Knowledge and Intuitive Interface Design: Developing a Knowledge Taxonomy

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1. Executive Summary

Creating an intuitive design is a design goal that is commonly sought in different industries and contexts; the objective is a design that can be operated successfully in a first attempt. Nonetheless, what makes a design intuitive is not necessarily well understood and has been implemented traditionally with the use of analogy, replicating characteristics from well-known or popular designs. This approach does not provide an understanding of the cognitive processes that make intuitive interactions possible.

The goal of this project was to develop an assessment tool based on understanding the knowledge that enables intuitive interactions with a prototype design. With this tool, the prototype's designers can gain understanding of how knowledge transfers between technology experiences and develop recommendations to facilitate incorporating this knowledge. Outcomes from the project will be applicable to diverse human-machine interfaces, representative of those in Deere & Company product lines.

A building block for the proposed assessment tool is a representation of knowledge, as research (discussed in Section 3) suggests that the use of knowledge is central to intuitive interactions. This report describes a specific categorization that we developed to classify knowledge required for interface use. We developed this representation, named the Knowledge Taxonomy, through a process that is described in detail in Section 4 and that resulted in six high-level categories of knowledge required by a user: Interface Family, Specific Displays, Specific Controls, Specific Procedures, Contextual, and Equipment Knowledge. These categories (and their underlying sub-categories) are presented in detail together with examples of their application with Deere & Company products in Section 5.

In addition to the assessment tool described above, we identified several potential applications for the Knowledge Taxonomy in the realm of human-machine interface development and evaluation. These applications are described in detail in Section 6 and summarized in Table 1.

Table 1. Summary of Potential Applications for the Knowledge Taxonomy

Application	**Brief summary**
Assess knowledge demands in a prototype design	Evaluate and document knowledge demands imposed by a prototype design.
Assess current user knowledge	Evaluate and document knowledge that users have about a prototype design at any given moment.
Evaluate knowledge demand consistencies across product lines	Identify knowledge demands for different products and compare them for consistency.
Develop training curricula and materials	Evaluate and address training needs to bridge knowledge demands and current knowledge.
Create designer orientation materials	Design training programs that help orient new members of design teams.

2. Introduction

The usability of a prototype design can be greatly improved by incorporating what can be referred to as "intuitive design" attributes. Although often mentioned as a design goal in different industries and contexts, the specific attributes that constitute intuitive design are not well understood and varying definitions exist (for an in-depth discussion of this literature, see O'Brien, Rogers, & Fisk, 2010). Traditionally, attempts to create intuitive designs have relied on the concept of analogy, where a prototype design mimics that of an artifact that users are familiar or experienced with (Figure 1 provides an example). This approach is incomplete as it lacks an understanding of how prior experience with the analogous artifact and knowledge gained through those experiences are used in intuitive technology interactions.

Figure 1. Analogous use of human anatomy in a Human-Machine Interface. (Source: Volvo Car Corporation)

The goal of the current project was to gain a deeper understanding of the characteristics that make a design appear "intuitive" by eliciting in users knowledge gained through previous experience and allowing them to use such knowledge effectively. Through this understanding we sought to:

- Develop an assessment tool and an accompanying protocol to evaluate a prototype design's incorporation of knowledge that users can apply to engage in intuitive interactions.
- Understand how users transfer knowledge gained through previous experience with systems and contexts to engage in intuitive interactions.

- Produce recommendations for system and user interface designers to incorporate knowledge that enables intuitive interactions.

With this project we also sought to provide outcomes that can be applied to a broad set of Deere products that involve human operators. For that purpose, the analysis focused on intuitive characteristics in human-machine interfaces, defined as "*the means by which the human is connected to the machine"* (Salvendy, 1997, p. 37). Interfaces are designed artifacts where interaction between a human and a machine occur, allowing users to complete specific tasks.

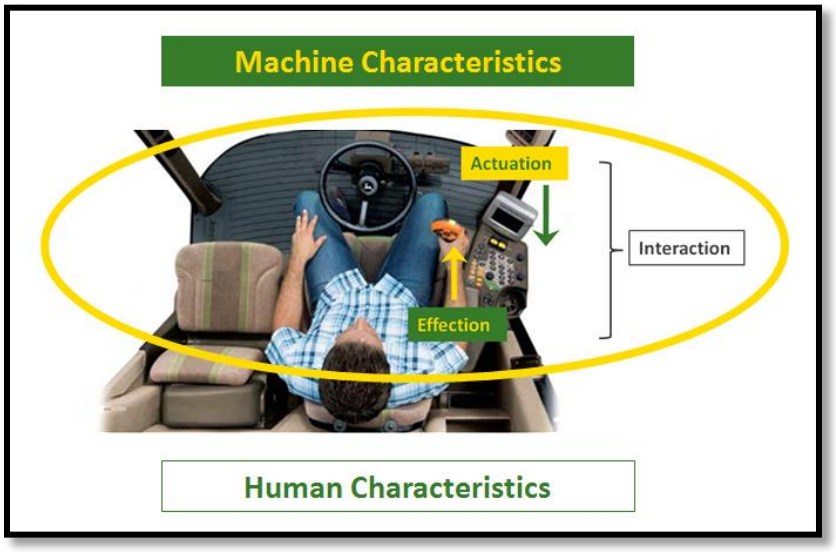

Figure 2. Conceptual Model of Human-Machine Interfaces. (Adapted from Salvendy, 1997, p. 37)

3. Relevant Literature

Previous work in human interaction with novel technologies provided formal and informal definitions for intuitive interface interactions. Literature describes these interactions as those that take place with minimal training, when a user walks up to a device and quickly understands the basics of its operation (Spool, 2005). More formally, it has been defined to include additional aspects: "*interactions between humans and high technology in lenient learning environments that allow the human to use a combination of prior experience and feedforward methods to achieve their functional and abstract goals*" (O'Brien, Rogers, & Fisk, 2008, pp. 1645-1649).

This definition provided by O'Brien et al. (2008) has commonalities with other models of Human-Machine Interaction discussed in the literature. It considers the motivations and goals that a user, as a rational being, is trying to achieve as contemplated by the GOMS analysis (Card, Moran, & Newell, 1983) and the applications of Activity Theory in HCI (Kaptelinin, 1996). The definition also considers cognitive processes that lead to actions (deciding what to do next) similar to the evaluation of conditions and selection of actions in the Human Information Processor Model-HIPM (Newell & Simon, 1972) and the GOMS analysis. Nonetheless, the four models differ on the type of computer use they focus on: Intuitive Interactions addresses novel technology use, HIPM and GOMS describe expert interactions and Activity Theory describes computer use in social and cultural contexts.

Research in this space coincides on the importance of knowledge and operations with knowledge (acquisition, transfer, elicitation) as enabling intuitive interactions. This research references two types of knowledge as components of a technology interaction (Norman, 2002). The first is *Knowledge in the Head*, which a user brings from developing abilities, from culture, and from prior experience with other systems and contexts. The second type of knowledge is *Knowledge in the World*, which users acquire in the moment of interaction through the environment, instructions, and labels incorporated in the system.

O'Brien suggested that intuitive technology interactions take place when these two types of knowledge are articulated to successfully interact with a design. This is facilitated by the incorporation of the appropriate *Knowledge in the World* to elicit and guide use of a user's target *Knowledge in the Head* (O'Brien, 2010, pp. 150-152). The relationship between these types of knowledge and intuitive interactions is summarized in Figure 3.

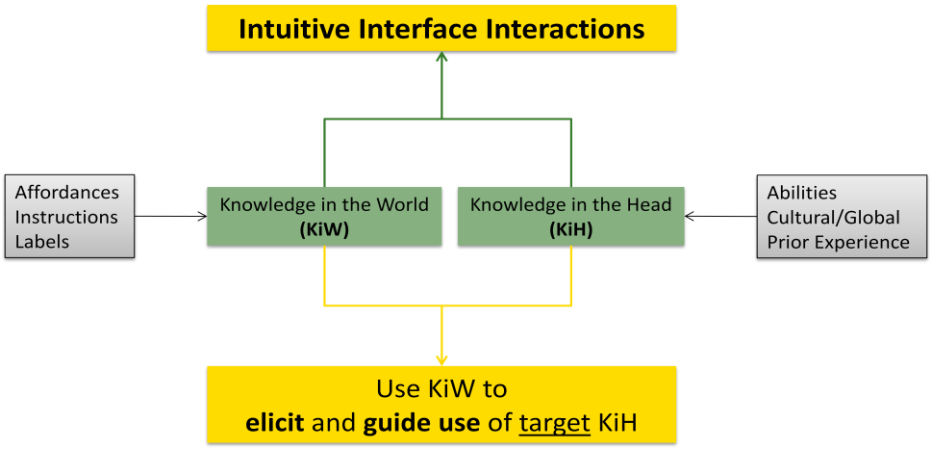

Figure 3. Knowledge in intuitive interface interactions.

