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Web-based interactive 3D concept maps as complementary tool to structure learning contents in engineering drawing course

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Abstract

Concept maps are not a new phenomenon in engineering education and are nowadays used to enhance “meaningful learning”. In literature a lot of works on the use of the concept maps in education exist, but not many within the “interactive” context. This study contributes to expand the framework of research on the development of web-based 3D interactive concept maps. They incorporate web-based 3D interactive images that support the learning of abstract and difficult topics in Engineering drawing course, motivating the students and increasing their attention. The effects of different learning strategies (2D concept mapping vs. web-based 3D interactive concept mapping) on the learning outcomes and on the spatial ability are investigated. The results of this study show that web-based 3D interactive concept maps compensate spatial ability deficits, that is, helps students who have low spatial ability to build an effective mental representation of the learning content.

Introduction

In order to enhance understanding and to reduce cognitive load is well-known the use of visual communication. Research indicates that certain visual languages like concept maps act as a working memory extension and enhance direct interpretation of information through pattern detection [1].

Concept maps are representations of concepts and their interrelationship that are intended to represent the knowledge structures that humans store in their minds [2]. Nodes (which represent concepts) and links (which show relationship among concepts) are the elements of a concept map. The key concepts are represented in a structure (arranged by nodes and links) that can be hierarchical, cyclic or hybrid [3]. Concept mapping has been a subject of investigation for some time now, and in education, it is a tool for research, communication and notably it is a process of establishing relationship between concepts. Concept maps can enhance the acquisition of macro-level ideas [4], improve affective responses to studying and testing [5], enhance cooperative learning [6] and lead to positive transfer of text processing skills [7].

From the literature study, it has been evidenced that concept maps have been used as an effective tool both for teaching, learning as well as assessment. Concept mapping has been successfully used as an assessment technique [8-11], as a learning tool to help the students to organize their structured and declarative knowledge [10, 12-17] as an advanced organizer [3, 18, 19]. As regards the teacher's activity, concept maps also have some interesting properties. Constructing concept maps allows the teacher to identify the key concepts and the relationship between them [20]. Many educational contexts have used and experimented concept maps, for example, for teaching Mathematics [21], Engineering [17, 22, 23], Science [24, 25] and Chemistry [26] for meaningful learning.

Memory for visual imagery is more strong than that for textual information only. Considering the recall of information, pictures have a superior effect [24]. The picture's superiority in explicit memory tasks is due to its stronger associative perceptual information than that of words [24]. Pictures enable the extraction and

retention of information that readers do not encode effectively [24]. Pictures highlighting details effectively increased the recall of those details, and picture-depicting relationships effectively increased recall of that relational information [24, 27].

So images may complement text-based concept mapping and then play an important role in improving students' learning. The ability to incorporate images in concept maps allows users to portray concrete instances of concepts and may provide for a more engaging user experience [16, 18]. Paivio's (1991) work demonstrates that memory of a given material is better when this material is encoded from different formats [28]. Hence, the dual coding predicts that if pupils are offered the same conceptual material in a concept map format, versus a more normal, non-graphic format, the concept mapping approach would lead to better memorization of the material [28]. Students who use image-based concept mapping performed better than the students who use text-based concept mapping on the cognitive level of understanding and creating [16].

Much research has been conducted in recent years on the question of whether animations or static pictures are superior for learning. Many authors reported benefits of animations [29-31], while many others did not [32-34].

In this work our attempt is that to use Web-based interactive 3D visualization into concept maps as a novel learning, teaching and assessment strategy to more comprehensively represent one's knowledge of a domain, to convey new information to learners and provide formative assessments of student learning.

This tool will permit to fill the gap regarding the use of interactive 3D visualization into concept map for educational purposes derived by our research findings. A such work, but not in the educational context, is that of Van Riel C., Wang Y., and Eliëns A. (2006) [1].

