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Application of design principles for assembly instructions – evaluation of practitioner use

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Abstract

Production complexity causes assembly errors due to that the demands on the operators are high and there is a need to improve assembly instructions. Design principles for Information Presentation (DFIP) is a method developed to support such improvement and its application was evaluated in three case studies, 152 practitioners. Results indicate that DFIP use help simplifying the information presentation so that complexity can be reduced, and that step 4 is easiest to understand. In addition, the implementation of assembly instructions gave positive results.

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Keywords: Digitalisation, Assembly, Operator tool, support, cognition.

1. Background

Production work will become more complex in the future [1-3]. Digitalization is transform the traditional working environment to an adjustable and personalized work environment [4]. Trends also point towards that the operator's work tasks will change so that more proactive work is performed and the operator will also manage many new and different tasks and technologies [2,3,5]. Regarding new technologies, the operator will collaborate closely with higher levels of automation e.g. cobots and support systems [6-9]. This will increase the level of complexity in production that will increase the need for understanding the operator views in such a system [1-3]. However, assembly work is already complex.

Complexity in a system is something that is “difficult to understand, describe, predict or control” [10]. Assembly work is complex due to the strategy to have mass-customized products [11] which also drives a high product variety [12-15]. Complexity is connected to decrease in ergonomics [16], quality [17,18], production reliability and uncertainty [19], performance [20,21] and production time [22,23].

In a complex system, the operators are invaluable due to that they are flexible and can manage the dynamic and fast changes caused by the complexity [2,3,24-26]. High demands are therefore placed on the operator to manage many different tasks [27]. To stay competitive it is therefore crucial to understand the operator and to support assembly work [19,28].

1.1. Reducing complexity

Complexity can be managed by removing, simplifying, avoiding or preventing complexity [29-31]. In assembly systems it is often not possible to remove product variants, which drives the complexity, due to market demands. One possibility is instead to simplify and thereby reduce complexity [31]. If information is presented in a simplified way the operator could save time and performance could be increased [32].

Today information is however presented using text and is based on the operators' experience [33]. Instructions are developed without consideration of what cognitive processes are active, therefore the operator is less informed than before and may make errors (due to information

overload) [34,35]. The information presented should support the possible behavioral characteristics used and tasks should be described in terms of the operators mental models (instead of system or customer requirements) [36]. There is a need to improve the way information is presented to operators [32,37-42].

One way to reduce complexity is to filter the information [43] and to present the information in an intuitive, effortless and fast way [44]. Based on these assumptions a method for better presenting information to operators was developed, the Design principles for Information Presentation (DFIP).

1.2. Scope and aim

This paper is a continuation of the paper Evaluation of Guidelines for Assembly Instructions, which evaluated the first version of the DFIP 1 [45]. In the first evaluation of the guidelines the use of DFIP showed that students and company representatives mostly used step 3 (had a bullet list). One of the groups said that “maybe it was too difficult for them to use the guidelines since they based much of the results on their own experiences and feelings” (Ibid.).

The aim of this paper is to evaluate the application of the further the DFIP regarding:

- The use of DFIP (what parts of the DFIP is used and how)
- The results of the use (are the instructions as good as expected).

Case studies are used to evaluate the application of the DFIP.

2. Design principles for Information Presentation (DFIP)

The DFIP are based on the work by Söderberg, et al. [46]. Söderberg et al. performed experiments where the relations between instructions, task time and emotion were studied in LEGO assembly. The guidelines are based on that active cognitive processes should be supported [47] and that the perceived view of a situation affects the operators behaviour [48,49]. In addition, information should be presented to support cognitive abilities and limitations e.g. that humans are good at handling dynamic situations and that the working memory is limited [25,26,50,51] and present fewer things [52]. The presentation of the information should be clear as well as have a focus on pictures [46,53-55].

Interviews were performed after each experiment and were coded. The codes were compared to assembly errors so that common errors could be highlighted. The data from 50 participants was used as input to improve assembly instructions (together with theory and existing design principles). Then 10 new participants performed the same experiment with new instructions and an improvement could be seen in productivity and satisfaction [46,56]. The DFIP was then used in education (both for students and company representatives) and an evaluation of the DFIP was performed and documented, this version was called DFIP 1. DFIP 1 had five steps:

1. Support active cognitive processes
2. Support mental models
3. Support abilities and limitations
4. Support individual preferences/differences
5. Support perception (placement)

When DFIP was entered into a course literature called Smart Automation – methods for final assembly [57], the steps of DFIP were altered so that it could be used as is by practitioners; this version is called DFIP 2. In DFIP 2 an additional step is added before the original steps, which was due to that the need to explain how DFIP fit together with the other methods presented in the course book. In addition, the steps were made more explicit so that they could be used directly by practitioners. The DFIP 2 also places the instruction development in a context e.g. by connecting information presentation to organization and other work processes. The DFIP has six steps (presented in full in Appendix A):

1. Choose a work task in the workplace
2. Identify and support active cognitive processes in each sub-task
3. Analyse tasks based on how the operator perceives the work environment.
4. Analyse tasks depending on cognitive limitations.
5. Analyse tasks depending on individual differences and needs.
6. Analyse tasks depending on placement of information content and carrier.