Target *Knowledge in the Head* that a prototype design will attempt to elicit from the user should be identified early in design stages. Not doing so could result in eliciting unintended, confusing knowledge and bring problems to the interaction. This *negative transfer*, occurs when the elicited *Knowledge in the Head* interferes with the user's ability to interact with a system. Similar to this is the use of *dead metaphors*, where a design presents users with representations that they cannot relate to and that do not elicit any *Knowledge in the Head*. Some examples of these occurrences are presented next.

Figure 4 shows a computer printer software interface that elicits knowledge a user would have from prior experience with a VCR. This knowledge might cause confusion, however, because it requires mapping VCR actions to those of a printer. This mapping is not always direct as in the case with the "rewind" action and its effect on a printer.

Figure 4. Negative transfer in a computer interface. (Source: Isys Information Architects)

Figure 5 provides an example of a metaphor that is increasingly disappearing from many environments today and might confuse specific user audiences if used in an interface to elicit knowledge related to storage or safekeeping.

Figure 5. File cabinets represent an example of a dead metaphor. (Source: Flickr)

Intuitive interactions, as mentioned above, involve presenting users *Knowledge in the World* in the form of cues (instructions, labels, and other interface elements). This requires awareness of the cognitive limits that users have to associate cues with specific *Knowledge in the World*. The concept of *vicarious mediation*, introduced in Brunswik's Lens model (Brunswik, 1955), suggests that cues available to a user are only probabilistically related to a specific event, or in this case, to specific knowledge. Brunswik also suggested that users learn from encounters with cues, and his model included a *feedback loop* that reflects how learning about a presented cue can be used in future encounters with it.

In summary, successful intuitive interactions with novel technology are explained in the literature with concepts that revolve around knowledge, and its effective use and incorporation into design. Nonetheless, there are risks that need to be considered, related to drawing unintended knowledge from the user. Because of the relevance of knowledge, we saw the need to develop a representation for it that could be used systematically and unambiguously to describe interface knowledge and incorporate it into design. To address this need, we developed a categorization of knowledge that could be used to assess knowledge and its use, but also to document and make use of outcomes from these assessments.

4. Creating a Taxonomy of Knowledge

To accurately describe knowledge required for interface use and its role in intuitive interactions, we developed a general representation for knowledge. We created a Knowledge Taxonomy, which is a hierarchical taxonomy of knowledge for analyses at different levels of granularity. We designed the Knowledge Taxonomy as a scalable tool, to be applied in diverse activities such as evaluating knowledge demands imposed by a prototype design or assessing current knowledge that users have. We also designed the Knowledge Taxonomy as a flexible tool that can be used even when information about some aspects of interface operation is incomplete. A more detailed description of potential applications is provided in Section 6.

The process we used to create the Knowledge Taxonomy borrowed from Knowledge Engineering methods to include an inventory of all relevant knowledge. We compiled a wide-ranging inventory of knowledge that users require for specific tasks with five human-machine interfaces. These interfaces were selected to represent a broad array of platforms, contexts, and interaction modalities, because we wanted to create a Knowledge Taxonomy that could be applied to a broad number of interface implementations. The five interfaces and the exemplar tasks used to compile the inventory are presented in Table 2.

Table 2. Interfaces and Tasks Used in the Knowledge Inventory

Interface	Exemplar Tasks
John Deere 6615 Tractor Cabin	Mow a citrus orchard as part of a team where each team member is equipped with a tractor and a mower implement.
John Deere Greenstar 2 Console	Configure a custom display layout and view the current state of the guidance equipment.
Microsoft Word 2007	Create an empty document with a 4x4 table, format it with the Word 2007 built-in styles and center and bold its headers.
Medicare.gov website	Use the Medicare website to determine Medicare eligibility and compare Home Health providers.
Amtrak Phone Reservations (IVR) 1-800-872-7245	Get schedules and AAA discount rates for three train tickets for a senior adult, an adult, and an infant between New York and Orlando.

After we assembled an initial inventory of knowledge, we followed several iterations to identify salient themes and to group instances of knowledge accordingly. With this process, we refined the identified themes into six high level categories (and their sub-categories) that comprehensively cover

interface interaction knowledge. This section provides an overview of the six high level categories of knowledge and they are described (together with their sub-categories) with more detail in Section 5.

The first of the six high-level categories we identified consists of general knowledge that is common to a group of interfaces that share a denomination and other similarities (described as sub-categories in Section 5):

- Interface Family Knowledge: *Knowledge that a user requires that is common to a collection of interfaces and not specific to a system or task.*

In this report, we refer to the collection of interfaces defined above as an Interface Family. Two examples of Interface Families are provided by Figure 6, and described in detail in Section 5: "Tractor Cabins" captures knowledge required to operate a group of tractor cabin implementations and "Management Software Consoles" would capture knowledge required to operate devices used to monitor and configure electronic equipment.

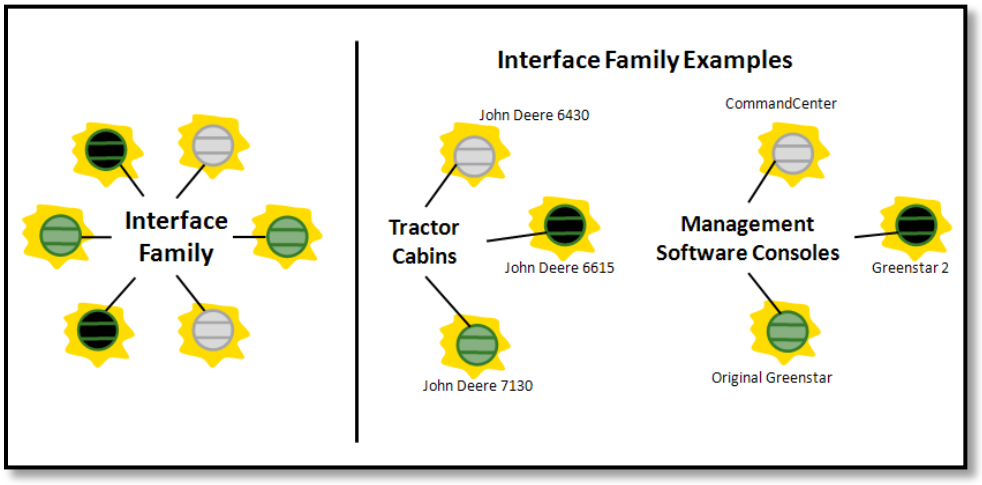

Figure 6. The Interface Family category of knowledge and two examples: Tractor Cabins and Management Software Consoles.

The Knowledge Taxonomy includes five high-level categories that capture knowledge required to interact with a specific interface within the Interface Family. A specific interface can also be thought of as

a prototype design that is being studied with the Knowledge Taxonomy. Continuing with the examples provided above, these categories capture knowledge users would require to interact with a specific Tractor Cabin (e.g., the John Deere 6615 Tractor Cabin) or a specific Management Software Console (e.g., John Deere Greenstar 2 console).

Interface-specific knowledge includes details about the design of the interface and its operation, and is captured in these categories:

- Specific Displays Knowledge: *Knowledge a user requires about means with which to perceive the state of a specific interface*.
- Specific Controls Knowledge: *Knowledge a user requires about means with which to provide input to a specific interface.*
- Specific Procedures Knowledge: *Knowledge about how to use a specific interface to complete a task*.

In many circumstances, users require knowledge about factors that are external to the interface (as defined in Section 2) and are critical to successful interaction. For this purpose, the Knowledge Taxonomy includes Contextual and Equipment Knowledge categories:

- Contextual Knowledge: *Knowledge a user requires about factors external to the interface and that affect task performance*.
- Equipment Knowledge: *Knowledge a user requires about specific mechanical components that support system use*.

