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Language independent transfer of assembly knowledge

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Abstract

Transferring assembly knowledge for workers with different cultural and linguistic background is challenging. The established solution of translating written instructions into multiple languages is mostly cost intensive, holds a potential for mistakes and the result might be hard to understand. To cope with this challenge, three different assembly instructions with language reduced or language independent content have been tested in a study with students in Vietnam and Germany. The types of instructions were interactive 3D-PDF, Utility-Film and illustrated manual. Assembly errors, assembly time, safety symbol awareness and assembly sequences understanding are compared and evaluated based on students' technical pre-knowledge and experience. The 3D-PDF showed to be the best solution to be applied in this complex environment, because users were able to assemble the parts faster and experienced a higher degree of interactivity compared to the other instructions.

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Keywords: assembly; learning; learnstruments

1. Introduction

Globally acting special machinery companies face the challenge of training workforces with different cultural and linguistic backgrounds. Highly educated and skilled workers are needed in this extraordinary one-of-a-kind producing business. Two solutions are established today to cope with this challenge. The first one is to send workers to different locations on the globe for teaching purposes, which is cost intensive. To translate existing assembly instructions, consisting of written text and technical drawings, is the second solution, which is cost intensive as well

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and prone for translation errors. One promising attempt to cope with this challenge are language reduced or language independent instructions, as they are established for mass- or serial production. In a first attempt to create a language reduced instruction, a manual for radial compressor assembly was enriched with pictures, symbols and Blissymbols. Workers appreciated the high amount of pictures as the assembly became more visual and easier to understand [1]. When an assembly process becomes complicated, static images showed several deficits compared to dynamic ones. So called Utility-Films [2] or interactive 3D-PDFs [3] are promising attempts to cope with this challenge, while offering the opportunity to use only a limited amount of language. A survey on 40 global acting companies in 2014 shows that the usage of classic design elements like text, tables and drawings decreases and IT-based dynamic solutions like animations and videos become more and more popular, compare Fig. 1 [4].

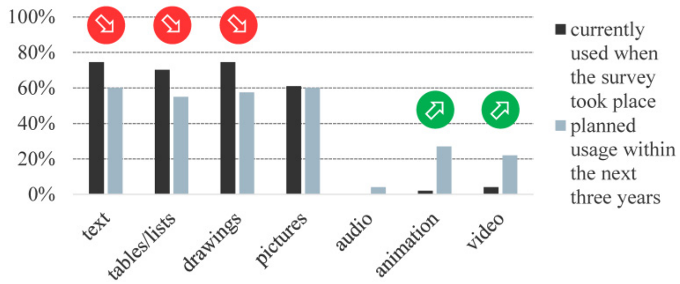

Fig. 1. Use of design elements for assembly assistance systems [4].

2. State of the art

"Learnstruments are artefacts and systems which automatically mediate their functioning to their user" [5]. They can combine learning and working environments through which knowledge and skills are transferred together [5]. One basic idea behind learnstruments is their simple usage through which they increase teaching and learning activities. Manual assembly processes efficiency can be improved through learnstruments. In an exemplary application for a learnstrument, a human motion capture system is used at an assembly table to track worker motions. Depending on his motions the system shows the worker the next assembly step and teaches him basic knowledge about Methods-Time Measurement (MTM)-codes [6]. By "help of a so called qualification module, intuitive work descriptions can be generated and distributed. The qualification module consists of a combined pose-recognition [and] learning module for assembly sequence definition and control" [6]. Additional learnstruments features are: the interactivity between user and learnstrument and in addition to learn the assembly a second learning topic, the MTM-codes. Supplementing to the original learnstruments definition [5] it is possible in special machinery field that learnstrument and learning object are initially not in the same place. But, after the learner got used to the learnstrument and traveled to the learning object, both can be used together. Example: A service technician flies together with the learnstrument to a customer where a machine has to be maintained or repaired. He is able to extend his knowledge about the machine with the learnstrument in advance on the flight and afterwards on site. This paper, like learnstruments in general, focuses on a learner-centered approach, were no teacher is directly involved. Table 1 gives an overview about different instruction types in this field.

