement (MacLeod, 2012). If U.S. manufacturing industry would systematically implement solutions described on this site, workers' compensation costs would drop on the order of \$50 billion and manufacturing GDP would increase on the order of \$200 billion.

### **Commercialization**

Plans for commercializing the knowledgebase are progressing with high expectations.

### **Publications**

The grant applicants are in the process of submitting a paper about this project for a 2014 international ergonomics conference. Also, the project itself constitutes an on-line publication.

## Section II — Scientific Report

### Background for the project

The Principle Investigator (PI) is president of an ergonomics consulting firm (Dan MacLeod LLC) that specializes in working with employers in general industry to identify practical solutions that reduce the risk of workplace Musculoskeletal Disorders (MSDs)\*. The company maintains a large library of reports, photographs, video clips, and related information on feasible methods to reduce MSD risk factors compiled from ergonomics evaluations over a 30-year period in more than 1500 individual workplaces. The project was designed to convert this information into a website of ergonomics solutions for common tasks in general industry that create risks for MSDs.

The primary consultant to the project is a company (Ergoweb, Inc.) that provides a website of training materials, task evaluation, and program management tools for employers and practitioners. This website is available with paid subscription and provides the foundation for the commercial requirements of the grant (see Phase III below).

The scientific basis of the risk factors of MSD risk factors is well-established in the literature (NIOSH, 1997; NAS, 2001). The solutions in the website provide numerous techniques for reducing these risk factors. For example, the harmful effect of working with a bent posture of the lower back has been well established and accepted, including quantitative guidelines and models (e.g. NIOSH, 1994; Chaffin and Andersson, 1999). The website provides hundreds of techniques that can improve lower back posture for various common tasks in general industry.

Fortunately, there is widespread evidence that MSDs and their related costs can be controlled. For example, BLS data show a 50% reduction in upper extremity MSDs from 1991 to 2001 in the industry with by far the highest rates of repeated trauma, i.e., the meatpacking industry. The time period of this reduction paralleled the publication of OSHA's *Ergonomics Program Management Guidelines for Meatpacking Plants* and related OSHA enforcement activities (OSHA, 1991). This reduction can be readily related to ergonomics programs and modifications in tools, equipment, and tasks in that industry, based on the PI's own work (MacLeod, 1989, 1996).

An in-depth review of five companies concludes that long term, systematic ergonomics programs reduced injuries and related costs. The workers' compensation costs in these case examples were reduced an average of 66%, with one company showing a 90% reduction in these costs (GAO, 1997). Various other sources provide case examples of similar reductions in injuries and costs along with the managerial actions needed to prevent MSDs (e.g., Liberty Mutual, 2006; NSC, 2002; OSHA, 2000, 2007, NIOSH, 1997, 2007).

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\* A general class of conditions that involve the nerves, tendons, muscles, and supporting structures of the body. Risk factors include awkward postures, excessive force, repetitive motions, static load, and vibration.

## Specific aims and results

### A. Product

#### 1. The solutions knowledgebase

##### a. Results

This project created a website knowledgebase of roughly 5000 practical solutions for common causes of workplace MSDs in manufacturing operations. These solutions were adapted from actual improvements taken from the Principle Investigator's library of reports, photographs, and other information that have been accumulated in ergonomics consulting projects performed in more than 1500 individual workplaces.

The knowledgebase contains approximately 3000 photographs of the solutions. These photos consistently receive positive comments from users and reviewers for adding interest to the web pages, improved ability to browse, and better understanding of the point of the particular solutions. Furthermore, it has become apparent that this library of photos is more unique than the PI initially understood when proposing this project. Other sources simply do not have the breadth of these photos or permission to use them publicly.

It is also worth noting that it is difficult to take clear photos in manufacturing settings because equipment in the area often obscures or distracts from the image of the actual solution. Thus, nearly all of the photos were edited to remove or darken unwanted items. The time required to edit the photos often was greater than the time needed to describe the solution in the text, but the results are dramatically improved with these graphics.

Considerable emphasis is placed on showing low-cost, low-tech solutions, including items that can be fabricated in-house. Vendor information is provided in many cases, with either direct links to product websites that are especially useful or general internet search categories and sources for commonly available items.

The goal of Phase I of the project was to develop and evaluate a prototype website based on the two categories of Material Handling and Workstation Design. Phase II added about 4000 more solutions, expanded in the categories of Machine Operation, Hand Tools, Maintenance, and Warehousing, along with other equivalent tasks in the service industry. Each category is further divided into topics that contain the specific solutions. The total list of 102 topics is shown in Appendix A.

Background explanatory material is provided at each level to guide users in proper application. Additionally, the site contains overviews of "cautions" and "common errors" to help guide users.