In summary, successful interactions with prototype designs require knowledge that can be categorized with the Knowledge Taxonomy as: knowledge general to a collection of interfaces (Interface Family Knowledge); knowledge about a specific interface implementation (Specific Displays, Specific Controls and Specific Procedures Knowledge); and knowledge about factors external to a specific interface implementation (Contextual and Equipment Knowledge). The relationship between these six

categories is illustrated in Figure 7. We present each category and its use in further detail in the next section.

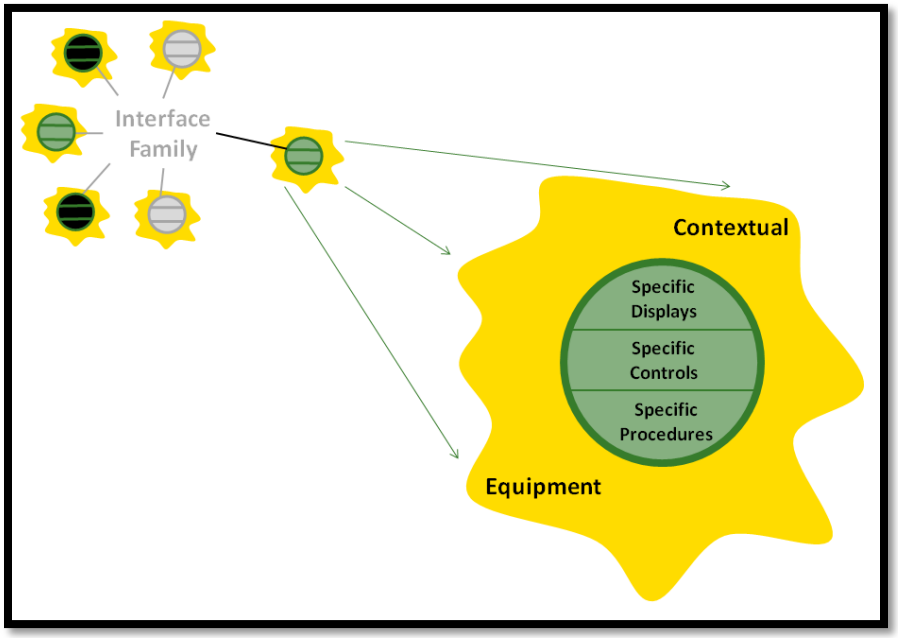

Figure 7. Categories for knowledge common to a collection of interfaces (left) and interface-specific knowledge (right).

5. The Knowledge Taxonomy in Detail

As we discussed in the previous section, the Knowledge Taxonomy describes knowledge general to a collection of interfaces (Interface Family Knowledge), knowledge about a specific interface implementation (Specific Displays, Specific Controls and Specific Procedures Knowledge), and knowledge about factors external to a specific interface implementation (Contextual and Equipment Knowledge). In this section, we present these six high-level categories and their sub-categories, and illustrate them with two non-exhaustive examples: a John Deere 6615 Tractor Cabin used in orchard mowing (rich with context knowledge) and a John Deere Greenstar 2 Console used to monitor and configure tractor guidance equipment.

5.1. Interface Family Knowledge

The Interface Family category includes knowledge that users require for interface operation that is common to a collection of implementations, not specific to a system or task. When applying the Knowledge Taxonomy to a prototype design, it is critical to adequately define the Interface Family that the design belongs to. Such definition has two elements: 1) the Interface Family is subject to a name or label that identifies all interfaces that make it up, and 2) it is possible to identify a set of user goals that can be achieved with all interfaces in the family.

Additionally, the purpose with which the Knowledge Taxonomy is being applied can also affect the definition of the Interface Family. The definition could be restricted to interfaces of a particular manufacturer or belonging to a particular period in time, again depending on the purpose of the analysis. Some examples of Interface Families that are expanded on with further detail in Appendix A include: Word-processing Software, Institutional Websites, and Interactive Voice Response (IVR) Systems. We present the sub-categories that make up Interface Family Knowledge in Table 3, using the examples discussed in Section 4.

Table 3. Examples of Interface Family Knowledge

Interface Family Sub-Categories	John Deere 6615 Tractor Cabin in orchard mowing	John Deere Greenstar 2 Console in monitoring and configuration
Family name	Tractor Cabins	Management Software Consoles
User goals	Cover a certain area Perform agricultural task	Learn about an issue Accomplish a task
Available tasks	Start equipment and go Power an implement	Configure a feature supported by the Console
Task flow	Turn ignition on, certain indicators turn on and off, shift into gear, press gas pedal Slow-down, engage PTO, implement is powered	Look for an option menu Bring up main menu Select icon menu option Evaluate displayed content Explore menu, content
Common displays	Speed, RPM gauges Engine-related indicator lights	Color graphics and text Bounded, non-clickable areas Widgets with different functionality
Common controls	Gas and brake pedals Steering wheel Gear change levers	Bounded areas identified as buttons Buttons have a pressed state (feedback) Single-press required Screen keyboards for text input

The Interface Family Knowledge sub-categories capture knowledge about the user goals supported by all interfaces in the Interface Family and the mechanisms they provide to allow users to achieve those goals. The definition for each sub-category is provided next.

5.1.1. Family name. Knowledge about the label that identifies the Interface Family where a prototype design belongs.

5.1.2. User goals. Knowledge about common objectives that can be achieved with all interfaces in an Interface Family. Together with the family name, they define what a Family is.

5.1.3. Available tasks. Knowledge about activities that can be performed with all interfaces in the family. These activities are completed using functions implemented in the interfaces.

5.1.4. Task flow. Knowledge about the sequence of function use that is common to all interfaces in the family.

5.1.5. Common displays. Knowledge about the display attributes that are common to all interfaces in the family. These attributes can include information content, placement, or sensory modality.

5.1.6. Common controls. Knowledge about the control attributes that are common to all interfaces in the family. These attributes can include control type, location, operation or coding used.

5.2. Specific Displays Knowledge

The category in this section and those described in the following sections are specific to an interface implementation member of an Interface Family (e.g., a prototype design). The Specific Displays Knowledge category captures interface knowledge about the means with which to perceive the state of the interface and the outcomes of operations performed in it. We present the sub-categories that make up this category in Table 4.

Table 4. Examples of Specific Displays Knowledge

Specific Displays Sub-Categories	John Deere 6615 Tractor Cabin in orchard mowing	John Deere GreenStar 2 Console in monitoring and configuration
Color	Meaning of colors used in indicators: red, green, orange	Colors highlight buttons, panels, need for input, covered area in map display Equipment status, settings
Icons	Identify control panel functions Lever settings Indicator lights	Identify the Home, Menu buttons Functionality icons Equipment components
Layout	Row of lights -instrument panel Cluster -above steering wheel, controls panel Array of lights in progress bar (temp.)	Buttons panel on right Clock widget Menu, home buttons Progress bars Different layouts, custom layouts
Saliency variations	Flashing lights (on startup) Static lights (signal a feature on)	Static elements on screen
Sensory modality	Visual (color codes, lights, gauges)	Auditory (display alerts) Visual (color codes, icons)
Textual labels	Numeric-speed/RPM gauges Text -safety warnings Numeric -gear positions (I, II, III) Numeric -hydraulics positions	Text -Feature labels Text -Settings labels Text -Status messages, output
Related event	Engine problems present Feature has been activated	Equipment performance status Task performance (area covered, alignment) Call for action or input

The Specific Displays Knowledge sub-categories capture knowledge required to identify an interface element as a display, the formats it uses, and the information it conveys.

5.2.1. Color. Knowledge related to the meaning of color, saturation and hue combinations used in the interface. This includes knowledge about color codes used or colors that signal specific circumstances.

5.2.2. Icons. Knowledge about representations of objects, actions or scenes used in the interface that excludes the use of alphanumerical characters.

5.2.3. Layout. Knowledge related to the meaning of an arrangement of display components. This includes knowledge about displays grouped together or the order in which displays are sequenced.

5.2.4. Saliency variations. Knowledge about the meaning of differences in how display components are exposed. This includes knowledge about the meaning of a display being intermittent or static.

