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Testing Operator Support Tools for a Global Production Strategy

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Abstract

Globalisation of industry puts new demands on technologies and instructions to work in different time-space contexts. This paper examines four different support tools that can be used for different time-space contexts: face-to-face instructor (same time-same place), remote guidance with augmented reality (same time-different place), movie-based instructions and text-picture based instructions (different time-same place). Experiments of simulated product assembly were conducted to measure assembly time, product quality and the operators' subjective emotions of the support tools. In total, 46 number of tests were conducted. Results indicate that the different support tools have both advantages and disadvantages, and therefore selecting appropriate support tools is dependent of the situation.

Keywords: globalisation; technology comparison; experimental study; operator emotions; assembly instructions; support tools

1. Introduction

The manufacturing industry is becoming more globalised, with an increasing number of companies having production sites scattered around the world. Companies with production globally manage a diverse range of products in its portfolio. Such companies cope with coordinating its production strategy and planning at multiple sites [1,2].

In manufacturing, improving productivity and quality are important factors for assessing an overall system [3,4,5,6]. Another important factor for good performance is satisfaction or emotion for the operators [7,8]. In this context, quality relates to effectiveness, productivity relates to efficiency and satisfaction relates to comfort perceived by the operators [8]. For the different support tools, there exist both advantages and disadvantages for these three factors. When evaluating different support tools, it is important to consider the support tool's prospective purpose [9].

The trend of mass customization and changes of product variants creates complex assembly systems [10]. This production complexity should be simplified and prevented [11]. Hence, there is an urgency for supporting assembly operators' training in final assembly [2].

In order to create a socially sustainable work environment for operators, this paper explores how different support tools can help operators to better understand their work tasks.

Previous research has concluded that by improving text-picture based instructions, operator performance and product quality can improve [12]. The arrival of Industry 4.0 and the concept of Internet of Things are enabling new possibilities in how to support operators in production [13], such as information and communication technology (ICT) tools.

The aim of this paper is to demonstrate how time-space flexibility affect a meeting situation, by using four different support tools. The tested types of instructions are:

- face-to-face instructors
- text-picture based instructions
- remote guidance with augmented reality
- movie-based instructions

The main assumption is that these different instructions can support operators in various extents and may be advantageous in different time-space contexts.

The parameters measured are how the different instructions affect assembly times, product quality and the operators' self-assessed emotions. The meeting situation in this research is an assembly task where the meeting is between a novice operator and an expert instructor.

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2. Frame of Reference

Time and space groupware matrix is a model based on the following four categories of different time-space contexts [14]:

- same time-same place; e.g. an instructor guiding an operator in real time
- same time-different place; e.g. telephone calls
- different time-same place; e.g. information between shifts
- different time-different place; e.g. an expert in Sweden recording instructions to an operator in Brazil

The different time-space contexts challenge companies' capabilities to spread and share information. For each time-space context, there exist different methods to support communication.

Depending on different time and space contexts, information and communication tools need to come together with people and their knowledge to create structured meeting arenas, where knowledge can be shared [15,16].

2.1. Information quality

The quality of information is important and not the quantity and for creating such efficient information, there are six qualitative criteria [17]: relevance, timeliness, accuracy, accessibility, comprehensiveness, and format.

2.2. Information sharing strategies

The qualitative information can be shared in different ways to cognitively support the intended users. On an organisational level, there exists two strategic approaches towards sharing information: *personalisation* and *codification* [18].

While the *codification approach* relies on documenting explicit knowledge, the *personalisation approach* emphasises human-to-human interaction for sharing tacit knowledge. Neither approach excels individually, but a balanced combination of the two approaches can improve an organisation's internal sharing of information [19].

2.3. Cognitive automation

Cognitive automation could be defined as: *"software intended to automate cognitive activities, such as situation assessment, monitoring, and fault management that are currently performed by human operators"* [20]. A more detailed definition is *"technical solutions helping the operator, e.g. HOW to assemble (levels 1-4) and situation control (levels 5-7)"* [21].

Automation has an impact on the operators' cognitive functions, i.e. the operator's thinking as well as doing [22].

2.4. Technical solutions

Among recently available technology is augmented reality, and research have initially shown usefulness in manufacturing as an operator support tool. For example, augmented reality goggles can be used to: overlay information visually [23], combine information from mobile devices [24] and integrate information from expert systems [25]. Movie-based instructions are multimodal, which helps memorising activities and gives operators a certain user control that individualises learning and boosts self-confidence [26].

