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Can we better understand the technology in engineering education with virtual 3D models?

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Summery

This study examines the effects of using different types of visualization for task instructions within engineering studies. Participant observation and guided group interviews were used to determine both the learning difficulties of students and their expectations towards the educational use of 3D models. Comparing between three different modes of representation of the same model (2D drawings, perspective 3D models and stereoscopic object representations), the performance of task execution, the speed for task handling and the perceived cognitive workload of one task were measured. 183 students take part in the study. It was found, that the participants that used stereoscopic object-representations perceived task less complex than the groups using perspective 3D or paper based 2D-representations.

1. Introduction

Technology enhanced learning has become a kind of magic spell among the struggle for supremacy in the field of education, which gains a rising weight in economic and political competition, rhetoric and – consequently – funding programs. An accompanying effect of this phenomenon can be seen in an increasing number of commercial players that seek new fields of profit for their products that initially derive from the fiercely competitive market of consumer electronics. This also holds good for stereoscopic display technologies, which are leaping into the different educational sectors. From a scientific point of view, there are several investigations that deal with the value of 3D-tools in different contexts of science education. We share the common perspective, that three-dimensional visualization is an important issue to understand topics that include spatial information or relations. This ‘spatial ability’ includes the mental representation, rotation and inversion of objects, which are provided graphically in a two-dimensional way [2]. To explore the aptitude and worth of the use of stereoscopic 3D-models for pivotal topics in basic engineering education, some preliminary qualitative research was done to identify learning difficulties and crucial topics. A need-based and custom-built 3D environment was used, to compare the influence of stereoscopic 3D, perspective 3D and a paper-based version of content representation on the task handling of the test persons

2. 3D in education: Perspectives and previous findings

As 3D – in a common sense – seems to be a quite simple and unambiguous term, the variety of associated concepts and applications is rather vast. A large amount of studies interpret the term 3D as connected with the immersion into a second life environment, where learning is situated in virtual worlds including avatars. Examples are Merchant’s (2010) study about literacy learning at school [11] and Wan et al.’s (2011) study about “student engagement in 3D virtual learning environments” [19]. Those kinds of examinations predominantly deal with the influence of immersion on psychological categories like social cognition or motivation and the potential for collaboration to focus on their function for learning. Nevertheless, they don’t reflect the effects of different modes of content representation. Additionally there is no differentiation between perspective and stereo-scopic 3D.

A further field for employing virtual worlds are training purposes, where a training in certain real life situations wouldn't be feasible, e.g. the qualification of firefighters, pilots, military personnel, etc. [16]. Those vocational trainings aim to foster the development of behavioural routines by experience through simulation, not the understanding of curricular content or methods.
Schuchardt & Bowman (2007) explored the spatial understanding of underground cave systems under different grades of immersion, effectively resulting in a stereo (high immersion) vs. a non-stereo (low immersion, stereo googles turned off) setting in a virtual cave that was equipped with a head-tracking system. Higher immersion resulted in faster task completion times and in an increased accuracy in task execution [17]. However, the setting of the experiment in a 3D-cave that natively incorporates spatial information, and the further variables of immersion, namely head-tracking and the field of regard, limit the attribution of the findings towards a comparison between 2D and stereoscopy. Korakakis et al. (2011) compare three types of stereoscopic visualization for science teaching that differ in its realization being 1) interactive, 2) animated or 3) static, but there is no comparison with a non-stereoscopic 3D-visualisation or a two-dimensional content provision [9]. The inquiry of Glick et al. (2012) finds that the use of three-dimensional but non-stereoscopic 3D-models within course mate-rial presentation increases their perceived learning of masonry and metals in construction management studies [5].
Remmele, Weiers & Martens (2015) investigated the impact of stereoscopic visualizations in comparison with 2D visualizations on the understanding of biological school topics. In reproducing the human nasal cavity with modelling clay, the eighth grade pupils reproduced more anatomical details when using the stereoscopic model independently from the grade of possible interaction with the model [15].
The previous review about relevant studies provides a rather inconsistent picture about stereoscopy in 3D that corresponds with the conclusions of McIntire & Ligett (2014) that point on the decisive importance of task characteristics and the impact of technological limitations, disturbing effects and discomfort for estimating the value of stereoscopic 3D in diverse contexts [12]. These factors have to be supplemented with the above mentioned further aspects, that are more or less commonly coalesced with stereoscopy, which are interactivity, animations and additional textual, auditory or pictorial content.
This insight leads us to choose a scientific approach, which defines the categories for an investigation of the impact of stereoscopy in basic engineering education by itself. To ensure a binding as close as possible to the classroom reality of the undergraduate students from our local university of applied sciences, we started our investigation with field research by participant observation according to [4], covering 15 basic courses for construction and machine elements. After identifying frequently occurring difficulties of understanding and therefore crucial contents, we applied the findings to construct an interview guide, which was used to conduct four fo-cused and problem-based group interviews. The analysis was guided by the method of Grounded Theory [18] to create subject-oriented categories. Those had been applied to define the basic issues for the final test design. Put in a brief summary, the students have problems...