5.2.5. Sensory modality. Knowledge about the type of stimulus used by the display (auditory, visual, somatosensory, olfactory, and gustatory).

5.2.6. Textual labels. Knowledge about the system of words and alphanumerical characters (from a specific set or alphabet) used in displays to identify or communicate.

5.2.7. Related event. Knowledge about system occurrences that are notified to the user through a change in a display.

5.3. Specific Controls Knowledge

The Specific Controls Knowledge category captures knowledge required to interact with a specific interface, pertaining to the means with which to provide input to that interface. We present the sub-categories that make up this category in Table 5.

Table 5. Examples of Specific Controls Knowledge

Specific Controls Sub-Categories	John Deere 6615 Tractor Cabin in orchard mowing	John Deere GreenStar 2 Console in monitoring and configuration
Appearance	Dial Buttons Wheels Pedals Switches	Icon, text buttons Scroll lists Drop-down lists Non-draggable bar Tabs for additional pages Checkboxes
Feedback	Indicator lights (features) Engine gauges (speed change) Dial click / lever travel	Button state/color changes on input Change in gauges, fields
Function	Change speed Change of direction Raising/lowering implement	Large number of functions associated with control types listed in appearance
Layout	Steering column buttons Hydraulics levers Controls panel dials Gas, brake, differential lock pedals near the floor	Top row tabs Vertical menu button panel (right) Content display w/ zoom Different layouts, alignment between screens
Operation	Pressing Pushing FW/BW Turning Pushing-to-release	Pressing
Sensory modality	Somatosensory (switches, wheels, levers, knobs)	Somatosensory (used for input)

The sub-categories under Specific Controls Knowledge capture knowledge required to identify an interface element as a control, understand its mechanics and operation and recognize when input has been provided through a control.

5.3.1. Appearance. Knowledge about cues that inform users that an interface element is a control and its specific set of affordances.

5.3.2. Feedback. Knowledge required to distinguish an interface response that follows successful user input with a control.

5.3.3. Function. Knowledge about what a specific control does and its effect on the interface and the environment.

5.3.4. Layout. Knowledge about the meaning of the arrangement of control components in the interface. This includes knowledge about controls grouped together or the order in which controls are sequenced.

5.3.5. Operation. Knowledge about the method with which a control can be manipulated.

5.3.6. Sensory modality. Knowledge about the type of stimulus required to provide input to the interface (auditory, visual, and somatosensory).

5.4. Specific Procedures Knowledge

The Specific Procedures Knowledge category captures knowledge that users require about a specific interface, capturing knowledge about how to use such interface for a task. We present the sub-categories that make up this category in Table 6.

Table 6. Examples of Specific Procedures Knowledge

Specific Procedures Sub-Categories	John Deere 6615 Tractor Cabin in orchard mowing	John Deere GreenStar 2 Console in monitoring and configuration
Available tasks	Use wing mower Use differential lock Use front wheel drive	Configure display layout View guidance status Configure Greenstar setup
Task flow	Slow down, activate PTO, activate hydraulics Slow down, press differential lock button, wait for indicator to turn on, press gas Slow down, press FWD, wait for indicator to turn on, press gas	Press Menu button, press on "Layout Manager" menu option, and press "J four-way split" option. Select each one of four areas and assign a display from the three main options (Greenstar, Performance Monitor, and Rate). Press Home Page button to go to the preset home page.
Interface modes	Left/Right brake lock on/off Floating or fixed wings in hydraulics settings	Full screen view mode on/off

The sub-categories under Specific Procedures Knowledge capture knowledge required to understand the tasks that can be completed with the interface and how to complete them.

5.4.1. Available tasks. Knowledge about the activities that can be performed exclusively with a specific interface.

5.4.2. Task flow. Knowledge about the sequence of use specific to a task and a prototype design. This includes the sequence in which actions (with displays and controls) have to be performed to complete the task.

5.4.3. Interface modes. Knowledge about the different system states that render different responses to a given input.

5.5. Contextual Knowledge

The Contextual Knowledge category captures interface-specific knowledge related to factors that are external to the interface (as defined in Section 2) and affect task performance. We present the sub-categories that make up Contextual Knowledge in Table 7.

Table 7. Examples of Contextual Knowledge

Contextual Sub-Categories	John Deere 6615 Tractor Cabin in orchard mowing	John Deere GreenStar 2 Console in monitoring and configuration
Environment	Grove layout Other grove activities Terrain characteristics Weather (rain, wind, fog)	Latitude, longitude, speed, altitude Field, crop and row layout
Lexicon	Citrus grove elements Tractor component names Mower component names Teamwork coordination	Greenstar equipment GPS, data communication, John Deere Licensing
Organizational	Expectation, guideline sources, types Roles	Specific to agricultural task
Social nature	Individual interface use Teamwork for mowing area	Individual tractor use

The sub-categories under Contextual Knowledge capture interface knowledge required for a specific context of operation. If the information is available, it captures knowledge about the physical surroundings and the social implications that technology use involves.

5.5.1. Environment. Knowledge users require about their physical surroundings and how they affect interface operation.

5.5.2. Lexicon. Knowledge about the terminology and vocabulary that is inherent to the tasks being completed.

5.5.3. Organizational. Knowledge required about the rules or guidelines that must be considered to complete a task with the prototype design. This knowledge is relevant when an interface is associated with or used to interact with an organization.

5.5.4. Social nature. Knowledge about the individual or collaborative nature of the tasks supported by the interface.

5.6. Equipment Knowledge

The Equipment Knowledge category captures interface-specific knowledge that users require about specific mechanical components that support and affect use (see Table 8).

Table 8. Examples of Equipment Knowledge

Equipment Sub-Categories	John Deere 6615 Tractor Cabin in orchard mowing	John Deere GreenStar 2 Console in monitoring and configuration
Installed equipment	Engine parts Filters Hydraulics, PTO Wheels Connections	GPS receiver Greenstar display
Optional equipment	Flex wing mowing implement: widths, wings, clutches, bolts Equipment selection depending on terrain (bed or swales)	AutoTrac steering kits HarvestLab NIR sensors External Display Control
Maintenance	Dusting air filters Checking oil/water levels Clean mower Grease/tighten bolts Check tire air pressure Check blades	Keep screen clean Turn switch OFF when performing maintenance
Problems	Hitting obstacles with mower Bent, worn blades raise dust Clutch wear produces smoke Hydraulics hose tangling	When system fails to respond, perform 3 second reset

The sub-categories under the Equipment Knowledge category capture knowledge required to identify, troubleshoot and maintain interface support mechanisms.

5.6.1. Installed equipment. Knowledge about the attributes of mechanical components that are part of the system and the task.

5.6.2. Optional equipment. Knowledge about the attributes of available mechanical components that are not part of the system but that may be used in the task.

5.6.3. Maintenance. Knowledge about procedures required to keep mechanical components in good working order.

5.6.4. Problems. Knowledge required about technical difficulties related to mechanical components.

In summary, in this section we provided descriptions and examples of the knowledge that can be captured with the Knowledge Taxonomy. The examples were taken from the inventory we created for its development. As we discussed in the introduction of Section 4, we developed the Knowledge Taxonomy as a scalable tool. The hierarchy of categories, sub-categories and the definitions presented in this section can be applied to study interface knowledge required by a diverse set of interfaces independent of the modalities of interaction or the platform where they are implemented. Appendix A summarizes the application of the Knowledge Taxonomy to list interface knowledge for five distinct implementations, demonstrating its scalability.

We also designed the Knowledge Taxonomy as a flexible tool, an aspect highlighted by Appendix A, as the amount of information available for all interfaces differs. The examples presented using the Knowledge Taxonomy include both general purpose applications (Microsoft Word 2007) as well as specific purpose applications (JD 6615 Tractor Cabin for Orchard Mowing). The flexibility with which the Knowledge Taxonomy can be applied also relies on the way the Interface Family is defined. As discussed in Section 4, the definition can include or exclude certain interfaces and user goals depending on the objectives of the knowledge analysis.

We present a summary of the categories, sub-categories and definition that make up the Knowledge Taxonomy in Table 9 and a discussion of its potential applications follows in the next section.