3. Evaluation of practitioner use

Two case studies were performed. First, DFIP was used in quizzes that assess 102 students' knowledge within the course Production Ergonomics and Work Design (during the spring of 2016 and 2017, MPP027 at Chalmers University of Technology), *Case A*. For the first year the first version of DFIP was used (DFIP 1), and for the second year the new version of DFIP was used (DFIP 2). The students were given the same introductory theory i.e. how cognitive ergonomics should be applied in production and what cognitive capabilities operators have. They were given the quiz-question as a home assignment (so could use course literature) and were asked to describe and argue for how the cognitive/mental processes are supported (using at least 4 of the DFIP steps).

Secondly, DFIP was used in education and workshops with companies and where assembly instructions should be improved, *Case B* (2016-2017). In education and workshops practitioners were given a theoretical introduction to cognitive ergonomics (similar to the one in Case A, but not the same). The task was to develop new assembly instructions based on the DFIP (in groups of 2-4 participants).

In *Case C*, two students developed paper and video instructions in a bachelor thesis. The aim was to support knowledge management at a small company. A summary of how cognitive ergonomics work for assembly operators was part of their theoretical frame (no lecture was given). Both paper and video instructions were developed together with

the author and the video instructions were made based on DFIP (for the same product, although they were not designed for video applications) [58]. Both instructions were tested and evaluated by operators.

3.1. Sample

Sample data is presented in Table 1. Practitioners were divided according to educational level and number of participants.

Table 1. Case study sample.

Case study	Number of participants	Description
A: Quiz results with DFIP 1	47	Students on master level, course MPP027 2016
A: Quiz results with DFIP 2	57	Students on master level, course MPP027 2017
B: Lego assembly instruction improvements with DFIP 1 and 2	32 (11 instructions developed)	Part of education package where theory is first presented (similar to course) but included also company representatives. Experience levels varied.
C: Paper and video instructions development (DFIP 2)	2	Students on bachelor level.

3.2. Analysis

In Case A, investigatory triangulation was performed. Two researchers studied results from the quizzes using a pre-set evaluation form. The evaluation was performed separately and evaluations that different were evaluated together. The evaluation form studied:

1. What DFIP steps that were used
2. To what extent the DFIP was applied (words were correctly used, words were explained or argued for).
3. An average of 1 and 2 were calculated and a graph was constructed.

For Case B and C, the results of developed DFIP instructions were evaluated. This was done using the following evaluation form:

1. Which DFIP steps were used
2. Which DFIP steps were disused
3. Is it easy to understand the assembly steps
4. Is the overview good (final step)
5. Is it possible to assemble the product wrong

In Case B, the developed assembly instructions were given points based on 1-5 (one point for good response, minus one for steps that were dis-used and 2 points for very good use).

4. Results

In Case A, step 3 was applied more often than the other steps (result for DFIP 1 and 2), see Fig. 1. Since the steps in DFIP 2 has the same content as the ones in DFIP 1 (in general, and except for the first step) the use of DFIP steps can be presented in the same graph.

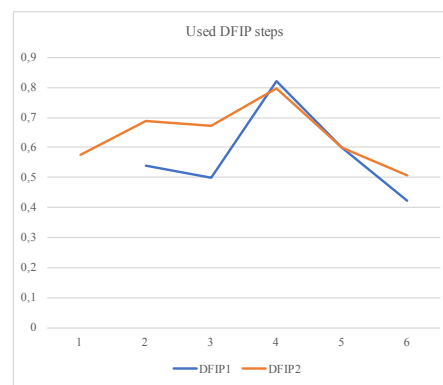


Fig. 1. Used DFIP steps for DFIP 1 and 2 (on average).

In addition, the average for step 2 (active cognitive processes) and step 1 was higher for DFIP 2 than for DFIP 1. The extent of how DFIP was applied was calculated as an average of 1.66 (where 1 was 'words are just used and not explained', 2 was 'words are explained' and 3 was 'choices are argued for'). For DFIP 2 (N=1.59) it was lower than for DFIP 1 (N=1.74).

In Case B, again, the step for cognitive limitations was the most used, what active cognitive processes and the overview picture were also used. Step 4 and 6 were the most disused (too much information, no consistent format). The steps were in general OK to follow and only one group thought of an instruction where it was not possible to assemble wrong (a fixture for the assembly). Half of the instructions had a good overview of the final product. The points given to the instructions were on average 3.6, e.g. the highest point was 6 and the lowest -1.5.

In Case C, students developed two work instructions for a single workstation: paper-based instructions with mainly pictures and some text for a product, and video-based instructions for another product. The application of DFIP 2 was affected to that there is a difference between paper and video instructions and that the instructions were developed for different products. The evaluation of the use of DFIP in Case C is presented in Table 2.

Table 2. Results of evaluation of Case C.