- to create an accurate and complete mental model of an object or issue that is represented by a drawing (1).
- with the transfer between directional relations and its representation in a two-dimensional mode (2).
- to correctly identify the same object represented by views from a different perspective (3).
- with the correct understanding of functional relations in an assembly (4).

Referring back those empirical findings to Barnea's conceptualization of skills that form spatial ability, the students implicitly describe problems with the categories according to [2]:

- "Spatial visualisation": Ability of understanding three-dimensional objects from their two-dimensional representations. This matches with (1) & (2).
- "Spatial orientation": Ability to imagine how a representation will look from of another perspective. This matches with (3).
- "Spatial relations": Ability of mentally manipulating objects by inversion, rotation or reflection. This matches with (2) & (4).

The students also articulate some positive expectations towards the use of stereoscopic 3D-Models, they anticipate...

- a more correct and accurate impression of the displayed object or issue.
- a better discriminability of single elements of an assembly.
- a faster understanding of objects and issues that leads to a higher speed and better efficiency in task handling.
- a principled facilitation in task handling, because of a more concentrated representation of objects or issues.

3. Experimental setup

Like indicated in chapter 2, the design of the study is primarily orientated towards a learner's perspective and therefore guided by the aforementioned categories that emerged during the qualitative preliminary studies.

1.1. Dependent variables

The dependent variables have been derived from the expected benefits of 3D for students' learning. Consequently (1) the number of correct answers and (2) the time that was required for task handling were measured for each of the two tasks. Additionally, solely for task 2, we measured (3) the subjectively perceived task complexity by applying a raw version1 of the NASA TLX (NASA Task Load Index) [6]. This validated item was exclusively coupled with the second task, because task 1 has a very simple structure, since it only comprises multiple choice questions.

Task 1 consists of six multiple choice questions. Those concern the function of several single assembly elements respectively their functional relation in concern of the overall context of the assembly. The last one questions the overall purpose of the equipment, which is a boring jig.

Task 2 requires the identification of the obstructed components of the boring jig by creating a standardized stock-list, which necessarily had to include the appropriate DIN/ISO standards.

1 We eliminated the pairwise comparisons, since our focus was not to explore the nature of the tasks, but the perceived complexity of task han-dling caused by the settings. Further, there is empirical evidence, that the use of a 'raw TLX', instead of the full version, may increase experimental validity [7].

1.2. Independent variables

Three test settings, shown in Fig 2, were arranged to distinguish between a stereoscopic (S3D), a perspective (P3D) and a paper-based (2D) provision of information.

The test persons had to complete identical questionnaires, into which the two tasks had been embedded. The P3D-group used exactly the same model of the boring jig as the S3D-group, only without the use of stereo-technology. The 2D-group was equipped with two sketches of the assembly, which show a cross-sectional and a top view, to secure, that no setting displays a potential surplus of information.