Table 9. Categories and sub-categories of the Knowledge Taxonomy

	Sub-categories	Definitions
Interface Family Knowledge: Knowledge a user requires that is common to a collection of interfaces and not specific to a system or task.	Family name	The label that identifies the Interface Family that a prototype design belongs to
	User goals	Common objectives that can be achieved with all interfaces in an Interface Family
	Available tasks	Activities that can be performed with all interfaces in the family
	Task flow	The sequence of use common to the family
	Common displays	Display attributes (e.g., information content, placement, modality) that extend across the family
	Common controls	Control attributes (e.g., type, location, operation, coding) that extend across the family
Specific Displays Knowledge: Knowledge a user requires about means with which to perceive the state of a specific interface.	Color	Meaning of color, saturation, and hue combinations used
	Icons	Representations of objects, actions or scenes used (excludes alphanumerical characters)
	Layout	Arrangement of display components
	Saliency variations	Meaning of differences in how display components are exposed
	Sensory modality	Type of stimulus used by the display (auditory, visual, somatosensory, olfactory, gustatory)
	Textual labels	System of words and alphanumerical characters from a specific set used to identify display components
	Related event	System occurrences notified to the user through a change in the display
Specific Controls Knowledge: Knowledge a user requires about means with which to provide input to a specific interface.	Appearance	Cues that inform users that an interface element is a control and its affordances
	Feedback	Interface response that follows user input through a control
	Function	What the control does
	Layout	Arrangement of control components
	Operation	Method with which a control can be manipulated
	Sensory modality	Type of stimulus required for input (auditory, visual, somatosensory)
Specific Procedures Knowledge: Knowledge about how to use a specific interface to complete a task.	Available tasks	Activities that can be performed exclusively with a specific interface
	Task flow	The sequence of use specific to a task and a prototype design (functions)
	Interface modes	Different system states that render different responses to a given input
Contextual Knowledge: Knowledge a user requires about factors external to the interface and that affect task performance.	Environment	Knowledge a user has about his/her physical surroundings
	Lexicon	Terminology inherent to the task
	Organizational	Rules or guidelines that must be considered in task (when interface is associated with organization)
	Social nature	Knowledge about the individual or collaborative nature of supported tasks
Equipment Knowledge: Knowledge a user requires about specific mechanical components that support system use.	Installed equipment	Attributes of existing system mechanical components used in the task
	Optional equipment	Attributes of available components that are not part of the system but that may be used in the task
	Maintenance	Procedures required to keep components in good working order
	Problems	Technical difficulties that components can experience

6. Potential Applications

The Knowledge Taxonomy we developed can be used as a general representation for required interface knowledge in distinct applications. Potential applications are outlined in this section of the report and they are also summarized in Table 10.

Table 10. Summary of Potential Applications for the Knowledge Taxonomy

Application	Brief summary
6.1 Assess knowledge demands in a prototype design	Evaluate and document knowledge demands imposed by a prototype design.
6.2 Assess current user knowledge	Evaluate and document knowledge that users have about a prototype design at any given moment.
6.3 Evaluate knowledge demand consistencies across product lines	Identify knowledge demands for different products and compare them for consistency.
6.4 Develop training curriculums and materials	Evaluate and address training needs to bridge knowledge demands (6.1) and current knowledge (6.3).
6.5 Create designer orientation materials	Design training programs that help orient new members of design teams.

6.1. Assess Knowledge Demands in a Prototype Design

The Knowledge Taxonomy we developed can be used to systematically assess the knowledge demands imposed by a specific prototype design. The Knowledge Taxonomy is a template that can be used to document the range and types of interface knowledge required by users. The process starts with the definition of an Interface Family for the prototype design as discussed in Section 4. The definition includes determining a label that identifies the Interface Family and determining a set of user goals that interfaces in the family support and that the prototype design will also support.

As we illustrate in Figure 8, the definition of the Interface Family is followed by the definition of benchmark tasks that involve the prototype design and that are exemplar of its use in support of the family's user goals. With these requirements met, a knowledge inventory for the selected task can be assembled using the Knowledge Taxonomy as a template and a guide to identify and classify knowledge.

A ready-to-use template of the Knowledge Taxonomy categories and sub-categories is included in Appendix C and a glossary of definitions for the whole hierarchy is presented in Section 5.

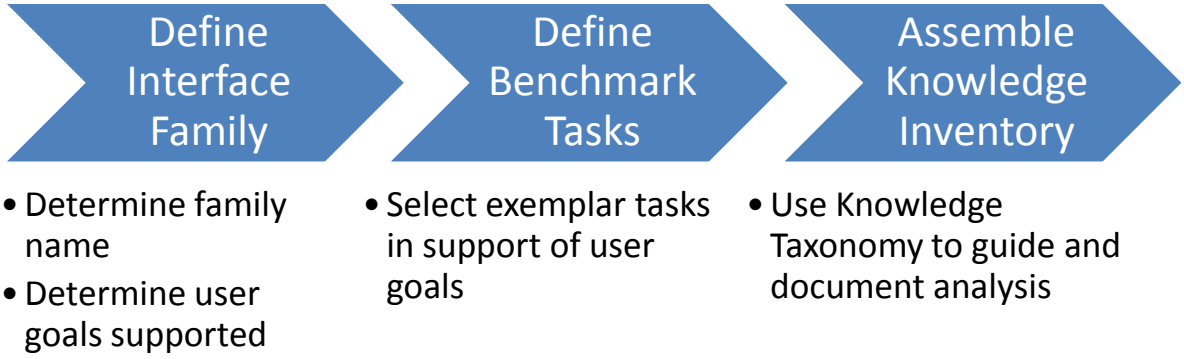

Figure 8. Using the Knowledge Taxonomy to assess knowledge demands from a design prototype.

The first table in Appendix A provides an example of the definition of an Interface Family, with sub-categories that list the family name, user goals, and benchmark tasks selected for five distinct interfaces. The complete inventory of knowledge for the same interfaces is provided in the six tables in the Appendix, one for each high-level category in the Knowledge Taxonomy.

6.2. Assess Current User Knowledge

The assessment we described in the previous section focused on the knowledge demands imposed by a prototype, but the Knowledge Taxonomy can be used to understand knowledge that users bring to the interaction at any given moment. We referred to this type of knowledge in Section 3 as *Knowledge in the Head*. This assessment can target specific user groups and collect data with inquiry and observation methods to understand interface knowledge that users have about an Interface Family and about a prototype design. The Knowledge Taxonomy can then be used to classify the knowledge into categories and sub-categories.

Although we are at an early stage of development for this application as part of this project, the analysis of user knowledge could benefit from the systematic organization and categorization provided by

the Knowledge Taxonomy. User knowledge could be documented with modified versions of tools such as *user personas,* used to document user profiles, needs, and preferences. These extended personas (enhanced with the hierarchy of the Knowledge Taxonomy) could be used to facilitate communication between design teams and improve the team's understanding of users and their capabilities.

6.3. Evaluate Knowledge Demand Consistencies across Product Lines

As we described in Section 6.1 and illustrated with examples in Appendix A, the Knowledge Taxonomy provides a detailed hierarchy to document knowledge demands imposed by a prototype design. These assessments can be conducted for designs in different product lines and the outcomes compared to highlight consistent and contradicting knowledge demands that might be posed by products. This comparative analysis can be performed matching knowledge demands at the level of each sub-category and might include products that a user might be exposed to simultaneously (e.g., the John Deere 6615 Tractor Cabin and Greenstar 2 Console used as examples in Appendix A).

The analysis of consistencies that we describe in this section could support the creation of interface design guidelines that build on the Knowledge Taxonomy hierarchy to go beyond display and control attributes. These guidelines would borrow from the six high-level categories to include parameters on how procedures with displays and controls are implemented in interfaces, how the equipment and context of operation are referred to, and the different Interface Families that were identified in the analysis of product lines.

6.4. Develop Training Curriculums and Materials

As a result of documenting knowledge demands from a prototype design and current user knowledge about the same design, an assessment of knowledge gaps can also be performed. This assessment can be performed with the granularity desired (categories or sub-categories) to better understand the needs that a training program and instructional material need to address. Using the hierarchy of the Knowledge Taxonomy and the knowledge gap assessment to design training programs is

a highly-targeted approach to training efforts that emphasize specific knowledge categories and sub-categories.