Phase I usability research revealed that users search differently depending upon their experience and background. Consequently, in Phase II, the website was structured to accommodate these differences. The solutions categories and topics are designed to be browsable by users who generally know what they are looking for and are comfortable with exploring using this framework. Additionally, there are three portals for users who

desire more explanation of how these topics fit together and how to approach workplace improvement in a step-by-step sequence.

Each of these portals has a different orientation for different users and purposes, but all are based on and link to the various solutions in the knowledgebase. The portals and the sections of each are as follows:

1. How to set up a production line
  - a. How to design a workstation
  - b. How to improve the machine-operator interface
  - c. How to improve manual material handling
  - d. How to optimize hand tool use
  - e. How to improve ease-of-maintenance
  - f. Putting it all together: Production systems
2. How to design equipment to prevent MSDs
  - a. Back injuries
  - b. Shoulder and elbow disorders
  - c. Hand and wrist disorders
3. Principles of human-friendly design
4. Training
  - a. Introductory course (with video clips, downloadable handouts, checklists, etc.)
  - b. Problem-solving exercises (including video clip evaluation)
  - c. Ergonomics – Foundation for production
  - d. Perspectives on practical applications in the workplace

Thus, the “production” portal might attract the attention of a manufacturing engineer or manager looking for ideas and best practices and who might not necessarily realize that ergonomics affects efficiency or quality. By following the guidance for production improvement, then the risk for injury would be expected to drop. The various sections of this portal are especially written to be followed in a step-by-step sequence.

The “prevent MSDs” portal might attract a plant nurse or safety manager who is tasked with preventing these injuries, but does not know where to start.

The “principles” portal provides an introduction to the knowledgebase in a manner that reinforces commonalities of issues independent of a specific task.

The “training” portal might attract either an individual or a team who wishes a systematic introduction to the field in a way that promotes shop floor improvements. The portal is structured step-by-step, that is, it provides a sequence for learning basics, then applying on the floor, then learning more, etc. (The specific approach was successfully field tested with safety teams in a major manufacturing plant in conjunction with this project, although not funded by the grant.)

## b. Comparison of milestones

A comparison of the projected milestones for the knowledgebase from the grant proposal and actual milestones achieved shows the success of this project:

Phase I base	Phase II goal	Actual
1000 solutions	4000 additional solutions	About 4000 new solutions
2 sections	5 new sections	5 new, plus 17 new sections in the portals
none	3 new portals	3 new

## c. Future development

The framework is clearly now established for easy future expansion, including new categories in other branches of industry. Furthermore, the foundation is set for individual companies and practitioners to donate more examples of solutions and to create in-house databases of best practices that link to the knowledgebase (see Phase III below).

## d. Significance of the knowledgebase

From the personal perspective and career of the PI, this knowledgebase marks a milestone in the evolution of the field of ergonomics:

- 1970s – Recognition of work-related MSDs, initial training materials on ergonomics, and first shop floor intervention projects.
- 1980s – Development of systematic programs to prevent MSDs, e.g. the *Ergonomics Program Management Guidelines for the Meatpacking*.
- 1990s – Widespread application of workplace ergonomics in multiple industries, development of solutions and best practices.
- Current – publishable knowledgebase of solutions

Furthermore, the drafting of the portal “How to set up a production line” marks a new plateau in the ability to communicate with senior managers and engineers. Likewise, the step-by-step guidance adds a new level of sophistication in ergonomics program management. Finally, these materials are fundamental and comprehensive, to the point that they serve as a primer on setting up production operations that can be used by both small and larger organizations.

As a final comment, the development of the internet and its daily access by personnel in general industry provided a pre-requisite for this project. The printed page does not lend itself to a knowledgebase of this sort. The internet allows hyperlinks, unlimited space for new solutions and information, and the ability to continuously edit and update the materials for users.

## 2. Website Architecture

### a. New state-of-the-art platform

The creation of this knowledgebase triggered a complete renovation of the ergoweb.com website architecture in order to:

- Optimize the management of the MacLeod content as it was transferred to the ergoweb.com system.
- Enable ongoing, semi-automated usability studies and continuous improvements.

- Facilitate the integration of the MacLeod content with existing and future content additions to the ergoweb.com content management system.

This upgrading of the software was not funded by the grant, but provided a foundation for successful implementation, ongoing continuous improvement functionality, and future management of the project. The ultimate choice of new platforms, however, was significantly influenced and tested against the requirements for this grant.

The new architecture constituted a major investment in time and financial resources. It provides state-of-the-art capability for the knowledgebase and access by users. However, the time required to research, plan and implement the new system delayed the initial plans for commercialization (see Phase III below).

#### **b. Software Platform Iterations**

Several software platforms were extensively tested. The ergoweb.com content management system (CMS) was originally built on the Adobe ColdFusion application server platform. Between the years 2000 and 2013, Ergoweb customized an extensive CMS system for the ergoweb.com knowledge system.