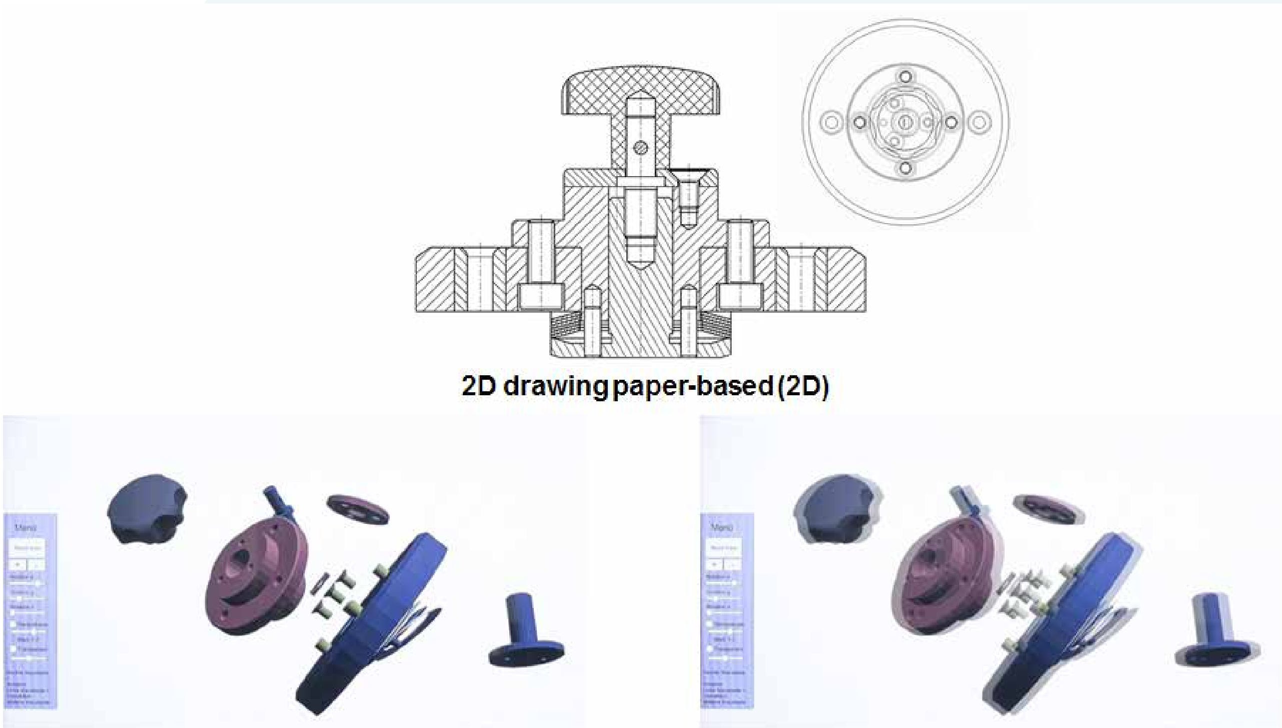

Fig. 1: Realisation of the three independent variables

1.3. Hypotheses

Analogously to the definition of the dependent variables, the hypotheses for the investigation are guided by the learner's expectations towards 3D.

- By using S3D-visualisations, the subjects should, including both tasks, produce more correct answers than by using P3D object-representations (hypothesis 1a). Both 3D-groups should be superior to the 2D-group (hypothesis 1b).
- By using S3D-visualisations, the test persons should, complete both tasks faster than by the usage of P3D object-representations (hypothesis 2a). Both 3D-groups should be faster than the 2D-group (hypothesis 2b).
- The usage of S3D-visualisations should decrease the perceived task complexity respectively the NASA TLX – score in comparison to the use of P3D (hypothesis 3a) while the 2D-content should cause the highest score (hypothesis 3b).