Evaluation form	Paper instructions	Video instructions
1. Which DFIP steps were used	Steps 1, 2, 4, 6	Steps 1, 2, 3, 4, 6
2. Which DFIP steps were disused	Steps 3, 5	Step 5
3. Is it easy to understand the assembly steps	Yes	Yes
4. Is the overview good (final step)	No overview	No overview
5. Is it possible to assemble the product wrong	Yes	Yes

Concerning the used DFIP steps, the students reflected themselves that the use of Hierarchical Task Analysis (HTA) to divide the work tasks into sub-tasks for both work instructions as step 1. However, they also made an

assessment of relevancy and feasibility of the selected workstation based on the work tasks, which also should be included in step 1.

Further, step 3 was used for the video instructions but not for the paper instructions. Because video recordings may include background noise from the factory, the students analyzed it in relation to the work environment and decided to not include audio in the video instructions.

The operators at the workstation thought that both the paper and the video instructions were easy to understand. While the paper instruction is clearer on *where* to do the instructed tasks, the video instruction simplifies understanding *how* the instructed tasks should be performed.

The use of step 6 focused on content placement within the work instructions, rather than including additional information carriers, such as an overview picture of the finished product. Even though both the paper and the video instructions follow DFIP 2 and support operators better than previous instructions, it is still possible to assemble the products wrong because much work is done based on experience rather than the instructions. See comparison of instructions in Fig. 2 (examples, not full instructions). However, the operators at the workstation expressed that both instructions would be useful for new operators in learning phase, suggesting that paper instructions could be used for simpler products and video instructions for advanced products.

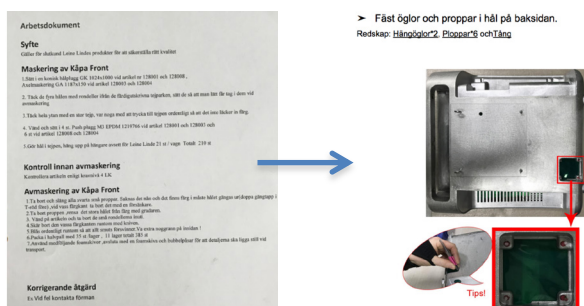


Fig 2. Old (left) and new paper instructions (right, developed with DFIP).

5. Discussion

Results indicated that DFIP step 4 (DFIP 2, step 3 in DFIP 1); concerning cognitive limitations were easy to apply in all cases. This could be due to that they are presented with a bullet list, however, it may also be connected to that they are the easiest to understand. In DFIP 2 steps were used more, however it was seen that their use was connected to not understanding them more. This could be due to that several issues were included in DFIP 2 e.g. that DFIP 1 was easier to use since it included fewer steps and fewer things to think about (which is also according to cognitive capabilities). However, in Case B more steps were used and in Case C the implementation in industry gave positive results. In addition, step 4 was also dis-used in Case B. The advantages of DFIP 2 are that it presents a

more comprehensive current state to the practitioner. However, if the practitioner is not used to developing instructions the simplified version might be better. Further evaluations are therefore needed.

It is important that instructions are presented in a usable way to operators, but to learn how to do this may be difficult. The results from the case studies showed that although DFIP steps were used the understanding of them could be improved. The next sections will describe how theory relates to DFIP and the case studies and also how learning may affect the application of the DFIP.

5.1. Design guidelines in industry

According to Agrawala, et al. [59] two things should be considered when designing instructions for assembly (regarding information content), planning and presentation. *Planning* means that the instruction order should be structured according to sequence and function since this affects the significance perception e.g. what is important. Often parts that have higher significance are combined with lower significant parts. This was seen in Case B, where instructions were formed based on a specific sequence, however, function was not specifically considered (not included in DFIP). This was analyzed by step 3 and 4 in the analysis for Case B and C. It was seen that. This is supported by DFIP 2 step 1, which states that a HTA should be used (not included in DFIP 1). The *presentation* of the instructions are connected to step 4 in the i.e. that the overview of the instructions are easy to follow. This is important since the operator can otherwise be cognitively overloaded [52]. Parts that are often used should be presented in a clear way and mixed formats should be reduced (DFIP step 4) [54,60]. The most used parts were not considered in the DFIP however the clear presentation is included in step 4. Separating similar parts by using arrows was used in many of the instructions developed (Case B and C). In addition, pictures similar to real product should be used [55,56], this was seen in almost all instructions.

5.2. Reflections and future work

A difference between DFIP 1 and DFIP 2 is that in the second edition, a new first step precedes the other steps, which suggest the choosing of a work task where information presentation is going to be improved by considering the aspects of relevancy and feasibility of the aforementioned work task. Even though a work task may already be designated for improvement efforts in some cases, this new first step can serve as a pedagogical purpose, helping to understand the motivation for conducting such an improvement effort.

Another difference is that while DFIP 1 suggests more solutions that could be applied and gives examples, DFIP 2 is in a greater extent highlighting topic areas for the designer to consider, which moves the usefulness of the DFIP from designing assembly instructions specifically, as in [45], to presenting information more generally.

6. Conclusions

By simplifying information presentation, complexity in production may be reduced. For the labor-intensive manufacturing industry, the development of DFIP lends support to engineers and shop-floor operators to create good work instructions. Due to that it can be difficult to understand operator behavior, this article shows what steps are best understood by practitioners and which steps need better explanations (or support).

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