##### *Iteration I: Cold Fusion & MSSQL*

In earlier phases of this project, we established a ColdFusion based version of the MacLeod system, duplicating the content and mimicking the navigation established in Phase I of this grant. In this model, we also attempted to organize the information that had previously been presented in long page format into elemental components, with the expectation that those elemental “chunks” of information could later be called upon to construct new “pages.”

For example, a one or two paragraph description of a specific type of hand tool may apply to different knowledge areas, and if the content were available in elemental form, that description could be dynamically pulled into other pages, reducing the potential or need for manually duplicating similar content in many related pages.

That version of the system was effective at dynamically reproducing the long format page design, but we encountered significant challenges when attempting to integrate the elemental “chunks” into other pages, because the information did not flow as a continuous document; re-using the “chunks” in new content formulations lacked the context that a continuously written and flowing long page format provides. The system was extensive and effective for our early purposes, but the ColdFusion platform has since fallen from favor among web developers for a variety of reasons, and therefore became increasingly difficult to support and expand upon.

##### *Iteration II: Drupal, PHP and MySQL*

Next, the MacLeod content was transferred to a Drupal and PHP development environment in order to test that platform’s efficacy in managing, growing and presenting the knowledgebase. While the Drupal platform has many ardent supporters in the web development community, it turned out to be a challenging platform for these purposes,

and determined it to be a substandard choice for the long-term viability of the system, more from the perspective of our internal system developers and administrators managing and growing the system over time than from the perspective of end-user usability.

#### *Iteration III: Word Press, PHP and MySQL*

Finally, a Word Press (CMS software), PHP (programming language) and MySQL (database software) platform was tested and chosen as the most sustainable path forward.

In order to facilitate the MacLeod content and integrate it with the overall ergoweb.com content, the Work Press facilitated system has since been extensively customized, and incorporated Javascript and AJAX programming languages to further improve functionality and the user interface.

In retrospect, it seems counterintuitive that the open-source Word Press platform became the platform of choice, but in the fast paced internet technology arena, an open source platform enjoys the support of many talented developers and thrives on continued innovation, features the team strongly desires as the system transitions into continuous improvement and commercialization phases.

#### **c. Taxonomies and Hierarchical Browse Style Searching**

At the outset of the project, the initial presumption was that the information architecture and navigational strategies might best be stored in a database and presented to users as hierarchical taxonomies. For example, the portal concept represents a navigational strategy with hierarchical, step-by-step drill-down to more and more specific information.

However, as a result of the usability studies, the team recognized that in the context of this project, taxonomies can take the form of a navigational taxonomy and information architecture taxonomy. For example, a navigation taxonomy, such as the portal concept employed, can begin with categories that target expected user interests or backgrounds, then offer them a structured path (hierarchical taxonomy) to drill deeper into the knowledgebase. An information architecture taxonomy, on the other hand, may or may not represent user navigation strategies, and is employed as a means to organize, store and retrieve information based on categories. Both taxonomy concepts were tested and used in this project.

Like many attempts to organize information into categories, the team struggled to develop a single taxonomy that served all needs, including content organization, data storage, and user navigation. To do so forces a fairly static and rigid model across a system that must remain flexible to accept future content additions, changing user needs and perspectives, and changing technology. A single model also proved unwise from the standpoint of database technology, because database management and response speed dictate data organization and storage requirements, not the mental model that a user or content administrator might expect or wish. A strict taxonomy approach can also lead to compromises that arise as the content designers attempt to force topics into more and more specific categories:

- How specific should the taxonomy become as it gets deeper?

- Should the categories be designed as mutually exclusive choices?
- Will content developers agree on how to categorize content, or will the choices and consistency vary from one developer to another (reliability)?
- Most important, how well will specific categories and associated terminology reflect user perspectives?

Ultimately, hierarchical classification systems are susceptible to the biases of the designers and the culture and era in which they are defined, and once designed and implemented, they can become difficult to change. Nevertheless, the team developed extensive taxonomies to explore ways to categorize content for data storage and hierarchical browse-style searching strategies.

Another evolving information categorization tool has become commonplace on the Web: tags. Tags are a non-hierarchical term or phrase, much like keywords, assigned to a piece of information. A collection of content creates a “tag cloud.” Depending on how they are implemented, tags are considered a much more flexible classification method. Some information systems allow users to add their own tags to content, which can lead to greater and greater personalization, yet make it challenging for others to search or browse if they do not share the same perspective that the tag originator had. In essence, an open tagging system can create the equivalent of distracting information “noise”.

For example, a picture of a powered nut runner might be “tagged” with words/phrases like “power tool”, “hand tool”, “nut runner”, or any number of verbal identifiers. A challenge with tagging systems is determining where to stop when applying such labels. How deep and how broad should tagging go? For example, should the nut runner be tagged with “vibration”, or “power grip”, or “wrist angle”, all of which are things that can be linked to a powered nut runner, but are they pertinent to effectively organizing, storing and retrieving information from the knowledge system?

