Design of web-based interactive 3D concept maps: A preliminary study for an engineering drawing course

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

E.Vezzetti, M. Violante

Dipartimento di Ingegneria Gestionale e della Produzione, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129,Torino, Italy

Tel.: +39 011 5647294; Fax: +39 011 5647299

Abstract

Concept map 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 incorporateweb-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 shows that web-based 3D interactive concept maps compensates 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-knownthe use of visual communication.Research indicates that certain visual languages like concept maps act as a working memory extension and enhancesdirect interpretation of information through pattern detection[1].

Concept maps are representations of concepts and theirinterrelationship that are intended to represent theknowledge structures that humans store in their minds[2].nodes (which represent concepts) and links (whichshow relationship among concepts) are the elements of a concept map. The key concepts are represented in a structure (arranged bynodes and links)that can be hierarchical, cyclic or hybridto [3].Concept mapping has been a subject of investigation forsome time now, and in education, it is atool for research, communication and notably it is a process ofestablishing relationship between concepts.Concept maps can enhance the acquisitionof macro-level ideas[4], improve affective responses to studyingand 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 map has been used as an effective tool both for teaching, learning as well as assessment.Concept mappinghas been successfully used as assessment technique [8-11], as a learning tool to help the students to organize their structured and declarativeknowledge[10, 12-17] as an advancedorganizer[3, 18, 19].As regards the teacher's activity, concept maps also havesome interesting properties. Constructing concept mapsallows teacher to identify the key conceptsand the relationship between them[20]. Many educational contexts had 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 textualinformation only. Considering the recall of information, pictures have a superior effect[24]. The picture’s superiority in explicit memory tasks is due to itsstronger associative perceptual information than that of words[24]. Pictures enable the extraction and

retention of information that readersdo not encode effectively[24]. Pictures highlighting details effectively increased the recall of those details, and picture-depicting relationshipseffectively increased recall of that relational information[24, 27].
So images may complement text-based concept mapping and then play an important rolein improving students' leaning.The ability to incorporate images in concept maps allows users toportray concrete instances of concepts and may provide for a more engaging user experiences [16, 18].Paivio's (1991) work demonstrates that memory of a given material is better when this materialis encoded from different formats[28]. Hence, the dual coding predicts that if pupils are offered thesame 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-basedconcept mapping on the cognitive level of understanding and creating[16].
Much research has been conducted in recent years on the questionof whether animations or static pictures are superiorfor 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 visualizationsvs 2D visualization
In recent years, animation(with refer todynamic illustrations, 3D interactiveillustrations and 3D interactive animations) is the cutting-edge of today'smultimedia learning environments and many media designersseem to be convinced that animations are instructionally morepowerful than static pictures. However, the empirical findingsare mixed, and we are still at the beginning of understandingunder which conditions and why animations can (sometimes) enhancecomprehension 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 differentconditions moderate the efficacy of static or dynamic representations,for example the task that is to belearned [40], the course topic[41]and the role of animation.When,for example,the role of animation is representational, thatis, when the topic to be learned is explicitly depicted in the animation,an overall superiorityof animations over static pictures can be observed[39].
3D visualization can present an object from different perspectivesand so enhance 3-D perception, convey proceduralknowledge, and demonstrate the dynamics of phenomena. Interactive 3D visualization demonstrates the interactive exploration of objects: learners can interact with objects, look behind or underthem and to examine them from different points of view. It is possible to manipulate thecharacteristics of a picture's dynamics for examplemanipulating position and/or angle of objects, creating or modifying point of views, zooming into or out ofthem, 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 isdifficult and there is few prior knowledge), cognitive overloadmight occur, and, as a consequence, the learner would profit lessfrom 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 tangibleobjects, 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.The3D interactive visualizationmay help learners visualizing a processby providing them with a model ready to be transformed into amental model, while with the only use of static pictures, thelearners have to construct the mental model completely by themselves.