1.4. Technical realization

The software used to display the 3D interactive content was specifically developed for the purpose of this experiment with the proviso to produce a cross platform device. Therefore we aimed to reach a low level of system requirements and a diminution of limitations for a fast break-in and a visceral user experience.

Software: The application is based on the Unity© Engine (v5.0.2f) and works by using an existing 3D model of the blender file type, assigning bounding boxes for the drag & drop function as well as shaders for transparency settings.

The user is enabled to rotate, translate and scale the model and also to adjust transparency. The available drag & drop function for the separation of parts is based on the principle of exploded view.

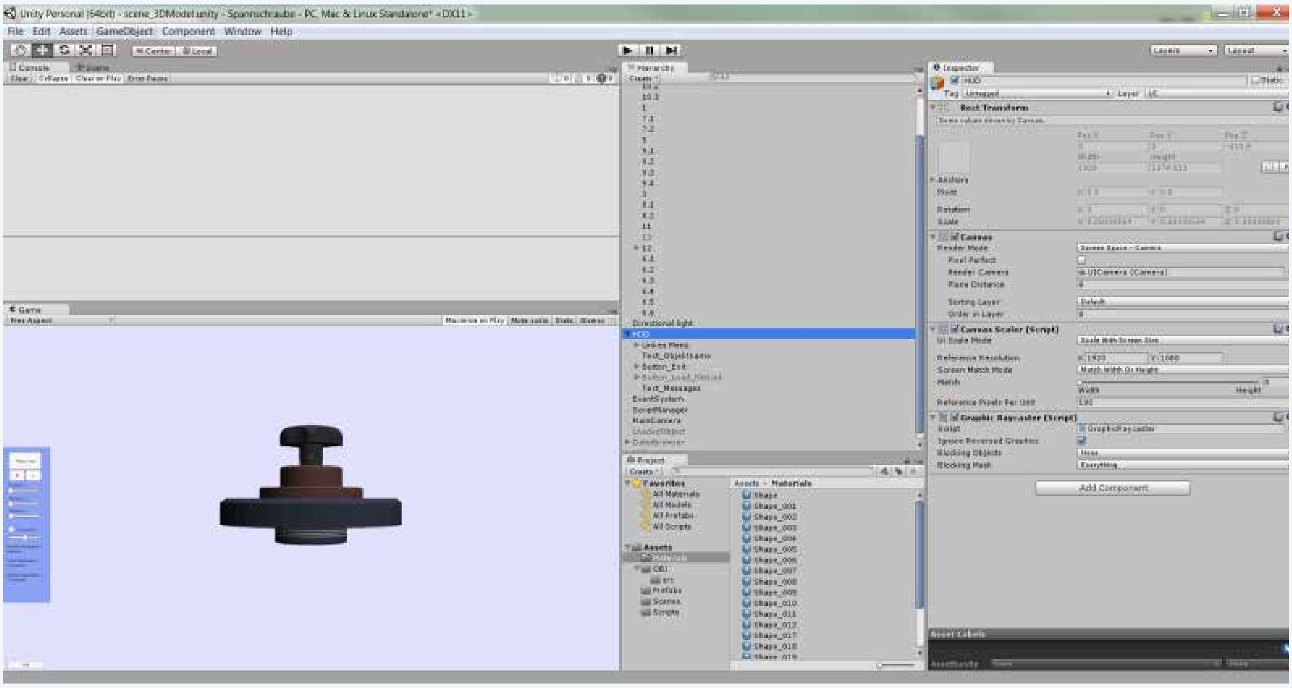

Fig. 2: Software Interface

Hardware: The software is able to run on every contemporary operational system, including mobile devices, too. For the 3D setting without stereoscopy the participants used an average 27” monitor. For the stereoscopic setting the nvidia© 3D Vision technology was used. The setup consisted of a 27’’ 120Hz monitor, nvidia© 3D Vision USB IR emitter and wireless shutter glasses. The 3D setting in the control panel was set to the standard value of 15%.