The team explored both hierarchical taxonomies and tagging systems and will continue to do so as part of the continuous improvement processes,. The current version of the ergoweb.com site uses a mix of the two. Hierarchical taxonomies are proving to be a preferred method when designing web site navigational strategies, and a combination of categories and tagging is being employed at the elemental content level.

Tagging content provides another distinct advantage for our purposes. By allowing users to “tag” content with labels that make sense to them, we are able to conduct ongoing, semi-automated Card Sorting type usability studies and improvements. Rather than leaving our tagging system open to any and all users, we will do so under controlled experimental conditions, and all tag suggestions will be evaluated by our team prior to being accepted, or rejected, to our tag cloud. In other words, we will not allow the tagging system to become too broad or diffused, creating information noise, but will instead employ an ongoing combination of end-user perspectives and expert oversight.

#### **d. Keyword / Phrase Style Searching**

Advancements in search technology have also significantly influenced the knowledge and user-interface architecture for this project. While structured information architecture remains important for browsing-based search and site navigation, natural language searching, such as that pioneered by Google, provides new and powerful options. The team will use keyword search technology as one means of end-user site navigation, and will also use keyword search entries as part of our ongoing continuous improvement processes, as discussed below.

### **B. Research**

There were two levels of research for this project: Data development and Website Usability.

#### **1. Data development**

The research on effective solutions was conducted over a 30-year period as part of a private consulting practice. This research was not funded by the grant, but was essential to the project. A large number of new solutions were developed or identified during this project, primarily as a result of additional consulting projects. Again, these activities were not funded by the grant, but contributed substantially.

Documentation of the effectiveness of the solutions was likewise not part of the grant, but examples are included in the training portal on the website.

Development of a meaningful taxonomy for the solutions was part of the grant and a target for usability research.

#### **2. Website Usability**

A website of this nature and ultimate size can easily become unwieldy and difficult to navigate. Thus the research portion of this project is devoted to insuring that the site is as user-friendly as possible.

##### **a. New technology – Automated usability testing**

A technological breakthrough affected the research plans. The initial goal was to conduct a series of tests to explore search behavior and identify barriers to effective use of the website. New software essentially automates these types of studies, permitting on-going testing in the future. Web developers can now:

- Track search behaviors, along with the search terms used to find solutions.
- Conduct “A/B testing,” which is a method whereby web visitors can be presented with two different versions of a page, then monitor their viewing behavior against goals and expectations

Thus, it is now possible to continuously improve content and navigation on the go.

This software was not available or anticipated when the grant proposal was written. Thus, the decision was made to cut back on the number of live subject testing, in favor of investing in the new capabilities. This change allowed better use of grant resources and enables achieving better results, on-going into the future.

## b. Live subject testing

### *Target Users*

Target users consisted of individuals involved in designing or improving a manufacturing or industrial process, including engineers, members of production teams, and members of safety and ergonomics teams. Target users were from both large and small organizations, and had varying levels of previous experience with ergonomics.

Note that usability testing commonly involves using small sample sizes, since the goal is to observe behavior in qualitative terms, rather than obtain statistically significant measurements. Recent experience shows that a very small group, such as four or five test subjects, provides equally useful feedback as larger groups (Krug, 2006; HHS, 2007; EU, 2007).

### *Focus Groups*

Phase I usability relied exclusively on focus groups. There were two primary findings based on the initial prototype.

(1) Internet search behavior varies. The expectation was that users would search for solutions on the internet in a particular way, and that the website should be designed to match that pattern. However, the evaluations showed that different users approach a search differently, depending upon their background and experience. For example, manufacturing engineers are satisfied with skimming a long list of solution categories. However, a plant nurse tends to approach the search more as a question, such as “How can I prevent back injuries.” Consequently, in Phase II, new introductory portals were added so that users with different styles of searching for information can access the solutions based on different frameworks and styles.

(2) The website has widespread general application. The target users of this website were initially anticipated as occupational safety staff and production engineers in larger workplaces. However, the Phase I evaluations showed that the site is down-to-earth, thus the target audience can be expanded to include small industrial operations without professional staff or previous exposure to ergonomics. Consequently, in Phase II, considerable emphasis was placed on developing the portal “How to set up a production line” as a framework for communicating with this group.

### *Card sorting*

The card sorting technique was used at the beginning of the web based design as a tool to design entry/home pages, menu structures, content architecture and navigation paths for various target user perspectives.

Five subjects were recruited from each of the following perspectives:

- Injury/Health Care perspective (Physical and occupational therapists, nurses)
- Task/functional perspective (ergonomic team members, union representatives)
- Equipment based perspective (EHS manager, safety professional, manufacturing engineer, etc.)

The 15 subjects participated in a one hour usability study conducted on March 19<sup>th</sup>, 2013 at the Applied Ergonomics Conference held in Dallas, Texas. Participants were given a \$50 Amazon gift card upon completion of the study.