The construction and evaluation of instructional material used in a training program could also benefit from the Knowledge Taxonomy hierarchy. The content in training materials should elaborate on the categories and sub-categories that a knowledge gap assessment suggests. The same hierarchy could be used to evaluate the effectiveness of training materials and programs, because materials, knowledge gaps, and learning evaluations can be all traced to specific categories and sub-categories.

6.5. Create Designer Orientation Materials

An additional application we consider for the Knowledge Taxonomy (in particular Interface Family Knowledge) is as part of an orientation programs for design teams. The Interface Family Knowledge category and its sub-categories could be used to document general characteristics that products from a design team share. These could include display and control attributes, and the user goals and technology use their products support. This application could help new members of a design team become familiar with the guidelines and motivations of design activities in their team.

In Figure 7, we provide an illustration of the six-high level categories that make up the Knowledge Taxonomy. This figure can be also used to illustrate the different spaces where design activities take place. Objectives and a shared vision of a design team can be captured by the sub-categories in the Interface Family (Section 5.1). The space where the creative process takes place, where individual designers can innovate lies in the Specific Displays, Specific Controls and the Specific Procedures (Sections 5.2, 5.3, and 5.4) that they can create to accomplish the intended user goals.

7. References

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Appendix A. Examples of an Application of the Knowledge Taxonomy

This appendix summarizes the inventory of interface knowledge that we assembled in the process of development of the Knowledge Taxonomy. It illustrates the flexibility and scalability of the Knowledge Taxonomy capturing knowledge from diverse interfaces, contexts and applications. The tables in this Appendix can be used to compare how interface knowledge demands vary and between some implementations and maintain between others.

Table A1. Examples of a knowledge inventory for Interface Family Knowledge

	John Deere 6615 Tractor Cabin in orchard mowing	John Deere Greenstar 2 Console in monitoring and configuration	Microsoft Word 2007	Medicare.gov	Amtrak Reservations 1-800-872-7245
Interface Family Knowledge **Definition:** knowledge a user requires that is common to a collection of interfaces and not specific to a system or task.	Family name Tractor Cabins User goals Cover a certain area Perform agricultural task Available tasks Start equipment and go Power an implement Task flow Turn ignition on, certain indicators turn on and off, shift into gear, press gas pedal Slow-down, engage PTO, implement is powered Common displays Speed, RPM gauges Engine-related indicator lights Common controls Gas, brake pedals Steering wheel Gear change levers	Family name Management Software Consoles User goals Learn about an issue Accomplish a task Available tasks Configure a feature supported by the Console Task flow Look for an option menu Bring up main menu Select icon menu option Evaluate displayed content Explore menu, content Common displays Color graphics and text Bounded, non-clickable areas Widgets with different functionality Common controls Bounded areas identified as buttons Buttons have a pressed state (feedback) Single-press required Screen keyboards for text input	Family name Word-processing Software User goals Modify a document to an intended state Available tasks Format a document and its objects Task flow Create an empty document Enter text using the cursor Select a document object Find desired format option Evaluate format applied Additional formatting Common displays Edited document Flashing cursor Common controls Entered text Formatting options	Family name Institutional Websites User goals Learn about an issue Accomplish a task Available tasks Find specific content Sign-up/Log-in w/ user id Search Task flow Start Internet browser Type web address to go to Wait for website to load Click on website links Evaluate content displayed Click on website links Common displays Common sections (about, contact, help, homepage) Website search results Displayed content changes Visited links color change Common controls Standard web form fields Mouse pointer (2 modes) Search box Field states (chk, unchk) Page scroll (bar, button)	Family name Interactive Voice Response (IVR) Systems User goals Learn about an issue Accomplish a task Available tasks Speak to a representative Get help Task flow Number is dialed Listen to system prompt and options Say representative/dial 0 Wait for human repress. Common displays Lists of results output Lists of menu options (with numbers) Common controls Silence following a prompt

Table A1. Examples of a knowledge inventory for Specific Displays Knowledge

	John Deere 6615 Tractor Cabin in orchard mowing	**John Deere Greenstar 2 Console in monitoring and configuration**	**Microsoft Word 2007**	**Medicare.gov**	**Amtrak Reservations 1-800-872-7245**
Specific Displays Knowledge **Definition:** knowledge a user requires about means with which to perceive the state of an interface.	Color Meaning of colors used in indicators: red, green, orange Icons Control panel functions Lever settings Indicator lights Layout Row of lights (instrument panel) Cluster (above steering wheel, controls panel) Progress bar lights (temp.) Saliency variations Flashing lights (on startup) Static lights (signal a feature on) Sensory modality Visual (color codes, lights, gauges) Textual labels Numeric (speed/RPM gauge) Text (safety warnings) Numeric (gears I, II, III) Numeric (hydraulics lever) Related event Engine problems present Feature has been activated	Color Colors highlight buttons, panels, need for input, covered area in map display Equipment status, settings Icons Home, Menu buttons Functionality icons Equipment components Layout Buttons panel on right Clock widget, Menu, Home buttons Progress bars Pre-set, custom layouts Saliency variations Static elements on screen Sensory modality Auditory (display alerts) Visual (color codes, icons) Textual labels Text -Feature labels Text -Settings labels Text -Status messages, output Related event Equipment performance Task performance (area covered, alignment) Call for action or input	Color Selected text (dark color) Feature on/off (shades) Highlighted text Comments/track changes Icons Activated format icon Functionality icons Mouse pointer mode (x2) Layout Ribbon Rulers Edited document Scroll bar Status bar Saliency variations Flashing (cursor) Intermittent info (save) Static (selection, toggle) Sensory modality Auditory (alerts, errors) Visual (control feedback, state of edited document) Textual labels Feature labels Settings labels Related event Formatting was applied Functionality was activated Document was saved	Color Identify groups of links Separate form items Marks text headers “Important” text (red) Icons Bullets, text items, menus Links (help, listserv) Features (secure) Layout Header links Header logo Section tabs Displayed content Results from filtering Saliency variations Static Hidden content Sensory modality Visual (color codes in content, different color for visited links) Textual labels Feature labels Section labels Related event Sign-in successful Missing form data Form input successful Found requested content	Color N/A Icons Processing search message Layout Options available list Option selected confirm Search parameters confirm Schedule search result Saliency variations Static Sensory modality Auditory (output) Textual labels Keyword to access options Related event Search parameters entered Train schedules available Fares available

Table A2. Examples of a knowledge inventory for Specific Controls Knowledge

	John Deere 6615 Tractor Cabin in orchard mowing	**John Deere Greenstar 2 Console in monitoring and configuration**	**Microsoft Word 2007**	**Medicare.gov**	**Amtrak Reservations 1-800-872-7245**
Specific Controls Knowledge **Definition:** knowledge a user requires about means with which to provide input to a specific interface.	Appearance Levers Dial Buttons Wheels Pedals Switches Feedback Indicator lights (features) Engine gauges (speed change) Dial click / lever travel Function Change speed Change of direction Raising/lowering implement Layout Steering column buttons Hydraulics levers Controls panel dials Gas, brake, differential lock pedals near the floor Operation Pressing Pushing forward, backward Turning Pushing-to-release Sensory modality Somatosensory (switches, wheels, levers, knobs)	Appearance Icon, text buttons Scroll lists Drop-down lists Non-draggable bar Tabs for additional pages Checkboxes Feedback Button state/color changes on input Change in gauges, fields Function Large number of functions associated with control types listed in appearance Layout Top row tabs Vertical menu button panel (right) Content display w/ zoom Different layouts, alignment between screens Operation Pressing Sensory modality Somatosensory (used for input)	Appearance Toggle buttons Ribbon menu tab Formatted result buttons Mouse pointer Hotkeys and combinations Drop-down menus Ruler controls Feedback Button state/color Changes in displayed doc. Information messages Function Large number of functions associated with control types listed in appearance Layout Quick access toolbar File menu Ribbon tabs/menus Rulers Edited document Scroll bar Status bar Operation Hover-over Pressing Press-drag (selection) Press-release-drag (move) Moving to target Sensory modality Somatosensory (used in input devices)	Appearance Special buttons (sign-up) Collapsible sections (+/-) Links (white, blue, orange) Links (underlined on hover) Feedback Error messages w/ missing information Function Start eligibility tool wizard Home health agencies tool Drug plan compare tool Layout Header links Header logo (home) Section tabs (some sections) Multiple content layouts Operation Hover (navigation menu) Pressing Moving to target Sensory modality Somatosensory (used in input devices)	Appearance Yes/No questions Fixed keywords for input Flexible input (date, time) Feedback Tone for keypad press Low volume input msg. Error (“I didn’t get that”) Successful input (“got it”) Function Access train schedules Access train status Access reservations Connect with agent Layout Keyword or keypad # options Provides examples of formatted input Both w/ “you can say:” Operation Provide input w/ speech Keypad number selection No wait for full prompt Sensory modality Auditory (input) Somatosensory (keypad)