Table 1. Selection of different types of (learner centered) instructions

static	dynamic	
	interactive	non-interactive
-illustrated manual: -real pictures -CAD-pictures -written instruction -mixture of written and illustrated instruction -technical drawings -bill of material -checklist -MTM-instructions -explosion drawings	-augmented reality -virtual reality -3D-PDF -Learning Content Management Systems (LCMS) -Learning Management Systems (LMS) -Knowledge Management Systems (KMS)	-film -Utility-Film -Hypervideo -audiobook

A visual way to describe different instruction types can be seen in Fig. 2. It gives an idea about what has to be considered when deciding how information is transported from the knowledge holder to the learner. User's comprehension, the way how to store information, automation capacity to deduct illustrations and openness to be transformed into other representation forms are relevant while comparing different instruction types [8, 9]. For animated and static graphic instructions, Jeske deduced more comprehensive instructions as well as higher assembly experience lead to shorter assembly times [10, 11]. Jeske also concluded the assembly instruction type is only essential for the first assembly executions by the same person. The more often a person repeats an assembly the more irrelevant the instruction type becomes for the assembly time. After an average of ten repetitions the assembly time was nearly the same for each instruction type used [10, 11].

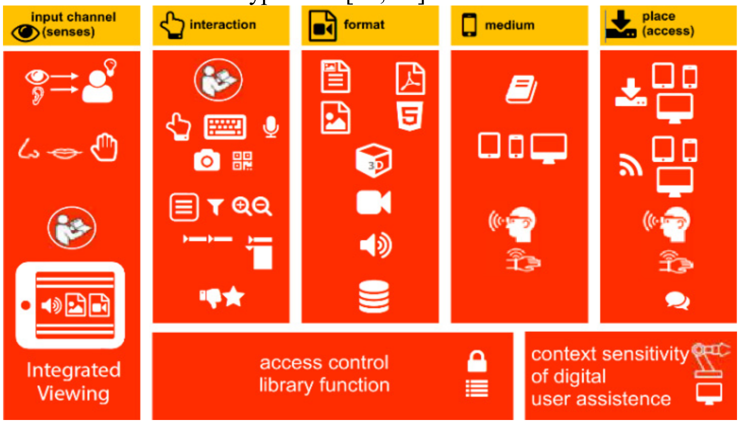

Fig. 2. Different instruction types, translated from [7].

Highly skilled special machinery workforces need a possibility to learn new assembly tasks quickly. In many cases the product to be assembled does not exist at the moment or at the place when/where the learning takes place. Instruction translation effort and translation error potential have to be minimized by aiming towards a language independent instruction. The effort to create and change instructions has to be minimized to cope with rapidly changing conditions in the highly competitive special machinery environment. This paper gives an idea which instructions suit for these conditions.

3. Test concept and implementation

Each assembly task is different in one-of-a-kind producing companies, considering number, size and appearance of parts. Therefore, it is difficult to compare and test many instructions for one assembly task with a sufficient large sample of skilled assembly workers in this segment. To be able to compare different instructions, a simple bicycle e-hub motor assembly was documented within three instruction types and tested with different students.