*Task 1:* Participants were provided with a description of the knowledgebase. All fifteen checked “yes” when asked if they would visit that type of site. The topic areas they checked that were of most interest to them are summarized in the table below.

Number of participants that checked the box	Type of Information
15	Workstations – Solutions and best practices
12	Injury Prevention
12	How to Design a Workstation
12	How to improve Manual Material Handling
12	Hand tools – Solutions and best practices
12	Personal Equipment – Solutions and best practices
9	How to Design Hand Tools: Issues and best practices
9	Machine Operation – Solutions and best practices
8	How to Improve Maintainability Human Factors
7	Maintenance – Solutions and best practices
6	How to Improve Machine-Operator Interface
5	How to Set up a Production Line
1 Fill-In	Other: New Technology / Products
1 Fill-In	Other: Host recent devices for process improvement
1 Fill-In	Other: List by equipment needed
1 Fill-In	Other: List by risk factor reduced
1 Fill-In	Other: List by work industry
1 Fill-In	Other: Lifting methods / techniques
1 Fill-In	Other: Setting up & Maintaining ergo programs

In summary:

- Solutions and best practices: All 15 (100%) were interested in “Workstations.”
- 80% of the subjects were interested “Hand tools” and “Personal Equipment.”
- ‘How-to’ guidelines: 80% of the subjects were interested in the documents “How to Design a Workstation,” “How to Improve Material Handling,” and “How to Prevent Injuries.”
- A majority of the subjects were interested in the remaining categories of solutions and ‘how-to’ guidelines, with the exception of the guidelines “How to Improve the Machine-Operator Interface,” and “How to Set Up a Production Line,” which interested only 40% of the subjects and 33% of the subjects respectively.

*Task 2:* Participants sorted 24 equipment photos into categories. They applied labels to each individual piece of equipment and to each category.

There was considerable variation in terminology used to describe particular solutions when no specific choices were offered. For example, the following terms were used to describe the same item: “Pallet lift,” “Pallet mover,” “Pallet hoist,” “Automated pallet,” “Lift device,” “Lift assist,” “Platform lift,” and additional combinations of these terms. However, the subjects generally placed similar solutions in the same categories, despite the differences in terms used.

Surprisingly, for common industrial solutions few subjects applied the correct technical name for the solution. For example, none of the subjects applied the technical name when labeling the photo of a skatewheel conveyor, and only 2 of the 15 applied the technical label to the rollerball conveyor. In addition, forklifts and pallet jacks were mislabeled by several of the participants. These results indicate that many of the users of a solution database will be unfamiliar with the technical equipment names. This needs to be considered when putting categories together that will help drive the user to the right solution based on other descriptors that they are more familiar with.

These results indicate that for the most part there is no particular taxonomy of solution types that the website should adopt, rather that the search function and tagging system should include a wide range of terms for each solution. Furthermore, for users who are browsing, it is important to include photos and clear labels and descriptions on (a) contents pages and (b) the top of each topics page to help users quickly understand the types of solutions found on a that page.

*Task 3:* Participants were provided with a set of cards. They were asked to sort the cards into groups and assign a name to each group. They were asked to note under each group if there were any additional categories they would expect to see in that group that were not in the cards they sorted.

Subjects were consistent when grouping injury related topics (back injuries, elbow and shoulder disorders, and wrist disorders). They also showed a common association of workstations with how to setup a production line. The data is less consistent when sorting other task and equipment topics. No consistent grouping was found when looking at specific risk factors (force, posture, motions, pressure points, and environment).

A review of the data for this section helped to resolve a potential source of confusion between what are now called the “Solutions and best practices categories” and the “‘How-to’ Guidelines.” It was noted that several of the proposed sections did not cover as wide a range of topics as the users would be looking for when using the database. For example, participants added several injury categories including neck, lower extremity, eye strain, and hearing.

*Task 4:* Participants were asked to place each of 10 photos under one of the following categories (where they would look to find a solution to the depicted issue).

1. Hand tools
2. Material Handling
3. Machine Operator Interface
4. Workstation
5. Maintenance
6. Other (label yourself)

If none of the categories fit, they were instructed to place the picture aside and label it with the category name it would fall under.

The subjects for the most part were consistent with each other and with the authors of the website in how they placed photos of specific solutions in the broad categories of “Workstations,” “Material Handling,” “Hand Tools,” etc. when these choices were offered. Thus these broad categories appear have standardized meanings and are well understood.

Subject comments indicated that they sometimes had difficulty identifying the equipment of focus in specific photographs. If other manufacturing equipment and tools were in the photo, they did not always focus on the solution intended by the author. After the study was completed, many of the photos were edited to remove distracting equipment and tools. Consideration was also given to use sketches instead of photos.

#### *Task Analysis*

Ten subjects participated in a one hour task analysis usability study conducted between October 23<sup>rd</sup>, 2013 and November 15<sup>th</sup>, 2013. Subject backgrounds in the area of ergonomics ranged from novice to experienced ergonomist.