Table A3. Examples of a knowledge inventory for Specific Procedures Knowledge

	John Deere 6615 Tractor Cabin in orchard mowing	**John Deere Greenstar 2 Console in monitoring and configuration**	**Microsoft Word 2007**	**Medicare.gov**	**Amtrak Reservations 1-800-872-7245**
Specific Procedures Knowledge **Definition:** knowledge about how to use a specific interface to complete a task.	<u>Available tasks</u> Use wing mower Use differential lock Use front wheel drive <u>Task flow</u> Slow down, activate PTO, activate hydraulics Slow down, press differential lock button, wait for indicator to turn on, press gas Slow down, press FWD, wait for indicator to turn on, press gas <u>Interface modes</u> Left/Right brake lock on/off Floating or fixed wings in hydraulics settings	<u>Available tasks</u> Configure display layout View guidance status Configure Greenstar setup <u>Task flow</u> Press Menu button, press on "Layout Manager" menu option, and press "J four-way split" option. Select each one of four areas and assign a display from the three main options (Greenstar, Performance Monitor, and Rate). Press Home Page button to go to the preset home page. <u>Interface modes</u> Full screen view mode on/off	<u>Available tasks</u> Create table and apply theme Import from Office apps. <u>Task flow</u> Press Office button, create new document, insert content Press on "insert" ribbon tab, select "table" button, use table drag control to create a 4x4 table. Select "design" ribbon tab, select "light list – accent 1" from the "table styles" formatted result buttons. <u>Interface modes</u> Current document view Hotkey combos visible (Alt)	<u>Available tasks</u> Learn about Medicare plans and services File insurance claims Access enrollment services <u>Task flow</u> Hover over "search tools" menu option, move pointer and select "Find Medicare Eligibility", fill wizard form fields, move to next screens and fill fields, read about eligibility <u>Interface modes</u> Signed-in, not signed in Duplicate links in search tools Tabbed interface present	<u>Available tasks</u> Find schedules and prices Find train status Make reservations Get help on system <u>Task flow</u> Dial number on touch-tone phone, wait for input options, and say "schedules". Say departure city, wait for confirmation, say arrival city, wait for confirmation, say departure date and time, listen for schedule search results. <u>Interface modes</u> Default, novice modes Availability of help option

Table A4. Examples of a knowledge inventory for Contextual Knowledge

	John Deere 6615 Tractor Cabin in orchard mowing	**John Deere Greenstar 2 Console in monitoring and configuration**	**Microsoft Word 2007**	**Medicare.gov**	**Amtrak Reservations 1-800-872-7245**
Contextual Knowledge **Definition:** knowledge a user requires about non-system-related factors that affect task performance.	<u>Environment</u> Grove layout Other grove activities Terrain characteristics Weather (rain, wind, fog) <u>Lexicon</u> Citrus grove elements Tractor component names Mower component names Teamwork coordination <u>Organizational</u> Expectation, guideline sources, types Roles <u>Social nature</u> Individual interface use Teamwork for mowing area	<u>Environment</u> Latitude, longitude, speed, altitude Field, crop and row layout <u>Lexicon</u> Greenstar equipment GPS, data communication, John Deere Licensing <u>Organizational</u> Specific to agricultural task <u>Social nature</u> Individual tractor use	<u>Environment</u> Specific to each document editing task, and operational environment <u>Lexicon</u> Document editing formats Conventions: sections, fonts, paragraphs, spacing Operating system actions <u>Organizational</u> Specific to document editing task <u>Social nature</u> Editing individually Collaborate, track changes	<u>Environment</u> Location geography: state, county, city, area/zip codes <u>Lexicon</u> Medicare services Health insurance Health care services Web browsing (link, click) <u>Organizational</u> Medicare policies Local insurance companies Care quality measures vs. state, national averages <u>Social nature</u> Browsing individually	<u>Environment</u> Location geography: states, cities <u>Lexicon</u> Rail travel Train names, times, cities <u>Organizational</u> Amtrak fare policies and restrictions <u>Social nature</u> Querying individually

Table A5. Examples of a knowledge inventory for Equipment Knowledge

	John Deere 6615 Tractor Cabin in orchard mowing	**John Deere Greenstar 2 Console in monitoring and configuration**	**Microsoft Word 2007**	**Medicare.gov**	**Amtrak Reservations 1-800-872-7245**
Equipment Knowledge **Definition:** knowledge a user requires about mechanical components that support system use.	Installed equipment Engine parts Filters Hydraulics, PTO Wheels Connections Optional equipment Flex wing mowing implement: widths, wings, clutches, bolts Equipment selection depending on terrain (bed or swales) Maintenance Dusting air filters Checking oil/water levels Clean mower Grease/tighten bolts Check tire air pressure Check blades Problems/Damage Hitting obstacles with mower Bent, worn blades raise dust Clutch wear produces smoke Hydraulics hose tangling	Installed equipment GPS receiver Greenstar display Optional equipment AutoTrac steering kits HarvestLab NIR sensors External Display Control Maintenance Keep screen clean Turn switch OFF when performing maintenance Problems/Damage When system fails to respond, perform 3 second reset	Installed equipment Input devices CPU Computer screen Optional equipment Printer Network Maintenance Clean screen, input devices Dust CPU and fans Problems/Damage Electrical failures Program/OS crash	Installed equipment Input devices CPU Computer screen Network Optional equipment Printer Maintenance Clean screen, input devices Dust CPU and fans Problems/Damage Electrical failures Program/OS crash	Installed equipment Keypad Speaker Microphone Optional equipment Headset Speakerphone Maintenance Dust microphone, keypad Problems/Damage Electrical failures Call dropped

