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Information Display Preferences for Assembly Instructions in 6 Industrial Settings

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ABSTRACT

We detail the results of an ongoing study into the preference of workers in 6 different industrial companies for assembly instruction display types and modalities for their tasks. This study is performed as a part of a project that aims to create a theoretical framework for understanding requirements for instruction presentation in industry, and providing guidance to the creators of assembly instructions. The study, as well as the project as a whole, aims to expand on approaches from the Industry 4.0 framework, with a particular focus on the more recent Operator 4.0 approach that adds a focus on more human-centric aspects of digitalisation in industry. The study being presented is comprised of facility visits to each partner company where the current state of practice was presented by each company, an examination of information presentation and operating procedures by the authors, and in-depth interviews with assembly workers at each site. All companies examined deal with variants in production, and the complexity of assembly spans from low to extremely high. The companies involved mostly rely on experienced workers, with high training, and relatively long times to train new personnel. The interviews led to findings such as simplified images being strongly preferred for both beginners and experienced workers, with an emphasis on the image matching the worker's viewpoint to the product, and experienced workers preferring simplified images with highlighted markings for details that can be seen from where the task is performed, and more. The findings will be used in further work to create a theoretical framework around digital work instructions, as well as used directly to help partner companies better standardise their instructions to support the cognitive abilities and limitations of their assembly workers. The goal with this is to create safe, comfortable and profitable workplaces that fulfil goals of social sustainability in the long term.

Keywords: Cognitive ergonomics, Instructions, Assembly instructions, Assembly, Operator 4.0, Digitalization, Digitalisation

INTRODUCTION

In the era of digitalisation and large technological leaps being made almost daily in European industry, stressing the need for human centricity as is done in the EC white paper on Industry 5.0 (Renda et al., 2022) is essential. As computerised systems of many kinds become more advanced and spread quickly among companies, remembering that in many cases, the efficient utilisation of these systems will often still require a human touch. The

Operator 4.0 typology projects eight different types of industrial operators as they will emerge from the technological advancements made in the Industry 4.0 paradigm (Romero et al., 2016) and is heavily cited in the Industry 5.0 white paper. It also highlights among other things the need for proper communication between systems and users to be able to utilise the coming technological advancements. Something that is even further highlighted in the cognitive operator 4.0 by Thorvald et al. (2021).

We detail results from a study into assembly worker preferences for information presented in assembly instructions. This study was comprised of company visits and interviews at six manufacturing companies in Sweden, and is a part of a research project, Digitalis (DIGITALa arbetsInStruktioner för kognitivt arbete, Eng. DIGITAL work InStructions for cognitive work) that aims to create support material for selecting appropriate types and modes of information presentation for assembly workers. The complexity of assembly at the collaborating companies varies from extremely low complexity where instructions are used to support workers with no experience and in some cases with cognitive disabilities, to extremely complex assembly work requiring specialised skills and up to years of training. All but one of the companies must contend with product variation, ranging from infrequent variants, to nearly every assembly being unique.Two workers were interviewed at each company and the interviews transcribed and analysed.

The first stage, presented here, is to identify worker preferences for information presentation for the different assemblies, as well as analysing common strengths and weaknesses of the companies involved, as it pertains to supporting workers in assembly.

Some introduction is required as to the human aspect of assembly work and instruction use.

COGNITIVE ASPECT THAT AFFECT ASSEMBLY WORKERS

The selection of instructions that are presented to operators affect time efficiency, errors, as well as human cognition (Berlin & Adams, 2017; Konz & Dickey, 1969: Li et al., 2018). Higher cognitive functions, located in the prefrontal cortex, are responsible for our ability to reason, think, plan, and make decisions (Funahashi, 2015; Miller, 2000). These functions are used in everyday life, as well as in work-related situations. Whatever we do, easy or complex, cognitive load is affected. This is exacerbated during prolonged, difficult, or complex tasks. This means that a task that in normal circumstances creates a manageable cognitive load can cause excessive cognitive load when the task goes on for a longer time, which in turn can cause mental fatigue (Mizuno et al., 2011). Fatigue and cognitive overload are known to limit central functions such as memory and attention. These advanced functions are required for interpreting and processing instructions in order to successfully complete the task at hand (Berlin & Adams, 2017). Fatigue can further pose a great threat to workers' safety as their ability to quickly respond to unexpected situations significantly slows down. However, the state of fatigue is generally considered inevitable and is not bound to specific professions or task assignments (Williamson et al., 2011).