All of the subjects answered a series of tasks related to navigating a preliminary knowledgebase site on danmacleod.com. Five of the subjects conducted tasks on the navigation and content of the new ergoweb.com website. Participants conducted with study on their own computer with the interviewer either in person or over the phone. Participants were provided a \$50 Amazon gift card upon completion of the study. A summary of the user responses to the study tasks is summarized below. Questions from the tasks are *italicized*.

#### Background Questions (10 subjects):

All but one of the subjects had searched for an ergonomic solution in the past. All subjects indicated that they would initiate their searches on Google. In addition to Google searches, two participants noted that they would start their search by contact an ergonomist or a colleague. One experienced ergonomist stated he starts his searches by looking for case studies using the WA State Idea Bank or an internal company best practice database.

*Were you able to find what you were looking for?* – Three of the subjects answered yes. The remaining subjects indicated that their success varied depending on what they were looking for and that finding “exactly what you are looking for can be a challenge.”

*What do you remember about the experience?*

- “Everything was too vague. Hard to tell if the solution would meet my needs.”
- “It takes forever to google different words.”
- “Weird websites that you don’t trust or feel comfortable ordering from.”
- “There’s a lot of disparate resources out there - some hokey stuff and some real stuff - hard to tell the difference between the two.”
- “If googling it, sometimes I initially get something unrelated.”
- “I have searched on google where it takes a while to get to what you are looking for because everything is keyword specific. Can be difficult to get to where you want.”

*What type of information are you generally looking for?* – The novice participant indicated she would be looking for general recommendations. The remaining nine participants indicated that they want specific product and vendor information.

- “We want solutions that are industry standard, peer reviewed.”
- “Usually trying to find a product and a sales person that can help me understand and see if it meets my needs. Like a lifting device – there are so many things out there and you’ve never seen them in person, so need to go off the word of the sales person what kind they think is best for you application.”
- “Specific equipment or tools (handles, lifting equipment, etc.), and specifications including weight limits or load capacity.”

*Task 1 – Review of Knowledgebase Categories (10 subjects):* A screen capture of the knowledgebase site at the time of the study was provided. Subjects were asked to consider the primary navigation categories and subcategories and provide input as to the titles themselves as well as the anticipated content associated with each. They were also asked questions related to their interest in each category.

“Browse the Categories” – This category was the most confusing for the users. Several participants noted that they would expect all the other categories to be listed under this section, and they did not understand how this category fit with the other categories. “Categories of what? I would expect a search function to pop up. I wouldn’t but ‘Browse’ or ‘Category’ in the title. I would describe what it is... I have no idea.”

“How to Set up a Production Line” – Subjects that worked in a production environment understood this title and were mixed as to whether or not they would use it. More experienced ergonomists indicated that this information would be too basic. Those not familiar with production were confused by the bullet “Design a Workstation” and assumed that would be related to office.

Overall, user feedback indicates that separating out different work environments such as office, lab, production, and heavy industry will assist users in their search for information.

“Self-study Training” – This category was clear to the majority of users. Not everyone was interested in the category, but users consistently assumed that this would lead them to educational information that would be presented in a training format.

“Injury Prevention” – Users were mixed in their response to this category. Some thought it would help them prevent injuries for employees, while others thought it would direct them to information on things they could do personally to minimize their own risk of injury. Consistent with the feedback from the card sorting, participants noted the short list of body parts on the current site: backs, wrists, and shoulders. Moving forward, the list should be expanded to cover lower extremities and other common areas of occupational injury.

Overall, users were most interested in the categories “Injury Prevention” and “How to Setup a Production line.” Half of the users indicated that they were not interested in “Self Study Training.” Users suggested the following modifications to the navigation and category titles:

- “How to Design Equipment to Prevent Injuries” instead of “Injury Prevention” (based on content under category)
- Replace ‘Browse the Categories’ with a more descriptive title such as ‘Areas of Solution Development’, ‘Categories for Improvement’, ‘Mitigation’, ‘Improvement Strategies’, or ‘Solution Development’.
- ‘About Us’ instead of ‘Who Created This’
- Most users were confused by at least one subcategory under the ‘About this Site’ Category. They expected “Cautions”, ‘Common Errors’, and ‘Vendor Information’ to be located with the solution information as appropriate for a specific topic.
- Users thought the listing of categories on the left side the page and also within colored boxes on the page was unnecessarily redundant. The additional space could be used to better layout the content and show all the main topics above the fold (so users can view all the categories without scrolling).
- Users suggested few subcategories on the homepage.

*Task 2 – Review of content and layout of the “Design a Workstation” section of Knowledgebase (5 subjects):* All of the subjects agreed that the content was lengthy in this section. The more experienced users thought it was too much information, but the less experienced users indicated that they thought the length was necessary for the breadth of the topics covered. All of the users felt the appropriate audience for the content was someone with limited ergonomic background and experience.