1.5. Experimental procedure

The study featured 183 participants that were students from the first semester in mechanical engineering studies. Since there are standardized basic courses, which have to be visited by all students simultaneously, we were – to a certain extent – able to control the subjects’ task related prior knowledge. One week before the experiment took place, all students learned the identical method to create a stocklist by working with both the same example and table book. For the inquiry the subjects were randomly allocated per lots to one of the three settings and had exactly 35min to complete an identical paper-based questionnaire that featured the two tasks, the

NASA TLX and a variety of other questions, which are not featured in this paper. The time-dimension was represented by a giant display of a countdown to ensure, that all subjects are guided by the identical time.

Fig. 3: Test setup

4. Results

The results of the statistical analysis below display the comparison of the measured variables' in dependence of the three test settings. Therefore, we used boxplot diagrams that were enhanced with the arithmetic mean, which is characterized by an X.

1.1. Results for rask 1

Using stereoscopic visualizations the number of correctly answered questions was in average 1.72 (standard deviation = standard deviation: 1.073) while within the perspective 3D-group it only reached 1.46 (standard deviation: 1.128). Consequently hypothesis 1a could be confirmed. The group with paper-based information provision performs best with a mean of 1.83, thus hypothesis 1b has not been verified.

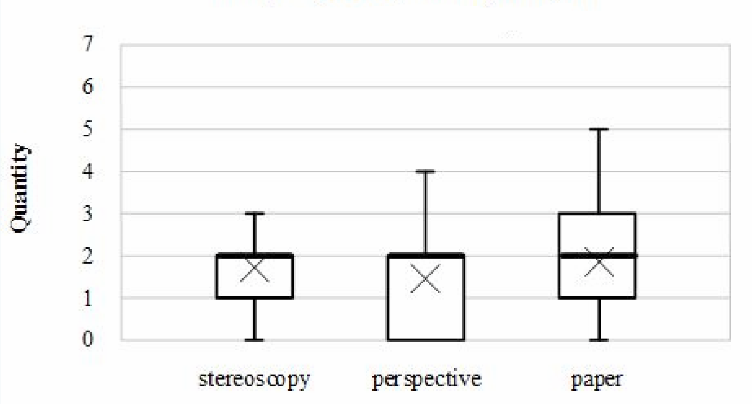

Fig. 4: Task 1, number of correctly answered questions

Regarding the time the participants needed to complete task 1, shown in Fig. 5, , both, hypothesis 2a und 2b could not be confirmed, since the 2D-group needed in average 05:03min (standard deviation: 02:21min) while the P3D-group worked 06:21min (standard deviation: 01:39min) and the S3D-group required a mean of 07:53min (standard deviation: 01:58min).

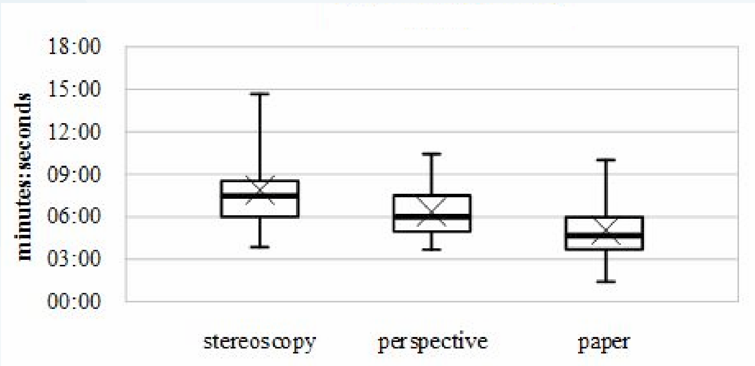

Fig. 5: Time required for task 1

In Recur to the estimated raise in efficiency during task handling, we can find an inverse tendency. In executing task 1 the students with paper-based visualizations performed better and needed less time, hence they have been more efficient.