3D interactive visualizations vs 2D visualization

In recent years, animation (with refer to dynamic illustrations, 3D interactive illustrations and 3D interactive animations) is the cutting-edge of today's multimedia learning environments and many media designers seem to be convinced that animations are instructionally more powerful than static pictures. However, the empirical findings are mixed, and we are still at the beginning of understanding under which conditions and why animations can (sometimes) enhance comprehension and learning more than static pictures [35-37]. As overall comparisons between animations and static pictures [37-39] did not lead to consistent results, it seems plausible that different conditions moderate the efficacy of static or dynamic representations, for example the task that is to be learned [40], the course topic [41] and the role of animation. When, for example, the role of animation is representational, that is, when the topic to be learned is explicitly depicted in the animation, an overall superiority of animations over static pictures can be observed [39].

3D visualization can present an object from different perspectives and so enhance 3-D perception, convey procedural knowledge, and demonstrate the dynamics of phenomena. Interactive 3D visualization demonstrates the interactive exploration of objects: learners can interact with objects, look behind or under them and to examine them from different points of view. It is possible to manipulate the characteristics of a picture's dynamics for example manipulating position and/or angle of objects, creating or modifying point of views, zooming into or out of them, hiding/showing parts and examining their cross-sections, adding realistic animations, adding lights or shades and creating high-resolution images [42]. The animation reduce the processing demands necessary for forming a mental model and encoding it into long-term memory. Moreover, animations are often attributed to be especially motivating for learners, which may in turn lead to better learning results [38, 43].

A reason for a possible superiority of static pictures to animations may lie in transitivity: Animations provide not permanent but transient information [43-45] and are therefore "fleeing". Drawing conclusions

from Cognitive Load Theory [46], this transitivity could impose extraneous cognitive load due to temporal limits of working memory, because many visual elements must be held in working memory simultaneously while new elements appear, change or disappear [43]. If the intrinsic load is high (i.e., the topic is difficult and there is few prior knowledge), cognitive overload might occur, and, as a consequence, the learner would profit less from animations than from static pictures.

According to Piaget's learning theory, a person gradually learns from concrete to abstract. Therefore, presenting learners with concrete images is the best means to help them understand the features of an object. In addition, the human mechanism of acquiring, elaborating and communicating knowledge, called perceptive-motory system, involves watching, touching, testing and then imitating or retesting. The only limit to this mechanism is that people can only apply it to visible and tangible objects, such as objects that exist physically [42]. So, interactive 3D visualizations allow the perceptive-motory system to be directly connected to non-physical (not real-world) objects that is, to interactive 3D objects.

On the basis of these studies, we have designed a concept map with two different forms of visualizations, 2D and 3D interactive visualization. The 3D interactive visualization may help learners visualizing a process by providing them with a model ready to be transformed into a mental model, while with the only use of static pictures, the learners have to construct the mental model completely by themselves.

Spatial ability

Individual differences such as prior knowledge and spatial ability can account for different learning results with animations or static pictures. Spatial ability may be defined as the ability to generate, retain, retrieve, and transform well-structured visual images. It is not a unitary construct. There are, in fact, several spatial abilities, each emphasizing different aspects of the process of image generation, storage, retrieval, and transformation. For spatial ability in general, Hegarty (2005) summarizes that, in learning with animations, spatial ability might play the role of an enhancer [38, 47]. In this case learners with high spatial ability might profit from learning with animations, while learners with low spatial ability might not. On the other hand, spatial ability might play the role of a compensator [48, 49]. In this situation learners with low spatial ability might be supported by animations because they are provided with an external representation of a process or procedure that helps them to build an adequate mental model (ability-as-compensator hypothesis) [38]; it should be unequally more difficult to construct such a model by using static pictures [38]. Animations might therefore act as a "cognitive prosthetic" for learners with low spatial ability [50]. Such an expectation is in line with Supplantation Theory proposed by Salomon many years ago, which states that an insufficient ability (spatial ability) can be supplanted by instructional design (the presentation of an animation depicting a dynamic processor procedure) [38]. Höffler (2011) showed the significant influence of spatial ability on the processing of visualizations and identified some moderators of this effect [51]. Though Hays (1996) did not find a statistically significant interaction of spatial ability and instructional design supporting this hypothesis, he showed, at least, that low-spatial-ability participants receiving animations made significantly greater gains than those receiving no animations [38, 52].