The types are: a 3D-PDF, a Utility-Film and an illustrated manual. All instructions "automatically mediate their functioning to their user" [7]. But only the 3D-PDF is a learnstrument as it has a high degree of interactivity and teaches additional knowledge about the product [3]. Fig. 3 and 4 show the mounting of socket screws into a cover for each instruction. On every instructions first page, parts and tools are introduced by picture, name, tool symbol and identification number to locate the part/tool. Symbols for tools, safety pictograms and additional pictures are displayed in an assembly sequence if needed. Buttons in the lower right corner allow navigating through assembly sequences in 3D-PDF and Utility-Film. The 3D-PDF offers possibilities to interact with the 3D-model as well as additional assembly and product knowledge [3]. 16 international students from Technische Universität Berlin (TU) and 40 students from Vietnamese-German University (VGU) were given an instruction on how to assemble an e-hub bike motor. TU students consisted of 3 women and 13 men between 23 and 30 years old and 26 years average. VGU students consisted of 7 women and 33 men between 18 and 40 years old and 24.7 years average. Each student got a short e-hub and instruction introduction. Additional possibilities/guidance on how to interact with the 3D-PDF have been mentioned in the introduction but they did not violate test fairness. The supervisor started a stopwatch when the student started the assembly. After the last part was assembled the time was stopped and the student was given a questionnaire. The students were asked to write their age and to rank their own experience in: technical drawings, assembly and electric engines from “very bad” over “rather bad” and “rather good” to “very good”. The same ranking was given when asked to evaluate the manual in comprehensibility, usability and structuring. To evaluate the ratings, the results were transformed into numbers, “very bad” was a 0, “rather bad” a 2, “rather good” a 4 and “very good” a 6. The average for each student can be seen in table 2. Three safety signs were presented after this and the possible danger, countermeasure and risk for the signs were shown in a mixed order. The students were asked to connect the statements to the signs. In a final question three parts from the previous e-hub assembly were shown by picture and should be named. The supervisor had another questionnaire and noted the instruction type presented to the student, assembly time and assembly errors. Possible errors have been pre-formulated like “false assembly sequence” or “false part orientation”. It was checked, if the student wears safety equipment according to the presented safety symbols. Finally, the supervisor observed whether the questions about safety signs and part names were answered out of memory or whether the instruction was used. Each student only assembled the e-hub once, because one-of-a-kind production is essential for special machinery. Distinctive learning curves for a special product like in serial production do not exist. Each student was given either the 3D-PDF, the Utility-Film or the illustrated instruction. 20 students tested the Utility-Film, 18 tested the 3D-PDF and 18 tested the illustrated manual.

Fig. 3. (a) 3D-PDF; (b) Utility-Film.

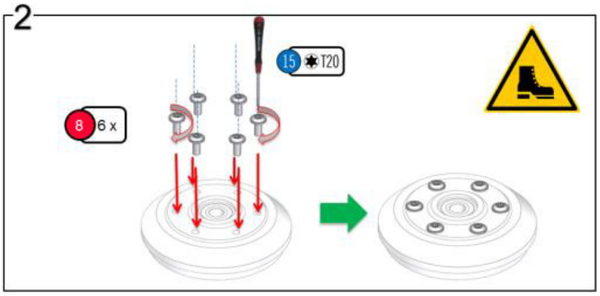

Fig. 4. Illustrated manual.

4. Comparison and test evaluation

A box plot was created to interpret the test results of table 2. Remarkable correlations for the attributes are pointed out and the instructions are compared based on creation, distribution, usage and error susceptibility.