1.2. Results for task 2

Like indicated by the diagram shown in Fig. 6, in compiling the stock list the S3D-group performed best with an average of 3.12 (standard deviation: 2.136) correctly identified parts, followed by the P3D-group with 2.91 (standard deviation: 2.066). The participants using 2D-materials reached in average 2.35 (standard deviation: 2.120) accurately identified assembly elements. Consequently, the hypotheses 1a and 1b are both confirmed for task 2.

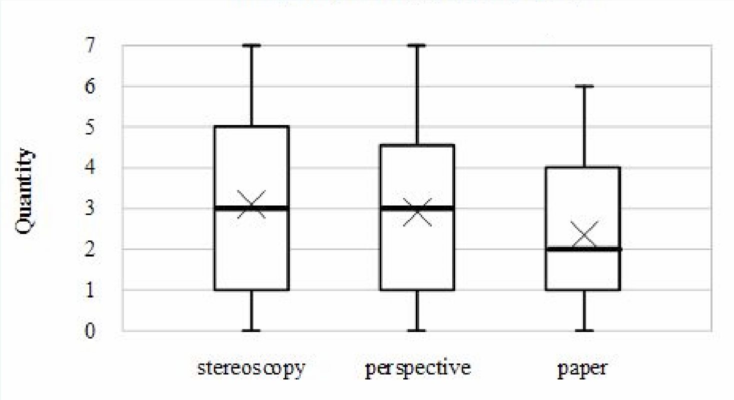

Fig. 6: Task 2, number of correctly identified objects

Regarding the time that has been required for task completion, shown in Fig. 7, again the participants in the 2D-setting worked faster than those in the 3D-groups, because they only needed 12:50min while the S3D-group required 14:22min and the P3D-group 14:57min to finish the stock list. Thus hypothesis 2b is not verified, but hypothesis 2a is.

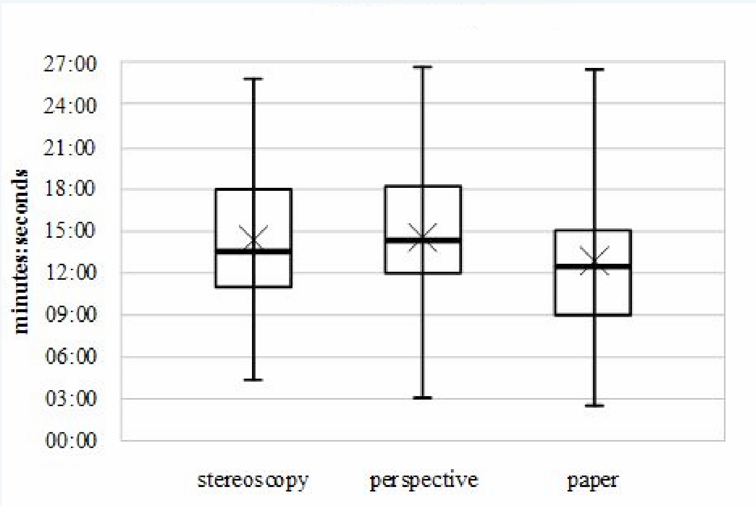

Fig. 7: Time required for task 2

Regarding the perceived task complexity of task 2, shown in Fig. 8, the participants in the 2D-setting rated the stock list-task with an average of 66 points (standard deviation: 16.6 points). The rate of the P3D-group reached 64 points (standard deviation: 17.4 points) while the S3D-group rated the task load with an average of 60 out of 120 points (standard deviation: 15.8 points). The hypotheses 3a and 3b are thus confirmed.