2.5. Perception of information solutions

The content is the information that an operator receives. The content is distinguished from the carrier, which is how the content is presented to the receiver of information, e.g. a support tool [27]. When evaluating support tools, it is important to consider the experience level and the specific needs of the intended user and the circumstances the support tool is going to be used [9,27]

3. Experiment set-up

Two rounds of experiments were carried out at Chalmers University of Technology. The first experiment round was carried out at the Production Systems Laboratory during spring 2014. The second experiment round was carried out at the Chalmers Smart Industry Laboratory during autumn 2015.

The test subjects were invited to assemble gearboxes with LEGO bricks, as shown in Fig. 1. None of the test subjects have assembled this LEGO gearbox previously, but their previous assembly experience varied.

Fig. 1. LEGO gearbox that the text subjects assembled.

The gearbox model has 21 components in total, and was selected because of its relatively low degree of complexity, which would give useable results in few assemblies.

The LEGO gearboxes were assembled with different support tools. The experiments focused on evaluating the support tools for work instructions.

The first experiment round tested: face-to-face instructors, and text-picture based instructions. The second experiment round tested: remote guidance with augmented reality, and movie-based instructions.

3.1. Development of instructions

In general, the instructions used in the experiments were developed with regard to information quality to support cognitive automation.

For text-picture based instructions, guidelines that improve operator performance exists. These guidelines have been used in developing text-picture based instructions that has been empirically tested [28]. Simplified, the guidelines include:

- structures; based on planned assembly procedure, include pictures of finished products

- layout; consistent and easy to find information, clear, concise, intuitive and informative headings
- pictures and text; relevancy and reality focus, preferably photographs, text can be a compliment if necessary

The text-picture based instructions in the experiments are developed based on these guidelines. The development of movie-based instructions was inspired by these guidelines and used when applicable.

The text-picture based and the movie based instructions contained similar information. However, while these two types of instructions are unidirectional, face-to-face instructions and remote guidance with augmented reality enable feedback.

3.2. First experiment round: Testing face-to-face instructor and text-picture based instructions

During the first round of experiments, 30 test subjects assembled five (5) gearboxes each at an assembly station. 15 test subjects assembled the gearboxes with a face-to-face instructor, the other 15 test subjects assembled the gearboxes with text-picture based instructions. 22 test subjects were men (73.33%) and 8 test subjects were women (26.67%). The average age of the test subjects were 22.7 years, with an age span between 20 and 27 years old.

The test subjects arrived to the laboratory individually and were first shown a picture of the gearbox they were to assemble in order to understand the nature of the task, but they were not shown the actual instructions. The test subjects were informed about the conditions of the experiments, their support tool and that they should focus on the quality of the product, i.e. it is more important to assemble correctly than being fast.

During the assemblies, the test subjects could watch an overview picture of the LEGO gearbox.

The assembly station is shown in Fig. 2, with the material façade in the centre and the assembly fixture below, an overview picture is to the left and the text-picture based instructions are on a touchscreen to the right.

Fig. 2. Assembly station for the first experiment round.

The 15 test subjects that assembled with a face-to-face instructor were shown how to assemble the gearbox by an expert. The test subjects were allowed to ask questions and get feedback at their own behest.

The other 15 test subjects that assembled according to text-picture based instructions had a tablet computer at the assembly station, where the test subjects could swipe through steps with images of different stages of the assembly.

3.3. Second experiment round: Testing remote guidance with augmented reality and movie-based instructions

During the second round of experiments, 16 test subjects assembled four (4) gearboxes each at an assembly station. 8 test subjects assembled the gearboxes with guidance from a remote instructor through augmented reality, the other 8 test subjects assembled the gearboxes with movie-based instructions. 9 test subjects were men (56.25%) and 7 test subjects were women (43.75%). The average age of the test subjects were 29.3 years, with an age span between 20 and 46 years old.

The test subjects arrived to the laboratory in pairs of two and were first shown a model of the gearbox they were to assemble in order to understand the nature of the task, but they were not shown the actual instructions. The test subjects were informed about the conditions of the experiments and their support tool.

The assembly station is shown in Fig. 3, with the material façade in the centre and the assembly area below, the movie based instructions are on a touchscreen to the left.

Fig. 3. Assembly station for the second experiment round.

The 8 test subjects that assembled with remote guidance with augmented reality were first introduced to the augmented reality goggles, as shown in Fig. 4, and how to use it. The instructor guided the test subjects from a station, as shown in Fig. 5, in a separate room using both overlay visuals and audio communication. The remote instructor could give frequent feedback on the assembly progress.

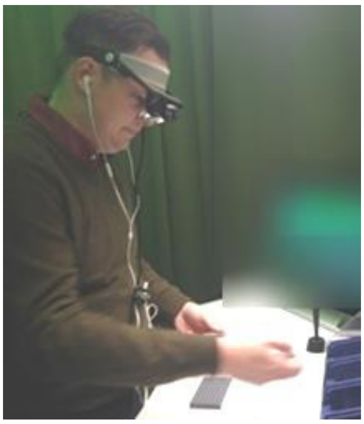

Fig. 4. The augmented reality goggles in use, during the experiments.