In case of animations, a 'ready-made' model which may be easily transferred into a dynamic mental model even by learners with low spatial ability is presented. In case of series of static pictures, different scenes must be connected, and different static elements must be mentally manipulated in order to establish a dynamic mental model; a highly developed spatial ability should help accomplish this task.

In previous studies, often no interaction of spatial ability and type of visualization were found [45, 53]. Therefore, the present paper investigates the role of spatial ability when learning from an instructional animation versus a series of static pictures.

Methodology

Participants

The participants is comprised of a class of 32 second-year engineering students without any previous educational experience in Engineering drawing during their secondary school education. These students attend the Engineering drawing course during one semester. Engineering drawing is an important technical basic course and it is compulsory for all students in the Engineering Faculty. Engineering Drawing is a communication media which is graphic based: it communicates by using simple and exact symbols, as well as conventions with its own procedures and standards. The frustrating discrepancy between the quality and quantity of grades obtained from this course, motivate us to search new approaches of teaching/learning to increase these results.

Materials

Threaded fasteners and connecting part is a normal standard part of the courses of engineering drawing. The main problem faced by the students in learning "Threaded fasteners" is the difficulty in understanding: (a) how to represent (with the right dimensions) clearance holes and threaded hole on an engineering drawing and (b) how to represent fasteners and threads on an engineering drawing. In this subject often learning outcomes are hard to achieve and also difficult to assess. Web-based 3D interactive concept maps could be a new, innovative and effective way of teaching and learning to be employed to motivate students' learning hence lead to more quality achievement.

The concept map is based on the integration of 2D images and interactive 3D objects created using Web3D technologies. The positive impact of Web3D technologies has already been demonstrated in the previous studies [42, 54, 55]. In any case, these technologies offer the possibility of sharing of 3D models of any CAD format, of providing intelligent interpretation tools (3D Pointer, Virtual Folding, Animated Drawing Views) that help the user easily understand and navigate the data and of creating files that can immediately be viewed by anyone with a Windows/Firefox operating system. No additional CAD/CAE software or viewers are required. In addition, Web3D technologies allow to measure distances, to add some other information concerning materials, textures, colours, labels, to turn 3D objects in many ways, creating or modifying point of views, zooming into or out of them, hiding/showing parts and examining their cross-sections, creating realistic animations, adding lights or shades and creating high-resolution images. Web3D technologies have the power to stimulate the search for more extensive information on a subject, a more satisfying solution to a problem, and more generally, a greater number of relationships among various pieces of knowledge or data [42, 56].

The figure 1 shows the 3D interactive concept map we have constructed about the "thread fastener" topic.