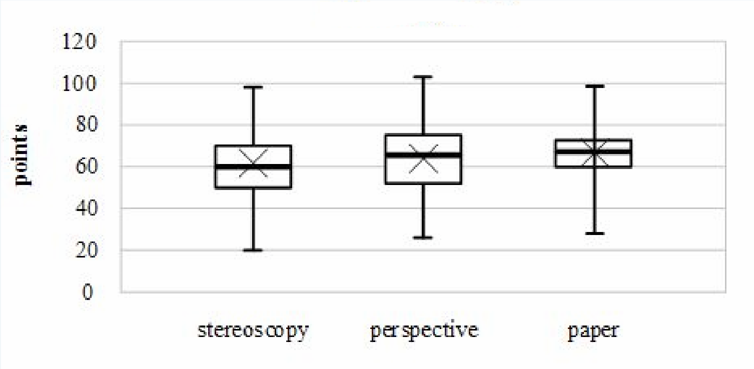

Fig. 8: Task 2, NASA-TLX-score

5. Discussion and conclusion

The previous work that deals with the impact of different three-dimensional visualisations on learning or task handling amounts to a mixed and inconsistent view. This complex picture might partially derive from the varying occurrence of diverse psychological effects commonly associated with multimedia learning and instructional design issues [3]. Another possible influence might be the accustoming of learners' visual perception to 2D displays showing 3D content, like indicated by Mukai et al. (2011). Their study compares stereoscopic information provision with an identical perspective version for the process of learning to assembly a handmade PC. The obtained results show a minor inferiority of the stereoscopic case, which is explained with technical shortcomings of the used 3D devices and configurations [13] .

In recognition of the multiplicity of factors a less concept-driven and thus more scientifically pure view seems very interesting. Bamatraf & Hussain et al. (2016) take the perspective of neuroscience to explore the impact of 2D and 3D educational content on memory recall and learning by measuring brain signals through electroen-cephalography. The results show no significant differences between learning with the perspective 3D and stereoscopic 3D on neither the short term nor the long term memory and the long term memory [1].

The findings reported within this paper keep in line with the ambiguous picture described above and draw a complex perspective by its own. The results show a slight tendency to the existence of certain benefits of the use of stereo-technology especially concerning task 2. Probably the accurate identification of objects involves spatial ability and the stereoscopic representation therefore provides cognitive advantages. This corresponds with the results obtained through the NASA TLX, since the S3D-group perceives the identical task less complex than the P3D-group and especially the 2D-group.

Nevertheless, there seems to be a trade-off between the speed of task completion and the quality of task handling. A possible interpretation for that issue could be motivational benefits induced by the interactive use of stereoscopic 3D and – to a minor extent – also perspective 3D-models. The longer task involvement could de-rive from a kind of stimulation by an experience of fun, which might occur while 'playing' with a 3D-model. This eventually could lead to a better performance.

For further research one should take a focus on the different components of educational 3D-content to better differentiate between the influences caused by different existent and emergent input devices, interaction possibilities and techniques [10].

The relatively high values for the standard deviations remain considerably stable when comparing between the independent variables. This occurrence covering all obtained results suggests an enormously heterogeneity among the students. For Example, the findings of Huk (2006) suggest that high spatial ability students benefit from the use of 3D-visualisations, while students with a low spatial ability became cognitively overloaded by the presence of 3D-Models [8]. The focus on the diversity of the learners, considering even relatively narrowly defined cohorts, promises valuable hints, how to estimate the impact of the use of stereoscopic representations as valid as possible. Therefore factors like prior knowledge, spatial ability and other individual characteristics have to be further investigated in terms of their connection to the potentially added value by the application of different modes of three-dimensional content representation.

The impact of different types of visual representations is highly influenced by the structure of the displayed content or tasks [13]. This fact is also confirmed by the present study since, considered independently of each other, the results for task 1 would indicate quite the opposite conclusions as those for task 2. For a practical value of the already present knowledge about task specific benefits of 3D-materials for education, a feasible method should be found how to determine possible advantages and shortcomings for specific tasks in educations' daily routine. Therefore it is necessary, to include a pragmatically perspective, when evaluating the suitability for use of a still pricey technology, that to this day brings along certain technological inadequacies.

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