Table 2. Test results

type of instruction	assembly time	total assembly errors	experience points	awareness of safety signs	age	gender	instruction evaluation
3D-PDF	09:33,5	4	4,0	no	25	m	2,0
3D-PDF	09:39,2	0	3,3	yes	33	m	4,7
3D-PDF	09:43,0	1	3,3	no	26	m	4,7
3D-PDF	09:59,1	4	4,7	no	27	m	5,3
3D-PDF	10:19,3	1	2,7	no	21	m	4,7
3D-PDF	10:39,4	1	1,3	no	23	f	4,0
3D-PDF	10:59,4	3	2,7	yes	22	m	3,3
3D-PDF	11:08,1	5	2,0	no	24	m	4,0
3D-PDF	11:12,8	2	4,0	no	22	m	5,3
3D-PDF	12:01,0	2	2,7	no	26	m	5,3
3D-PDF	12:15,8	1	4,0	no	24	m	5,3
3D-PDF	12:23,4	6	4,0	no	24	m	4,7
3D-PDF	13:05,7	2	2,0	no	19	m	4,0
3D-PDF	13:41,6	2	2,7	no	25	m	4,0
3D-PDF	14:38,0	2	2,7	no	27	f	5,3
3D-PDF	14:56,6	3	3,3	no	29	m	4,7
3D-PDF	18:26,0	8	2,7	no	27	m	4,7
3D-PDF	19:48,0	6	4,0	yes	29	m	2,7
illustrated	11:14,3	1	4,0	no	19	m	6,0
illustrated	11:30,5	3	2,0	yes	23	m	5,3
illustrated	11:50,7	0	4,0	no	26	m	3,3
illustrated	11:55,9	1	2,7	no	25	f	6,0
illustrated	12:02,1	5	4,0	no	24	m	4,7
illustrated	12:09,9	2	2,7	no	28	f	3,3
illustrated	12:31,0	6	5,3	no	30	f	5,3
illustrated	13:46,5	1	4,7	yes	19	m	4,7
illustrated	14:20,2	1	3,3	no	30	m	4,0
illustrated	14:43,1	1	2,0	yes	18	m	3,3
illustrated	15:04,0	0	4,7	yes	40	m	6,0
illustrated	15:46,8	3	4,7	yes	24	m	4,0
illustrated	15:46,8	3	4,7	yes	24	m	4,7
illustrated	16:57,0	2	0,7	no	22	m	5,3
illustrated	18:03,0	5	3,3	yes	26	m	4,0
illustrated	19:20,0	6	2,7	yes	24	m	4,0
illustrated	21:25,6	4	2,7	yes	24	f	2,0
illustrated	23:22,6	3	0,7	no	26	m	3,3
Utility-Film	10:18,4	2	3,3	no	22	m	4,0
Utility-Film	11:36,3	1	2,0	yes	20	m	4,7
Utility-Film	12:08,4	2	0,0	no	28	f	6,0
Utility-Film	12:21,7	2	3,3	no	26	m	6,0
Utility-Film	12:59,8	3	2,7	no	18	m	6,0
Utility-Film	13:07,5	1	0,7	yes	32	f	4,7
Utility-Film	13:21,8	3	4,0	no	28	m	6,0
Utility-Film	14:12,2	1	3,3	yes	19	f	5,3
Utility-Film	14:17,6	3	0,0	yes	21	m	4,7
Utility-Film	14:18,6	0	5,3	yes	25	m	6,0
Utility-Film	14:27,1	1	0,0	no	26	m	4,0
Utility-Film	14:47,8	5	3,3	no	27	m	4,0
Utility-Film	15:22,9	3	2,0	no	23	m	4,7
Utility-Film	15:25,6	3	1,3	yes	27	f	4,7
Utility-Film	16:10,8	0	3,3	yes	26	m	5,3
Utility-Film	16:22,1	1	3,3	yes	18	m	5,3
Utility-Film	16:51,0	0	0,7	yes	26	m	4,7
Utility-Film	16:51,2	3	4,7	no	32	m	5,3
Utility-Film	18:40,0	2	2,7	yes	30	m	3,3
Utility-Film	19:55,0	5	4,7	yes	25	m	3,3

Fig. 5 shows the mean time for the assembly as well as the highest and lowest time needed for each instruction. Analysing the process with the Universal Analysing System (UAS) from Methods-Time Measurement (MTM) shows that a trained worker in serial production would need 2 minutes and 6 seconds for the assembly. 83% 3D-PDF users were faster than the average Utility-Film and illustrated manual users. And still 78% 3D-PDF users were faster than 75% Utility-Film and illustrated manual users. The correlation between assembly time and instruction type is 0.31. General correlations found within this study were: Students being aware of the safety signs needed longer for the assembly (0.40). Students with work experience are more likely to follow safety signs (0.25). The higher the error number the higher the assembly time (0.30), is valid for 3D-PDF (0.58) and for illustrated instruction (0.34), but not for Utility-Film (0.08). The lower the rating for the instruction type the longer the assembly time (-0.32), especially while rating the comprehensibility (-0.45). The more the students liked the instruction the faster and easier the product assembly. A high error number resulted in a low instruction comprehensibility rating (-0.40). Fig. 6 gives an overview about student's technical experience. Most students rated their experience in all three categories with "rather good".

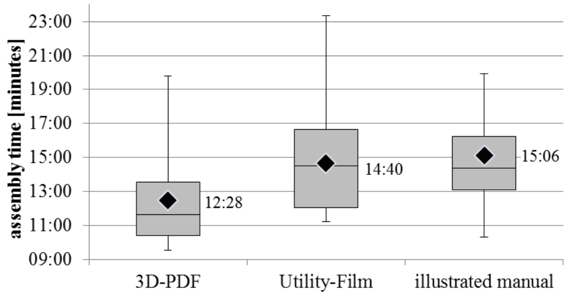

Fig. 5. Box plot of assembly times including written-out average.