Users indicated that they would like some type of flow chart or similar to show the process steps for designing a workstation more clearly. Some typos and content flow issues were documented during the study as well for use when editing the content for the next draft of the website.

*Task 3 – Search for specific solution for a lifting task in Knowledgebase (10 subjects):* Subjects were asked to start on the homepage and search for a solution to manual lifting of boxes from a floor height pallet to a waist height conveyor. All of the users were familiar with this type of task and the ergonomic risk factors associated it.

All of the users started their search with the 'Material Handling' link under the box 'Browse the Categories'. When asked where they would go for additional information after reviewing the MH page if staying on this site, all went back to the homepage and clicked on 'Back Injuries' under 'How to Design Equipment to Prevent Injuries'. Screen copies of the top section of both pages are shown below for reference. If allowed the option to search anywhere, about half of the users indicated they would use the keyword they had found on the MH page and then search google or YouTube to locate vendors of that equipment.

"Material Handling" – 70% of the users immediately selected the first row in the table, 'Pallet and Container Lifts'. Those did not scroll down and consider any other options on the page. The 30% of users that did scroll down the page also considered 'Lifter Transporters', 'Hoists', and 'Manipulator Arms'. This should be considered when redesigning the layout of the page to see if there is a way to show a list of all the items on the side with hyperlinks to assist users with navigating directly to the item of interest without scrolling if they know what they are looking for.

Users expected that they could click on the equipment title or the photos and navigate to more specific information. Overall, users expected specific equipment specifications and vendor information to be available.

As with the card sorting, about half of the users were not sure of the item of focus in some of the photos. Some thought one column was a 'before' photo and the other column an 'after' photo. Others assumed that both photos depicted an example of the solution for that column. When redesigning the site, consideration will be given on how to more clearly define the columns in the table.

"Back Injuries" – The two novice users preferred the 'Back Injuries' page over the 'Material Handling' page when looking for a solution, but commented they would not have thought to look there at first for solution information. The remaining users felt that this page was too wordy for a solution page and required too much reading to get to a solution idea. Several commented that the layout of the page felt 'homemade' or 'like I could have made it' which they did not think was a bad thing, but was something they noticed.

*Task 4 – Review of Ergoweb Navigation (5 subjects):* Users were asked questions related to the categories 'Solutions' and 'Knowledge'. Screen captures of the dropdowns of each of these categories were provided to the subjects. Note that the photo in the background on the site is a rotating image so users saw different images (office, warehouse, and production) when looking at the site.

Users noted a few display issues where word content overlapped. Users liked the layout and the navigation dropdowns Users were somewhat confused by the 'Master Supply Agreements' and 'Ergonomic Equipment Supplier' categories.

*What type of information would you expect to find under the "Solutions" tab?*

- “I would expect to be able to search for a question and see best practices or a product that was a solution versus a method or process.”
- “Solutions to different potential workplace issues like how to avoid back pain, lifting.”
- “Solutions to issues that have surfaced up with other companies. Probably office. Promoting solutions that this company Ergoweb has sold to other companies. I would be curious if there was anything there related to equipment for manufacturing.”
- “Probably contract help.”
- “From my experience in the past, the solutions tab would be the companies list of what they provide -- maybe not solutions directly to your problems, but these are product or consulting that they perform as a company.”

*What type of information would you expect to find under the "Knowledge" tab?*

- “I don't know. I have no idea. I don't have an expectation.”
- “I would think maybe case study information - how they came up with the solutions - general knowledge.”
- “I guess maybe some ergonomics consultants, someone with experience around various topics that can help. Published research, statistics that could help validate. Perhaps a search engine that will take to more information.”
- “I'm not sure what to expect.”
- “Definitely would expect to find blogs, white papers... and recorded webinars -- those are really awesome. The ones that keep me coming back are the ones that give webinars, record them, and allow me to view them without logging in or giving them much information.”

*Summary Questions (10 subjects):*

*“Would you use a “show images” feature?”*

Subjects provided mixed responses this question. The majority indicated they would like the feature if they already had a solution in mind and wanted to quickly scan to see if they could find an image that matched their idea.

*Would you be likely to use the knowledgebase website?*

All participants indicated they would be likely to use this website once the improvements had been made to it and it was fully functioning with live links and vendor information.

### **c. Ongoing Studies and Continuous Improvement**

Perhaps the greatest lesson learned in this project is that information architecture and end-user experience are fluid, and there is no one right or wrong way to organize, store and present information to a broad audience with varying interests and experiences. If the objective had been to treat the current development and usability work as a project with a start and an end, the researchers would likely have conducted more usability studies around a specific “one best approach” concept. However, this approach would probably have resulted in a knowledge system that strongly reflected the biases of the developers,

and would also likely become a static system that would be difficult to update and improve with time.