One simple explanation of cognitive load is how much information working memory can receive and hold simultaneously, and whether that information gets stored in long-term memory or not, thus affecting the capacity for learning (Baddeley, 1992). The working memory itself has a very limited capacity for simultaneous processing. Information that is consciously received and unfamiliar information is only held temporarily in working memory and hence requires a lot of mental effort (Funahashi, 2017; Sweller, 2005). More so, working memory is greatly involved in cognitive tasks such as reading, problem solving, learning, and decision making (Baddeley & Hitch, 1974). If the received information is too complex and requires more than the current attention capacity then working memory storage overflows, causing cognitive overload (Paas, Renkl, & Sweller, 2003; Sweller & Chandler, 1994). On the other hand, long-term memory (LTM) seems to have no maximum capacity (Funahashi, 2017). Cognitive load affects performance in many different areas (Fridman et al., 2018), and work-related tasks are no exception. Hence why Kalyuga, Chandler, and Sweller (2003) state the importance of maintaining an appropriate level of cognitive load while processing new information in an attempt to not only involve working memory, but to allow encoding into long-term memory as well.

Cognitive Load Theory

A widely used theory concerned with how humans process information, which is also critical during periods of learning, is the Cognitive Load Theory (CLT). CLT is widely used in the development of instructions, often with a focus on how the instructions should be formulated to make use of the limited human cognitive capacity (Paas et al., 2016). The CLT framework allows cognitive load to be separated into different sub-types of cognitive load as outlined by Sweller, (1994). These are: extraneous-, intrinsic-, and germane cognitive load (Sweller, 1994). Sweller (1994) describes intrinsic load as the basis for understanding concepts, extraneous load as being sensitive to poor instructions since it entails the link between presentation and design, and finally germane load which is concerned with more subjective aspects such as interest and motivation. Each type of cognitive load thus focuses on a different aspect of cognition.

Cognition and Assembly Instructions

It has further been shown that experience and prior knowledge are greatly related to the amount of cognitive load that the brain experiences (Cook, 2006; Kalyuga, Chandler, & Sweller, 1998; Kalyuga et al., 2003; Marcus, Cooper, & Sweller, 1996). One explanation for this is that schemas stored in long-term memory makes processing new information (such as instructions) require significantly less effort (Marcus, Cooper, & Sweller, 1996). This makes sense at an intuitive level, since more knowledge and experience within a certain area often connects with other tasks that are relatable to the system. Despite this smart function, allowing for a lowered experienced cognitive load, other issues can arise due to the expertise reversal effect. The expertise reversal effect claims that using the same instructions for experienced and inexperienced personnel can lead to negative consequences. As information from instructions is processed, it might be redundant for the experienced personnel and put unnecessary load upon them (Kalyuga et al., 2003); which is why instructional design (also known as instructional system design) is of importance. Not only does instructional design influence cognitive load but it also influences the learning curve. Multiple studies suggest that cognitive load can be improved by simply changing operators' instructions. One solution for this could be by including pictures onto altogether text-based instructions as suggested by Li et al. (2018). This is often referred to as multimedia instructions which include the use of pictures (illustrations, animations, etc.) and words (either printed or spoken) to speed up the learning process (see e.g., Mayer & Moreno, 2003). However, cognitive load, related to this field has not always been prioritised.

Common Instruction Types in Industry

Traditionally, the most common way to carry out instructions and educate workers of their tasks has been word of mouth. The method requires more experienced personnel (or other knowledgeable staff) to verbally explain to new workers how to carry out the work-related task (Fox, 2010; McCalla et al., 1997). The second most commonly used method, historically and currently and for both unexperienced and experienced personnel, is paper instructions (Funk, Kosch, & Schmidt, 2016; Serván et al., 2012). According to Lai et al. (2020), industrial companies are currently experiencing problems with having too few experienced workers and a rapid increase in new personnel simultaneously. This causes great variance in technical skills, culture, and educational level, within companies (Romero et al., 2016). Furthermore, as assembly workers' tasks are becoming more complex and increasing in variety due to global distribution requiring more customisation (ElMaraghy et al., 2012; Lai et al., 2020; Sand et al., 2016), methods adapted for human cognition have become more attractive in the field of instructional design (Funk, Kosch, & Schmidt, 2016); sometimes referred to communication design in research (Fox, 2010).