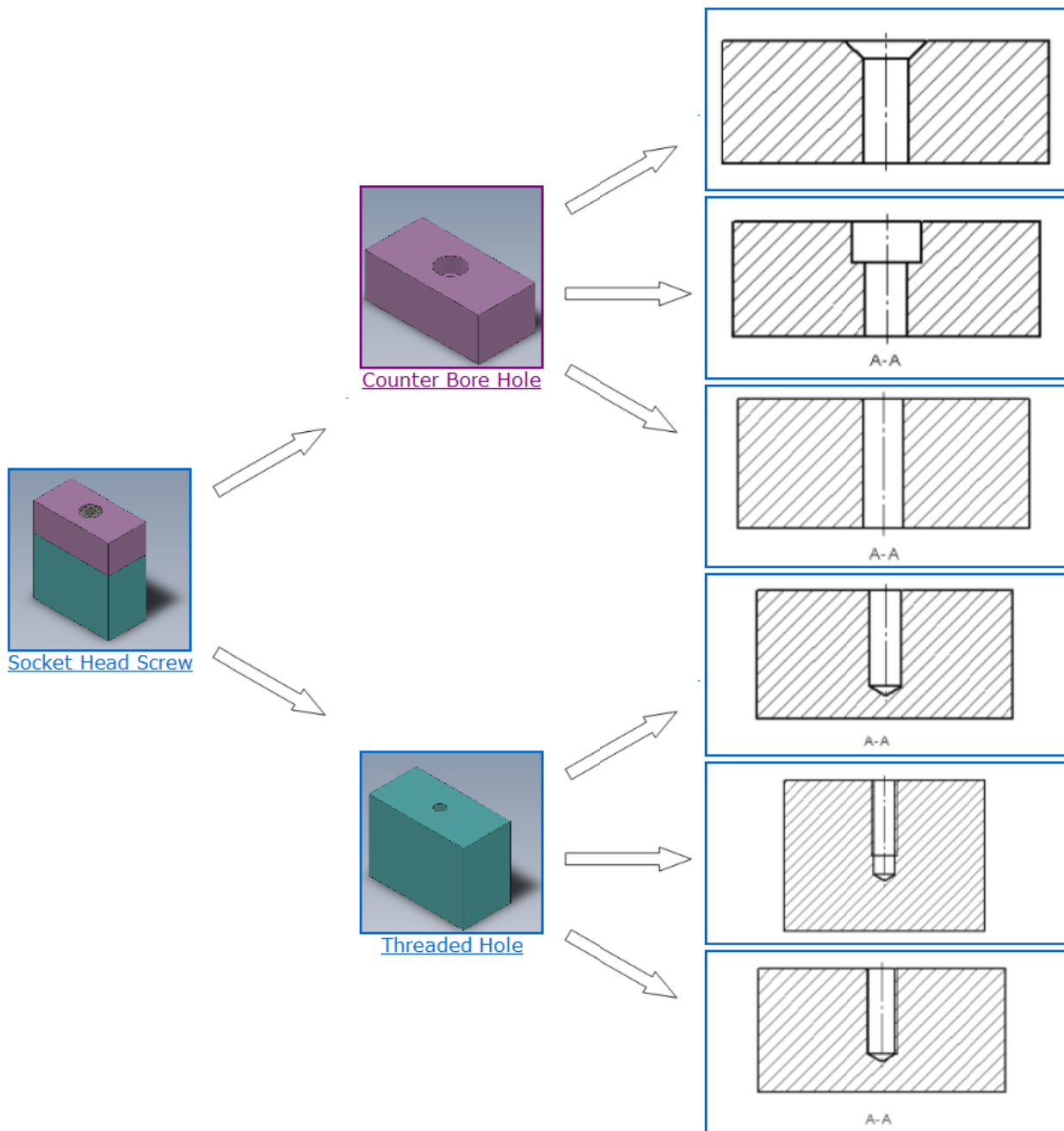


Figure 1 - Web-based 3D interactive concept map

Bolts and screws attach one material with a clearance hole (through, counterbore or countersink hole) to another material with another type of hole (threaded/not threaded hole). The type of hole depends on the type of fasteners used in the assembly (hexagonal bolt, hexagonal head screw, socket head screw, countersunk head screw, stud). In our concept map, each 3D object represents a real-world object and this helps students to visualize the real world situation and assist them in gathering information as well as information processing for better understanding about the problem and its context. The main difficulty of “threaded fasteners” topic is how to correctly associate the hole to the type of fastener and how to correctly represent the hole on an engineering 2D drawing with a simplified representation. The figure 2, 3, 4 show respectively three interactive 3D objects incorporated in our concept map. Specifically, the figure 1 visualizes two parts assembled with a Socket Head Screw, the figure 2 shows the clearance hole present in the upper part and the figure 3 displays the threaded hole present in the inferior part. Thanks to these 3D

interactive visualizations, the students can examine the hole shape present in the superior and inferior part and then, choose the correct 2D representation of each hole.