Instead, the goal from the start has been to build a technology foundation and develop processes to create a sustainable system that will grow and improve over time. In doing so, the researchers recognized that conducting numerous end-user usability studies on static versions of the system would be time consuming and resource intensive, and would result in fewer and slower improvement iterations over time. The team conducted the studies described above in order to develop a commercially viable launch of the system, but are most intrigued with, and invested most heavily in, technology and system architecture that will enable continuous improvement.

Going forward, the team will utilize web site user behavioral tracking, A/B page design testing, and user generated tags and keywords. For example, the developers will monitor and evaluate the keywords users enter when searching for information to learn what topics are of interest, whether or not the system contains such content, and whether or not the user was able to locate that content with their search. The plan also allows user generated content tagging on a controlled experimental basis. Tag suggestions will be reviewed and approved, or rejected, by the team on a case-by-case basis. A/B page testing, a method through which different versions of the same content are randomly presented to visitors, will be used to refine page layout, navigation, and information presentation.

Together, these technologies enable semi-automated usability studies on a continuous basis, leading to small, step-by-step incremental improvements on a regular basis.

### 3. Phase III Commercialization

The commercialization plan is proceeding as expected. The two businesses involved in this project are:

- Dan MacLeod LCC – developer of the content.
- Ergoweb, Inc. – website developer and coordinator of usability research.

Both businesses are currently involved in the field and have already established the mechanisms for product distribution, specifically, an existing commercial website.

Phase II provided the opportunity to explore various business arrangements. In Phase III, these two companies will form a joint venture to own the product and to continue with its development. The start-up is relatively simple because of the electronic nature of the website product. No manufacture, storage, or delivery is needed. Furthermore, no licenses or approvals are needed and there are no regulatory hurdles to overcome.

The rollout of the website to customers was delayed because of the extensive time and effort needed to upgrade the web architecture (see above). Several goals and timing for publicity and marketing have been extended, but should be achieved as planned in the early stages of Phase III.

A number of steps to promote the website have been taken, including the following:

- Presentations about the project were provided at three national and regional professional meetings.
- Preliminary plans have been completed for articles in major trade journals.
- The PI arranged to publish the 2<sup>nd</sup> edition of one of his texts during the time period of Phase II and structured the new written materials to support the website knowledgebase.
- On-line web teleconferences were held with two major national corporations to demonstrate the knowledgebase.
- A separate consulting contract with one of the above corporations led to completion of an in-house knowledgebase of best practices that can be integrated with the Phase III commercial product.
- The team is currently in the process of submitting a proposal describe the project to the 5th International Conference on Applied Human Factors and Ergonomics, 2014, Krakow, Poland.

Overall, the team is well-pleased with results to date and continue to anticipate that this knowledgebase will be a successful commercial venture that will in turn lead to substantial reductions in the risk for musculoskeletal disorders in general industry.

**Appendix A**  
**Taxonomy: Structure of Solution Categories and Topics**

Category	Topics		
<b>Workstations</b>	Arm Supports Clearance Fixtures Fixtures Floor Flooring Footrests Height Layout Lighting Magnification	Parts handling Platforms Seating Sit/stand Slanted Storage Surface material Surface size Visual Temperature	Conveyor workstations Pedestal example Potter's wheel example Die cart example Electronics example Packing Stretch wrap Tape and label
<b>Material handling</b>	Air casters Carts Containers Conveyors Dumpers Gates Hoists Lifter-transporters	Lifts Lift trucks Manipulators Pallets Slides Tilters Tuggers Wheels	Drums Hopper dumper Hopper loading Spools
<b>Machine operation</b>	Changeover Chip handling Controls Doors	Unloading Layout Loading Parts handling	Meat processing equipment. Valves
<b>Hand tools</b>	Grips Weight and balance Tool control, training Vibration Triggers Air hoses, couplings Torque reaction	Counterbalances Extenders Forearm brace Hand straps Mounts Second handles Reachers	Dispensers Wrenches Drills Scissors Scoops Wire strippers Pliers
<b>Labor-saving mechanisms</b> (currently addendum to tools)	Lever Quick releases Gearing Hinges	Pumps Foot pedals Ratchets Vacuum cups	Handheld fixtures Power assists
<b>Maintenance</b>	Access panels Platforms High mobile platforms Lift assists	Maintenance shop Maintenance tools Moving, hauling	
<b>Warehouse</b>	Load/unload Dock issues Checking and sorting	Picking – racks Picking – bins Spools	

**Appendix B**  
**Usability Demographics**

	<b>Goal</b>			<b>Actual</b>		
<b>Total subjects</b>	35			48		
<b>Ethnic Category</b>	Female	Male	Total	Female	Male	Total
Latino	2	2	4	3	5	8
Non-Latino	15	16	31	19	21	40
Total	17	18	35	22	26	48
<b>Racial Category</b>						
Asian	1	1	2			
Black	1	2	3			
White	15	15	30			

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