Appendix B. Five interfaces used to assemble the initial knowledge inventory

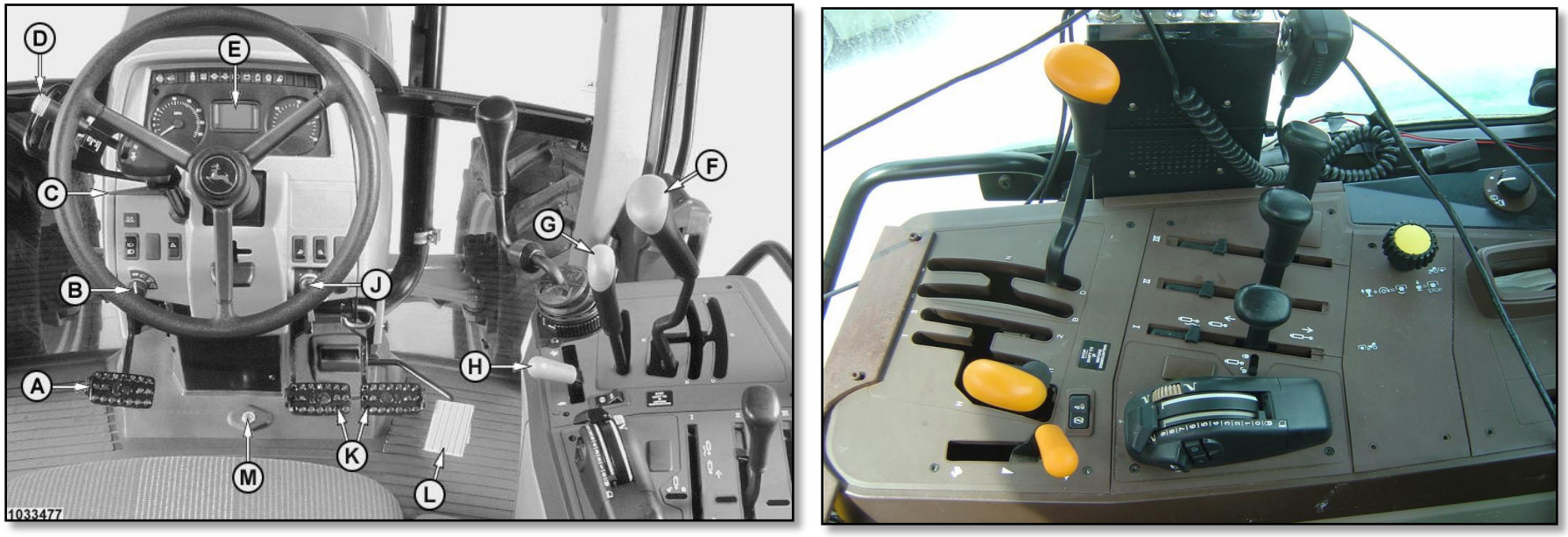

Figure B1. The John Deere 6615 Tractor Cabin

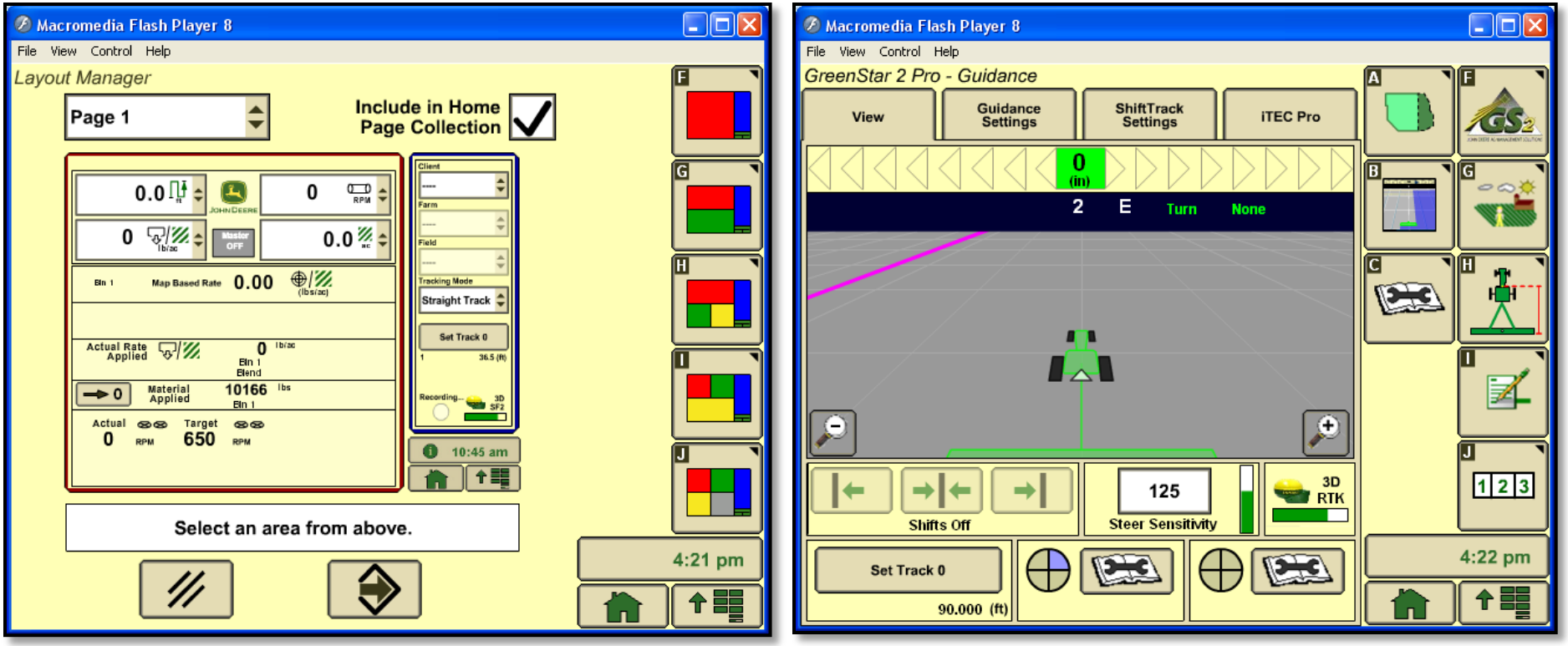

Figure B2. The John Deere Greenstar 2 Console Layout Manager screen (left) and the guidance status screen (right)

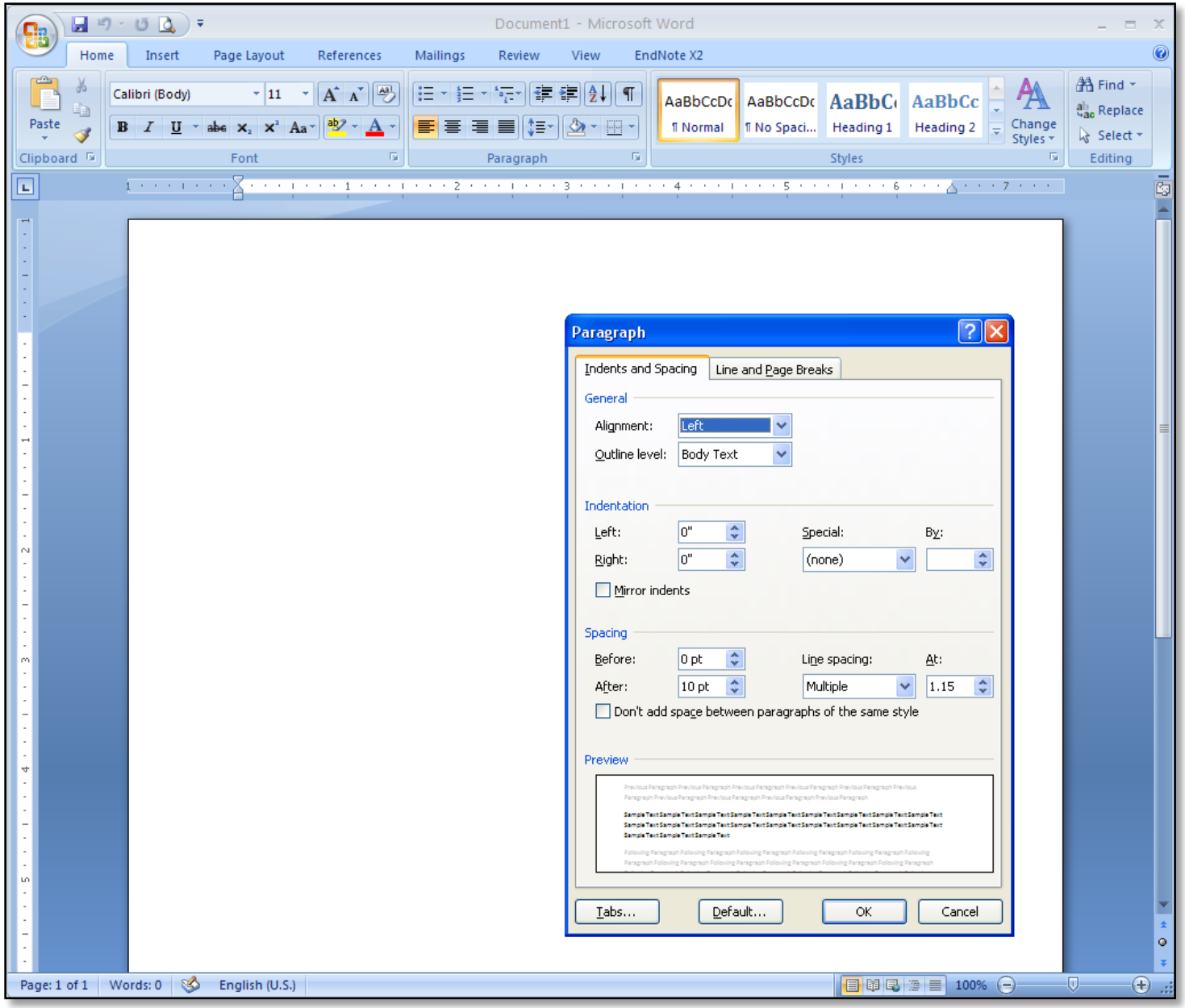

Figure B3. Microsoft Word 2007

Figure B4. Medicare.gov website