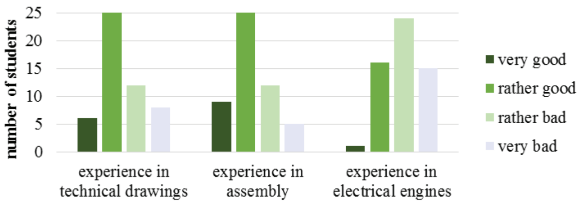

Fig. 6. Students experience.

For special machinery companies it is essential to know how long a new instruction creation takes. If the instruction is used for one product, the creation cost has a higher impact on the product price compared to mass production where it is used for products with higher quantity. To get a first idea how long a creation takes, a student group documented the required production time for each instruction and divided the processes into several steps. Table 3 gives an overview about how long these semi-experienced students needed to generate each instruction. Research, understanding software, and writing an html-script are not day-to-day work for experienced users. Table 3 gives an adjusted view about how much creation time would be necessary. Prerequisite for this is having a template and an experienced editor. Based on these adjustments, the creation of all instructions requires nearly the same time.

Table 3. Time needed for the creation of the instructions

work packages	original			adjusted		
	3D-PDF	Utility-Film	illustrated manual	3D-PDF	Utility-Film	illustrated manual
research	9.0h	10.0h	5.0h			
become acquainted with software	3.0h					
animation /filming/storyboard	8.0h	4.0h	1.5h	8.0h	4.0h	1.5h
film cutting		6.0h			6.0h	
image generation		5.5h	3.0h		5.5h	3.0h
include animation in PDF and adjustments	11.0h			6.0h		
include pictograms and symbols	3.0h	3.0h	4,5h	3.0h	3.0h	4.5h
writing an html-script		14.5h				
adjustments	6.0h	4.0h	14.0h	6.0h	4.0h	14.0h
sum	40.0h	47.0h	28.0h	23.0h	22.5h	23.0h

For an easy distribution among users all instructions have to be stored digitally. However, the illustrated instruction could be stored in a printed format as well. The 3D-PDF needed 4,9MB, the illustrated manual needed 2,5MB (PDF-format) and the Utility-Film needed 28,5MB disc space.

Students were asked to rate the used instruction in comprehensibility, usability and structure, see Fig. 7. Utility-Film and 3D-PDF are rated slightly better in comprehensibility than the static illustrated manual. The Utility-Film was rated best in all three categories. The 3D-PDF structure got the lowest rating as it was designed to show, additionally to the simple assembly sequence, information which is necessary for special machinery, like assembly group information, tools or problem solving steps. Altogether all instructions were rated similarly above “rather good”. Fig. 8 shows the average assembly errors made per student per assembly. Blue lines frame all error types and their sum. Green dotted lines show error types, relevant for experienced workers in special machinery. How to find and use a tool has not to be described for these workers as they are familiar with common tools. Students need this information, which is why these error types are shown.

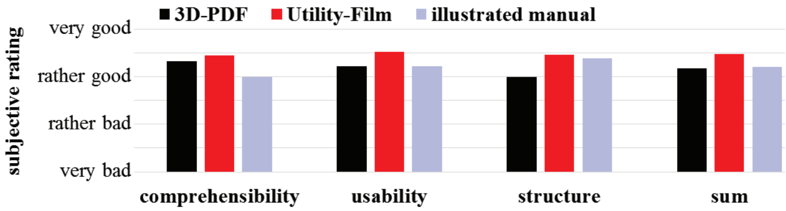

Fig. 7. Subjective rating of the instructions by the students.