Fig. 5. The station where the expert guides the test subjects remotely.

The other 8 test subjects that assembled according to the movie-based instructions had a touch screen where the test subject could watch a video of an assembly that could be fast forwarded and rewound.

Differently from the first round of experiments, the test subjects were not provided with an overview picture of the LEGO gearbox during the assemblies. However, the test subjects using movie-based instructions were allowed to pause the movie and use it as an overview picture, which was not a possibility for the test subjects having remote guidance with augmented reality.

3.4. Measurement of assembly times and quality

During the experiments, the assembly of every gearbox was documented with regards to time and quality.

The assembly times include the time using the support tools. So, for test subjects using face-to-face instructors, the assembly times include the guidance from the instructor, where the instructor shows the test subject how to assemble correctly during the first assembly alongside with the test subject's own assembly. Similarly, test subjects using text-picture based instructions studied instructions during assembly time, test subjects using remote guidance with augmented reality was instructed and guided during the assemblies, and test subjects using movie-based instructions watched the film during the assembly time.

A LEGO gearbox can be considered either of good or inadequate quality. Any number of errors on one LEGO gearbox makes the entire LEGO gearbox considered qualitatively inadequate. If all 20 bricks were correctly assembled, the LEGO gearbox was considered qualitatively good.

3.5. Measurement of emotion-based impressions

Psychologically, three dimensions of emotion represent the human responses when assessing environmental perceptions and experiences of test subjects [29]:

- valence; unhappy – happy
- arousal; calm – stressed
- dominance; little control – full control

These three emotional dimensions are represented in a picture-based questionnaire called the Self-Assessment Manikin (SAM), depicted in Fig. 6 with the rows representing the dimensions of valence (top), arousal (middle) and dominance (bottom), ranking from 1 at the left (unhappy, calm, little control) to 9 at the right (happy, stressed, full control) [30,31].

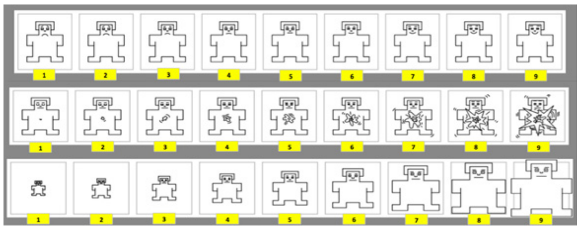

Fig. 6. Self-Assessment Manikin (SAM) questionnaire.

By letting test subjects fill in these questionnaires both before and after a certain performance, the change of the test subjects' self-assessed emotions can be evaluated. Thus, the impact of the performance on the emotion is evaluated.

Prior to starting the assemblies on both experiment rounds, all test subjects filled out a SAM questionnaire. The same questionnaire was filled out after the assemblies. This procedure enables the evaluation of the assembly situation's impact on the test subjects.

4. Results

The experiments resulted in data concerning time, quality and the test subjects' emotions of the tested support tools.

4.1. Assembly times

Fig. 7 shows the development of the average assembly times for each order of LEGO gearbox assembly with the four different support tools.

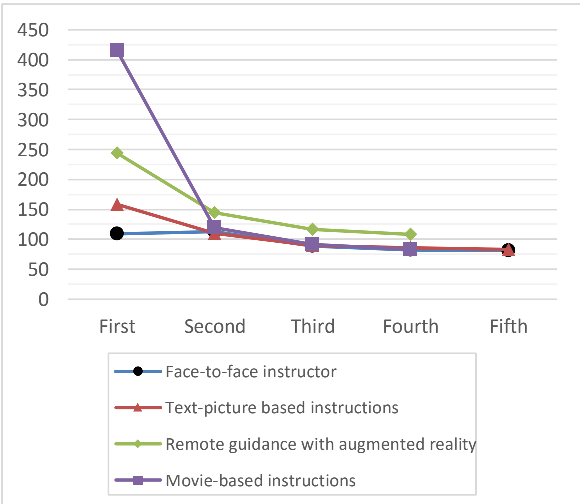

Fig. 7. Graph showing development of assembly time for each support tool.

The different support tools result in different assembly times for the first assembly, ranging from 109 seconds with face-to-face instructor to 415 seconds with remote guidance with augmented reality. The fastest first assemblies were with a face-to-face instructor, which were faster than the second assemblies with the other support tools. The slowest first assemblies were with movie-based instructions, where the test subjects spent time watching the movie.