Nowadays, instructions are also often shown on large computer screens near the assembly stations. These instruction can be quite similar to the old paper instructions, basically "paper on screen", or may be adapted to show more images such as photos, static or interactive 3D images generated from CAD software, or videos (Berlin & Adams, 2017). These on-screen instructions are more common in the companies being explored in this study, although paper instructions often exist as a backup, or to verify assembly tasks that have not yet been updated in the database for the on-screen instruction displays.

New technologies are also being explored for showing instructions, such as different forms of mixed reality, where instructions or virtual parts are overlaid in the worker's field of vision. These are largely divided into a few different forms of head mounted displays (HMDs) that can generat virtual reality (VR) or augmented reality (AR), projector systems that project an image onto the object in the world, or handheld augmented reality (HAR) devices where an image combined from the camera input and virtual objects is shown on screen.

These system may hold promise for certain applications, but results differ when testing HMD devices. While Funk et al. (2016) showed HMD based instructions to cause less perceived cognitive load and minimise errors, Drouot et al. (2022) found AR to increase cognitive load and reduce workers' ability to respond to external events, causing danger. However, Jasche et al. (2021), show handheld augmented reality (HAR) to generate fewer errors than HMD, inn addition to being more cost-effective (Sanna et al., 2015).

In addition to the possible limitations shown by Drouot et al. (2022) current HMDs have been found to cause discomfort such as nausea or headaches (Vávra et al., 2017). Based on this, mixed reality approaches will not be the focus of this work, due to limitations in their implementation at this time.

METHOD

Each company presented their requirements at project meetings. Each company was subsequently visited, and presented in more detail the information presentation for assembly instructions on selected assembly stations, how assembly is performed, and processes for e.g. improvement and quality control. The facilities were then toured, and assembly operations were observed.

Two workers were interviewed at each company. Workers' experience ranged between 2 to 25 years. Audio was recorded of each interview except at one company due to policies in place. In this case, extensive notes were taken. The interviews were transcribed verbatim, and coded. Codes were analysed to find similarities, or dissimilarities. Transcripts were also analysed from the standpoint of 3 main points: Worker experience (beginner/experienced), assembly complexity (simple/complex), and how common the variant is (common/rare).

FINDINGS

The findings presented are general findings that applied to multiple areas, then as lists of preferences for the different focus groups, beginner/experienced, then for simple/complex assembly, and finally for whether it involves a common assembly or a more rare variant. These categorised preferences may replicate the general, in which case explanations mostly apply to the specifics of the preference as it pertains to the current category.

In General, Workers Preferred

- Simplified visual instructions as the focal point, and mentioned CAD images as being far preferable to photographs.
- A picture of the final, assembled product after the current assembly step
- Step-by-step, with suitably small steps.
- Show text as support where needed. In some cases by interacting with the instructions (e.g. clicking on a particular image).

- A viewpoint on the image that matches the assembly worker's viewpoint was seen as being important.
- Clear and simple highlights on images.
- Standards, i.e. that all instructions follow the same standards for style and formatting. That highlights do not differ based on who made the instruction.
- Making the instructions representative of how the assembly is performed. If not, assembly workers find their own way.
- Integrating the assembly instructions into the task if verification is required. Workers report that where they should read one instruction, perform an assembly step, go to the computer to verify, then read the next instruction etc. they instead glance at all the instructions, perform all the assembly steps, then go to the computer and verify all at once. They are aware that this increases risks of mistakes, but argue that the risks are low and that mistakes can be caught at the next station. Workers ask for easy, low mental/physical/time cost ways for verification.
- Photographs are disliked by interviewees, who mention photos unprompted as being inferior (although having a photo is seen as being better than no graphical support at all). Interviewees made comments to the effect of photographs being hard to read in good conditions, but in bad conditions (e.g. poor lighting in the photo) or at the typical assembly distance then the photographs are generally not seen as being helpful at all.
- A simple connection between parts/tools in instructions and in the world. Avoid parts numbers for screws or tools, use instead a concept that works with human attention and both short term and long term memory. Concepts such as "10mm socket wrench" or 8x10mm screw are helpful, part numbers cause problems.