Spatial ability

Individual differences such as prior knowledge and spatial ability can account for different learningresults 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 unitaryconstruct. 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 fromlearning with animations, while learners with low spatial abilitymight not. On the other hand,spatial ability might play the role of an 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 learnerswith low spatial ability [50]. Such an expectationis in line with Supplantation Theory proposed by Salomon manyyears 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 statisticallysignificant interaction of spatial ability and instructionaldesign supporting this hypothesis, he showed, at least, thatlow-spatial-ability participants receiving animations made significantlygreater gains than those receiving no animations[38, 52].

In case ofanimations, a 'ready-made' model which may be easilytransferred into a dynamic mental model even by learners withlow spatial abilityis presented. In case of series of static pictures, differentscenes must be connected, and different static elements must bementally manipulated in order to establish a dynamic mental model;a highly developed spatial ability should help accomplish thistask.

In previous studies, often no interaction of spatial ability andtype of visualization were found[45, 53]. Therefore, the present paper investigates the role of spatial abilitywhen learning from an instructional animation versus a seriesof 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 theEngineering Faculty. Engineering Drawing is acommunication media which is graphic based: itcommunicates by using simple and exact symbols,as well as conventions with its own procedures andstandards.Thefrustratingdiscrepancy between the quality and quantity ofgrades 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 mainproblem faced by the students in learning “Threaded fasteners”isthe 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 andlearning to be employed to motivate students’learning hence lead to more quality achievement.

The concept map is based onthe integration of 2D imagesand 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 possibilityof 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 concerningmaterials, textures, colours, labels, to turn 3D objects in many ways,creating or modifying point of views, zooming into or out ofthem, hiding/showing parts and examining their cross-sections,creating realistic animations, adding lights or shades and creatinghigh-resolution images. Web3D technologies have the power to stimulate the search for more extensiveinformation on a subject, a more satisfying solution to a problem, and more generally, agreater 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.