For the second assembly, the assembly times for the tested support tools, except remote guidance with augmented reality, converged between 110 and 119 seconds.

Assembly times stayed together around 90 seconds and 84 seconds for the third and fourth assemblies respectively. But for remote guidance with augmented reality the average assembly times were around 25 seconds longer for each assembly.

4.2. Assembly quality

The quality of all assembled LEGO gearboxes were assessed. In Table 1, the numbers correspond to the percentage of LEGO gearboxes with all 20 bricks correctly assembled for each support tool and order of assembly.

Table 1. Quality; LEGO gearboxes assembled correctly.

Support tool	First	Second	Third	Fourth	Fifth
Face-to-face instructor	93.3 %	80.0 %	80.0 %	93.3 %	100 %
Text-picture based instructions	73.3 %	80.0 %	100 %	93.3 %	93.3 %
Remote guidance w/ augmented reality	100 %	100 %	100 %	100 %	-
Movie-based instructions	100 %	100 %	87.5 %	100 %	-

From an assembly quality perspective, the first experiment round's assemblies that use face-to-face instructors have relatively high quality, while the assemblies using text-picture based instructions have an increase of quality towards the later assemblies. For the second experiment round's support tools, the quality is higher throughout the assemblies.

4.3. Operator emotions

Table 2 shows the average changes of the absolute values of the test subjects' self-assessed valence, arousal and dominance between before and after each experiment of assemblies. Instead of showing whether the self-assessed valence, arousal and dominance are increasing or decreasing, the average change of the absolute values display the tendencies of where a lot of change is happening.

Table 2. SAM questionnaire; average change of absolute values.

Support tool	Valence	Arousal	Dominance
Face-to-face instructor	0.86	1.46	1.26
Text-picture based instructions	0.33	1.13	0.60
Remote guidance w/ augmented reality	0.50	1.13	1.38
Movie-based instructions	0.63	2.00	0.88

Notably, the movie-based instructions impact arousal, and so do face-to-face instructors. Valence was the least changed emotion. On dominance, face-to-face instructors and remote guidance with augmented reality seem to affect dominance more than the other two support tools. The assemblies using remote guidance with augmented reality have the largest change of dominance comparing before and after the assemblies, affecting the test subjects the most.

5. Discussion

This section will discuss how the four support tools affect assembly times, product quality and the operators' emotions. The choice of support tool depends on what time-space flexibility is needed.

5.1. Assembly time, product quality and test subject emotion

Assembly time in this study also encompasses the time using a support tool, which gives an overall result that considers the time spent for each assembled LEGO gearbox. For the first assembly, the support tools are used longer, which increase the average assembly times. The results indicate that the assembly times decrease after few assemblies, which is expected since the test subjects remember more and more and assemble from memory rather than dividing their attention between the support tool and the assembly.

The assembly times were generally higher for the use of remote guidance with augmented reality because the test subjects asked for feedback in higher extent, which prolonged the assembly time, but also increased the quality.

The results from the SAM questionnaires suggest that text-picture based instructions have the least emotional change, which may be because of other support tools' stress factors, e.g. guiding experts or interactions with the play and pause buttons.

5.2. Choice of support tool

This study is based on one assembly task. Therefore, it is difficult to generalise the results. The four support tools are set in different time-space contexts. These different time-space contexts may make the different support tools unavailable for other time-space context, e.g. it is difficult to have a face-to-face instructor while being at another production site.

Face-to-face instructors and remote guidance with augmented reality are within the *personalisation approach*. Text-picture based instructions and movie-based instructions are within the *codification approach*. Organisational favouring towards either approach may influence the choice of operator support tool, but it is important that the selected support tool supports the operators' perception of transferred information.

In the same place-different time context, text-picture based instructions are preferred when there is a time pressure. The results point towards that text-picture based instructions do not affect the operators' emotions in a large extent.

The results indicate that remote guidance with augmented reality provides a good alternative when the assembly quality is more important than shorter assembly times when the same time-same place context is tedious to achieve.

Using one support tool must not exclude using others. While a face-to-face instructor can be useful in the learning and training phase for an operator, text-picture based instructions can be appropriate in the long run.

6. Conclusions

Based on the experiments, the tested support tools have both advantages and disadvantages with regards to assembly time, quality and operators' emotions. When choosing support tool it is important to consider several factors. Depending on time-space flexibility and what kind of support operators need, different support tools may be preferable. However, to faster train operators from a global perspective, the different time-space contexts have to be properly supported.

It would be interesting for future research to introduce more product variants, since it would increase assembly complexity and make test subjects less dependable on their memory and more dependable on the support tools. Further, how future support tools and its features support operators in the future would also be interesting to pursue.

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