Highlights on the CAD image that show WHERE the screws or objects should be mounted are particularly highlighted by workers where either variants may have wildly differently mounted elements, or many points that need attention for screws, sealant, or other specific tasks to be performed or double checked. For this, the workers showed a preference for the clearest and simplest method used in their own company, in many cases red circles or the like.

Experience

- Beginners: Step-by-step instructions are seen as more important for beginners.
- Beginners: Require all steps to be included, in the correct order.
- Beginners: Video instructions, including looping video, is seen as being helpful.
- Experienced: Can handle more types of instructions and more complex assembly. Need little support for standard assemblies.
- Experienced: Prefer mostly images that can be seen from the assembly station, and avoid going to the screen for verification more than necessary.
- Experienced: Do not notice gaps in instructions or questionable order of operations. Assemble "their way" anytime instructions are unclear. More

precise instructions help with keeping a standard. Experienced workers mostly notice gaps or problems with assembly order when training new personnel.

Somewhat surprisingly, experienced assembly workers not only pointed out the benefits of simplified visual instructions for beginners, but also preferred those for themselves. The experienced workers showed a strong preference for simplified 3D images showing the product ready after the current assembly. The preference was particularly clear when it came to assembling variants that are less common or require unusual manoeuvring of objects. An extremely experienced worker said "I can work with text instructions that say, for example 'fasten clamp, connector inwards"', but they then follow that by stating that having images is much better for beginners, and also better for themselves, and visual instructions for orientation of elements such as clamps or other fasteners is helpful.

Complexity of Task

- Low complexity: Detailed instructions only needed for beginners, then step-by-step graphical instructions are seen as better, or videos.
- High complexity: Interactive 3D CAD images were seen as being helpful for complex assembly work.
- High complexity: Markings highlighting location of screws, sealant, or other items that must be placed correctly is critical. Text instructions were described as being particularly unhelpful for this, even for highly experienced workers.

Higher task complexity, unsurprisingly, led to a preference for more detail, but also a better overview. Experienced workers with access to displays that showed the product ready in a main picture and steps in images below were extremely positive as to how useful that type of display is, while workers with simpler tasks pointed to that kind of display as being useful to train beginners.

Variants

- Rare variants: Getting CAD generated images of rare variants was requested by most workers.
- Rare variants: Video (including looping video) was also suggested by some workers as being helpful for rare variants to assist the memory, even for experienced worker
- Common variants: Minimising the information shown, after training. Workers reported not using instructions for common variants, except for verification after assembly.

Surprisingly many interviewees pointed out problems with getting visual instructions updated. The more complex visualisations such as CAD images animated CAD videos were particularly prone to be missing steps, not be updated quickly for the a version of the assembly, or even having less common variants missing, all of which was reported as being problematic. The workers further pointed out that situations where easy to use instructions were most likely to be missing were the ones where good instructions make the most difference in assembly, such as with uncommon variants, new assemblies, or complex assemblies.

CONCLUSION

This study has had access to state-of-the-art manufacturing companies and highly experienced, and skilled personnel, both at the assembly tasks at hand but also in some cases experienced at training new personnel. As such, the findings are likely to apply to other companies of similar character. The interviewees were open, forthcoming, and very willing to discuss aspects of their work with the goal of improving the workplace.

The findings were varied, with some being quite surprising. Among these surprising findings is workers' strong preference for simplified images, and how they pointed to this being better not only for beginners but also for experienced workers, if the instructions are well done. Another surprising finding was that across the companies, and across very different personalities, experienced workers follow the instructions only so long as the instructions and associated systems are helpful in the work. If instructions are out of order, or require extra work (such as walking back and fort) for verifying, then workers will effectivise their work and rely on experience instead. This highlights the importance of designing, and indeed updating, instructions in collaboration with assembly workers, and suggests the need for a continuous process that involves technicians, CAD constructors, and assembly personnel at all times. In addition to this, workers' discussion about even well designed instructions being confusing if they differ based on who makes them is interesting in light of the work of e.g. Marcus, Cooper, and Sweller, (1996) around schemas, and how they help with processing new information. Schemas suggest that beginners' cognitive load is significantly affected by non-standard instructions, but the interview responses suggest that this also applies to experienced workers.

Further analysis will be performed on the collected data, as well as further studies being planned to test updates to instruction types in the collaborating companies, to then develop a theoretical framework for instruction type selection and instruction design.

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