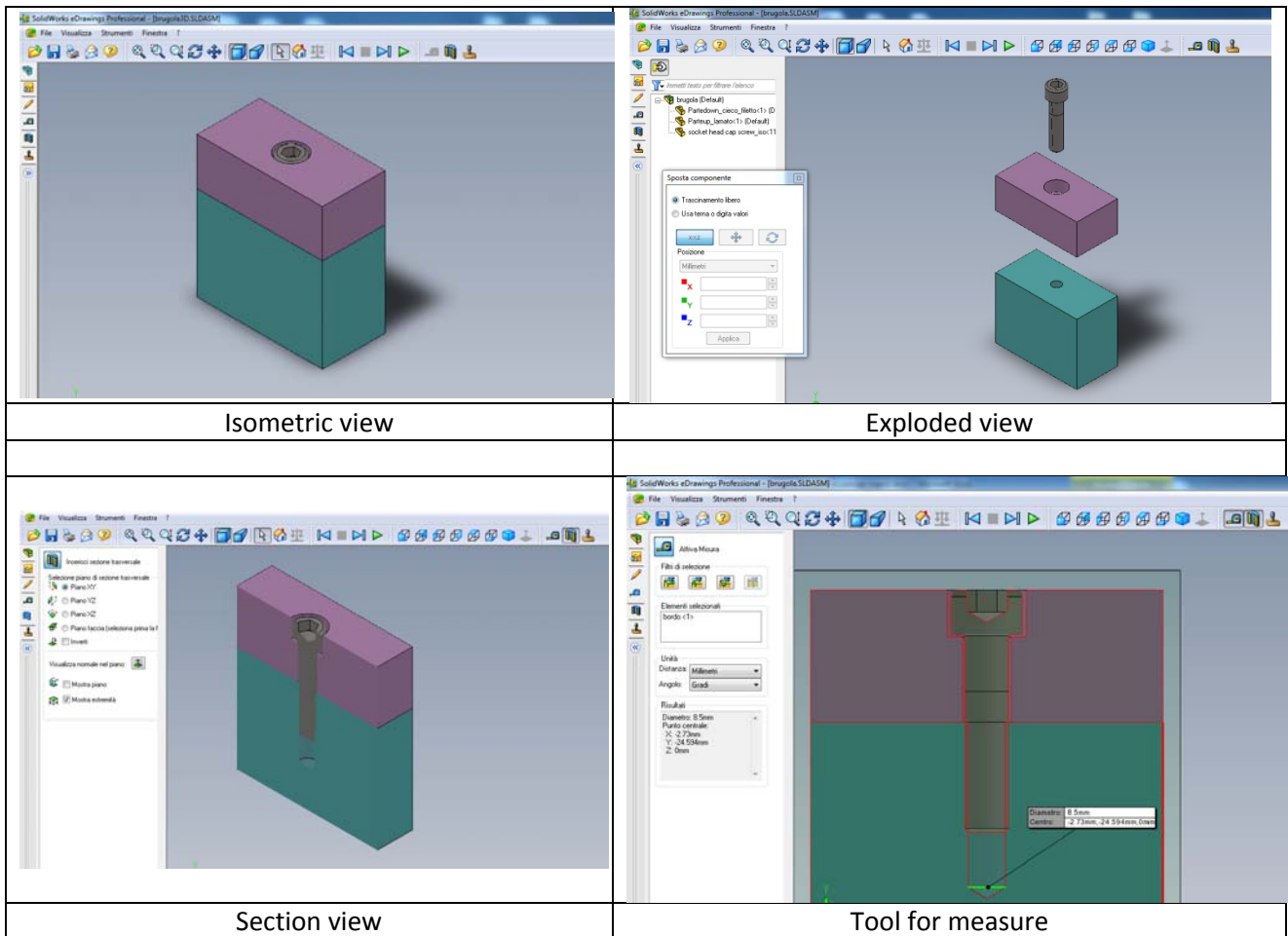


Figure 2 – 3D interactive thread fastener with a Socket Head Screw

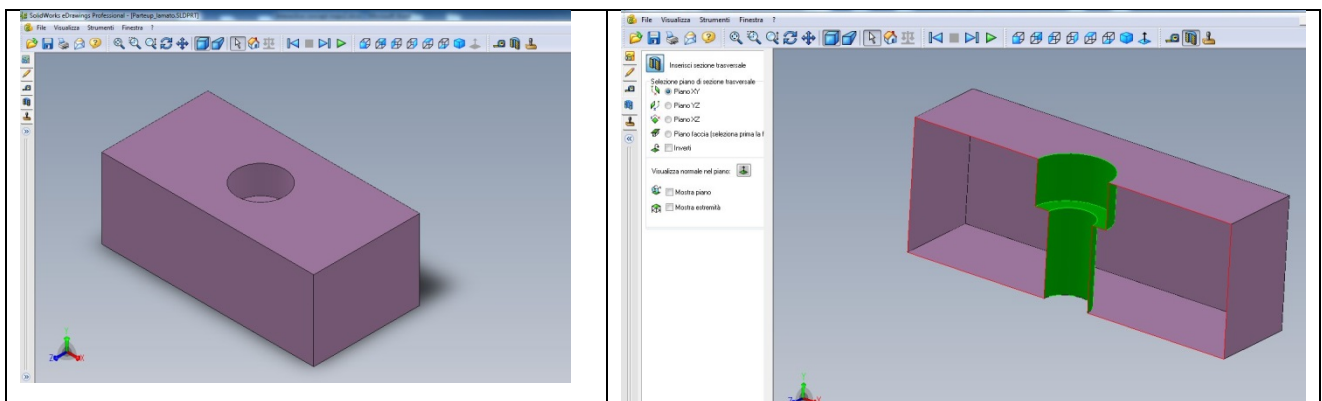


Figure 3 – 3D interactive counterbore hole

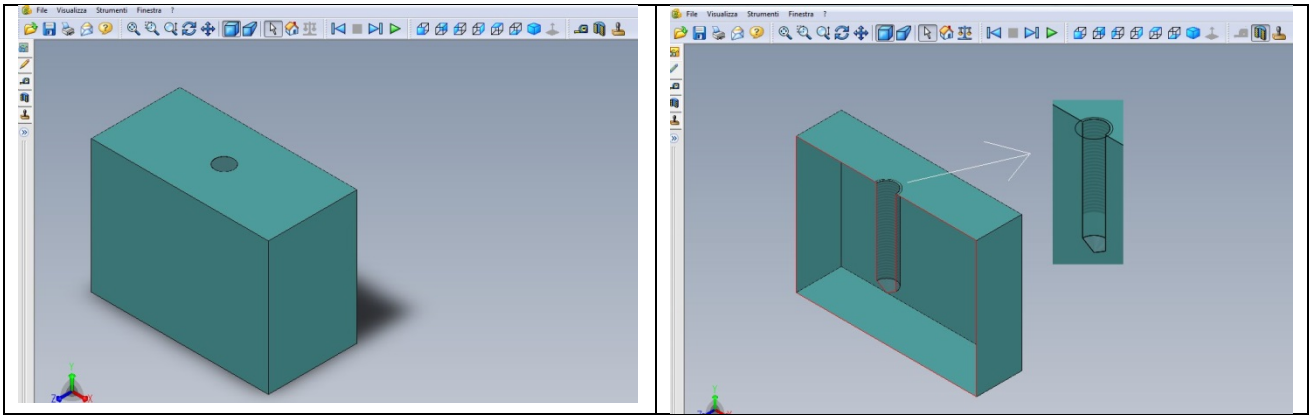


Figure 4 – 3D interactive threaded hole

Procedure

32 students has operated the empirical research. Table 1 shows the participants in the experiment. They were divided into two groups according to their spatial ability measured by the Surface Development test. This test involves giving participants a flat shape with numbered sides and a three-dimensional shape with lettered sides and asking the participants to indicate which numbered side corresponds to which lettered side. The result of the test was that 14 students had high spatial ability and 18 low spatial ability. The first group with high spatial ability was referred to as “High” group while the other group of 16 students was referred to as “Low” group. Both groups were assigned two different type of concept maps (2D concept maps and 3D interactive concept maps) for the learning of the topic “ threaded fasteners”. The 2D concept maps have been obtained from 3D interactive maps by replacing the 3D interactive objects with 2D images.