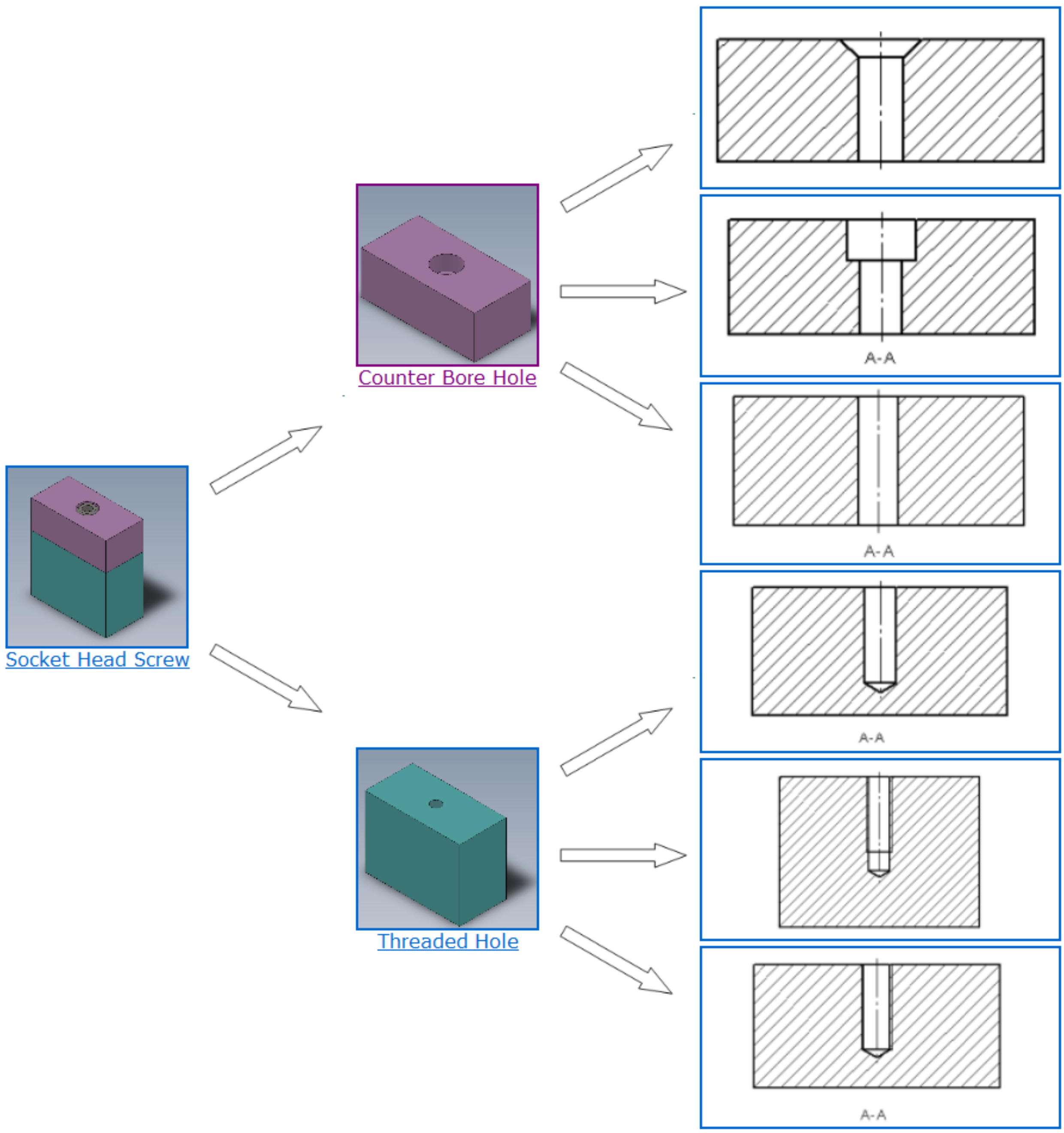

Figure 1 - Web-based 3D interactive concept map

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 fastenersused 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 helpsstudents to visualize the real world situation and assiststhem in gathering information as well as information processing for better understanding about the problem and its context. The main difficult 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 ourconcept map. Specifically, the figure 1 visualizestwo parts assembled with a Socket Head Screw, the figure 2 showsthe clearance hole present in theupper 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 holeshape present in the superior and inferior part and then, choose the correct 2D representation of each hole.