The illustrated manual visualized the assembly sequence best, most likely because past and future assembly state can be seen in the adjacent pictures. On the other hand, the illustrated manual was not capable to show part orientation like dynamic instructions. Parts location was shown in all instructions with the same illustration in the beginning. Therefore, the “part couldn’t be found”-error is hard to retrace. Illustrated manual and 3D-PDF didn’t show tool usage, which is why mostly “special pliers for a clip” were used wrong. A part was not mounted as planned if it was forgotten during the assembly or a wrong part was mounted. The differentiation between necessary information for students (blue) and experienced workers (green) shows the higher error potential for inexperienced 3D-PDF users compared to experienced ones. When workplace or part conditions change, time and work amount to implement these changes is different for each instruction. The time is as well dependent on the individual editor knowledge and experience, but some general differences exist. For the Utility-Film each scene containing the specific part or showing the modified area of the workplace has to be filmed again. This is way easier for serial production than it is for special machinery production where each part is normally only assembled once. For the illustrated manual new images have to be generated from the newly available CAD data, for each assembly step. Considering the time needed to crop and render each image this can be quite time consuming. For the 3D-PDF only the CAD data has to be replaced with the new data, which is a fast process.

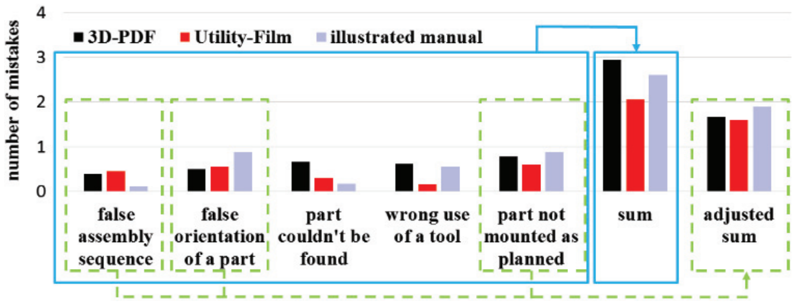

Fig. 8. Average assembly errors made per student per assembly.

5. Summary and Outlook

The goal of the paper is to compare three language independent instructions for their applicability in special machinery. Therefore, a study with 56 international students has been conducted, comparing 3D-PDF, Utility-Film and illustrated manual with respect to assembly time, creation time, distribution, usability, error susceptibility and changeability for each instruction. Results for every instruction type are listed below and the pros and cons for special machinery are pointed out.

Illustrated manual: Standard knowledge on Microsoft Office is sufficient to create a simple illustrated manual. Software like Microsoft Word and hardware like a low priced PC and a camera are suitable for designing the instruction. Image processing knowledge is not necessary but helpful to create graphics with high quality. Simple assembly steps can be easily visualized with this instruction type. Complex assembly sequences where multiple movements have to be performed in one sequence are hard to display. Therefore, automating the instruction creation is difficult as well. Tool usage is difficult to show, as this instruction is static. The creator is free of choice whether to use photos or CAD graphics, based on the availability and the parts complexity. Using CAD data opens the opportunity to transform the illustrations into other representation forms.

Utility-Film: The dynamic Utility-Film suits best for inexperienced users, as each assembly sequence is shown in the way how it should be performed and as each tool usage is visualized in a simple way. Equipment for filming and cutting the filmed scenes is necessary and expensive. The creator has to be familiar with image processing, video cutting and html coding. The biggest disadvantage is that the product to be assembled has to exist to create the film; this is normally not the case in special machinery. An automated video generation is possible if the camera has a fixed position. Scene cutting automation would be more difficult. Transforming the video into other representation forms would be possible, but only into video frame images and only with low video resolution.

3D-PDF: The dynamic 3D-PDF is suitable for complicated assembly sequences as the user can move and interact with the 3D-content freely. CAD-models are necessary for this instruction, but in special machinery they are always created way ahead to the assembly. Additional information can be added easily in supplementary PDF pages, directly within the 3D-content or within the animation using JavaScript. The creator has to be familiar with CAD programs and with JavaScript to design the instruction. Simple animations, showing only the necessary information allows to achieve a short assembly time with this instruction. However, the user still has the opportunity to enrich the animations through moving and rotating the CAD-content, showing part names or giving additional information on safety symbols by clicking on them, to name just three out of the many possibilities a 3D-PDF offers. As for the illustrated manual, using CAD data opens the opportunity to transform the illustrations into other representation forms. Process automation is possible as many programs offer possibilities to create automated CAD explosion animations. The content of the 3D-PDF can be exchanged fast because only the CAD data has to be renewed.

Therefore, this language independent learnstrument would be the best choice to be applied in the field of special machinery and should be tested more detailed under conditions suitable to this field.

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