Table 1 - Participants (n=32)

		Group		Total
		2D concept map	3D concept map	
Spatial ability	High	7	7	14
	low	9	9	18
Total		16	16	32

Results and discussions

After the experiment, two groups were assessed with 10 questions and evaluated on 5-point rating scale. Moreover, the students evaluated the effectiveness of 3D interactive concept map with a Likert-type scale. Most of the students agreed that the new approach were simple to use (Mean=4.58;SD=0.80), stimulated the learning (Mean=4,22;SD=0.75)and facilitated understandingof the topicmaking it more intuitive (Mean=4,44;SD=0,56) and less boring (Mean=4,03;SD=0,65). This remarkable outcome encourages the use of these web-based interactive concept map in educational contexts.

In order to evaluatewhich differences existin learning outcomes between students who use 2D concept map and 3D interactive concept mapand which is the role of the spatial ability in the learning outcomes between the two groups,a two-way analysis of variance (ANOVA) was conducted (table 2).

According to the results of the assessment test at the end of the experimental learning, the effects of the type of map and the spatial ability on the learning outcomes are shown in table 2.

Table 2 – Summary of learning outcomes(median scores) based on “Map” and “Spatial ability” variables

	2DConceptMap	3DConceptMap
High spatialability	49	55
LowSpatialability	40	47

The table 3 shows the results of ANOVA. They indicate that learning outcomes are different in relation to type of concept map used ($F=169 >> F_{crit}=18.51, Pr < 0.05$) and level of spatial ability ($F=289 >> F_{crit}=18.51, Pr < 0.05$).

Table 3 - Two-way ANOVA results

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Type of ConceptMap	1	42.25	42.25	169	0.04887*
Level of Spatial Ability	1	72.25	72.25	289	0.03741*
Residuals	1	0.25	0.25		

The results are in line with the spatial-ability-as compensator hypothesis. High spatial ability helps learners to handle 2D concept maps as well as 3D concept maps, whereas with 2D concept maps, learners with low spatial ability perform worse than with 3D concept maps. In terms of Salomon's Supplantation Theory, high spatial ability can be expected to be able to supplant missing characteristics of the 2D concept map (i.e., the interactivity that helps to build a dynamic mental model), whereas the interactivity can supplant low spatial-ability (i.e., with the interactivity, learners with low spatial-visualization ability learn better). In other words, the external visualization (i.e., the animation) can compensate for lack of internal visualization ability (i.e., spatial-visualization ability). Our findings support the results of Höffler, 2011 and show that some learners (learners low with spatial ability) seemingly learn better with 3D interactive concept map compared to 2D concept map and other learners (those with high spatial ability) learn equally good when provided with static pictures but their results increase with the use of 3D interactive concept map [38].

The importance of the consideration of individual differences when administering different types of visualizations is hence, once again, emphasized. Moreover, the extensive construction of an animation (in contrast to series of static pictures) that takes resources in terms of costs and time may be worth the effort when confronted with learners with low-spatial ability.

Conclusions

Concept mapping is one of the famous chart-based learning strategies to enable formalization and analysis of the process of learning in different educational context. The graphical representation of conceptual knowledge provides a concise and aesthetic format for describing concepts and relationships between them [16]. They allow abstractions, eliminate unnecessary details and allow readers to focus on critical components. The concept of using chart-based learning strategies to engineering drawing learners with different spatial ability could be a suitable way to establish structural knowledge in these learners. The present study suggests that spatial ability plays a crucial, but also rather specific role in learning with web-based 3D interactive concept map and 2D concept map. Web-based 3D interactive concept map can be used to assist students in exploring and discovering concepts, understanding of the abstract and difficult concepts, enhancing student's knowledge and attracting user's attention. The results of this study are in line with the ability as compensator hypothesis: high spatial ability compensates instructional-design

“deficits”, that is, helps to learn with static pictures. Web-based 3D interactive concept maps for learning compensates spatial ability deficits, that is, helps students with low spatial ability to build an effective mental representation of the learning content.

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