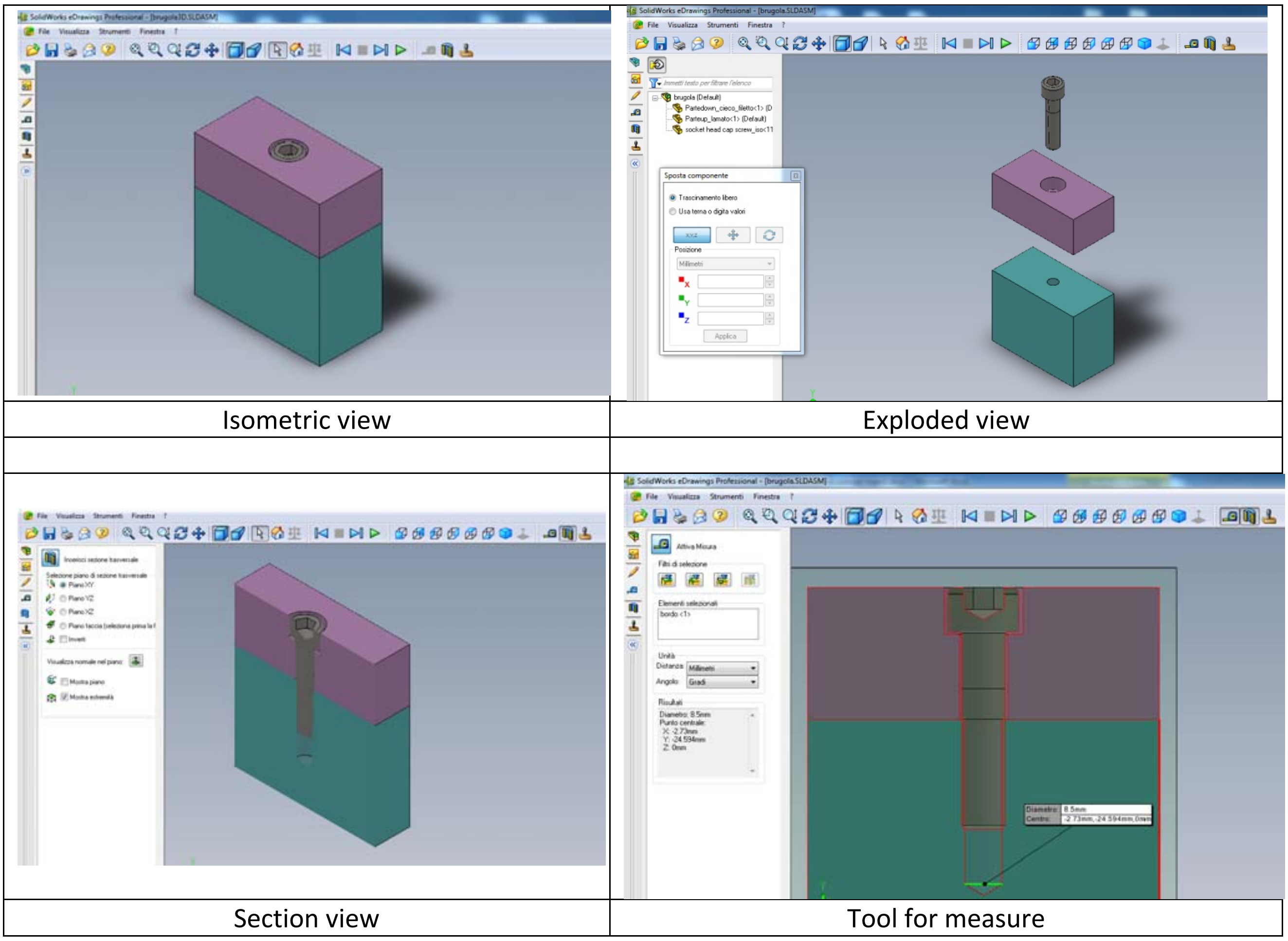

Figure 2 – 3D interactive thread fastener with a Socket Head Screw

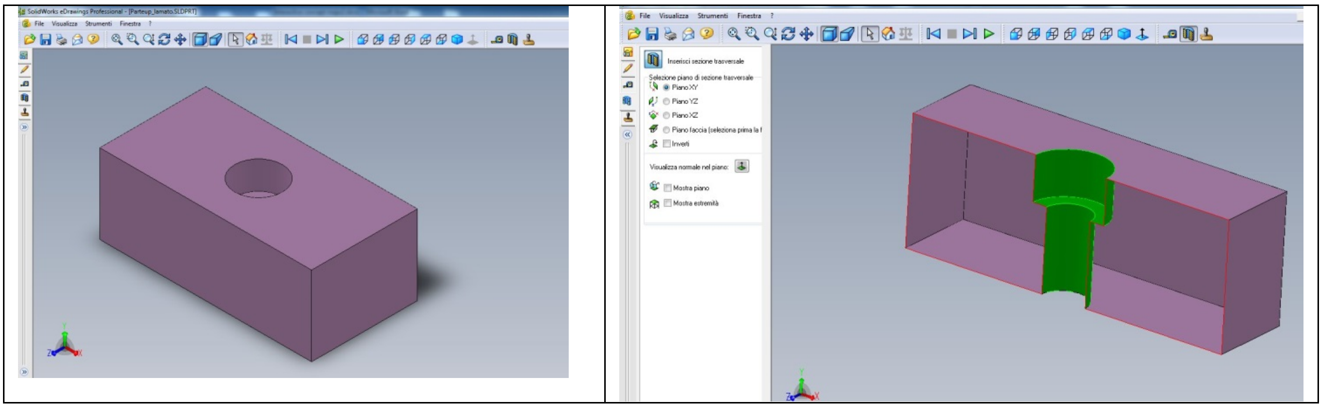

Figure 3 – 3D interactive counterbore hole

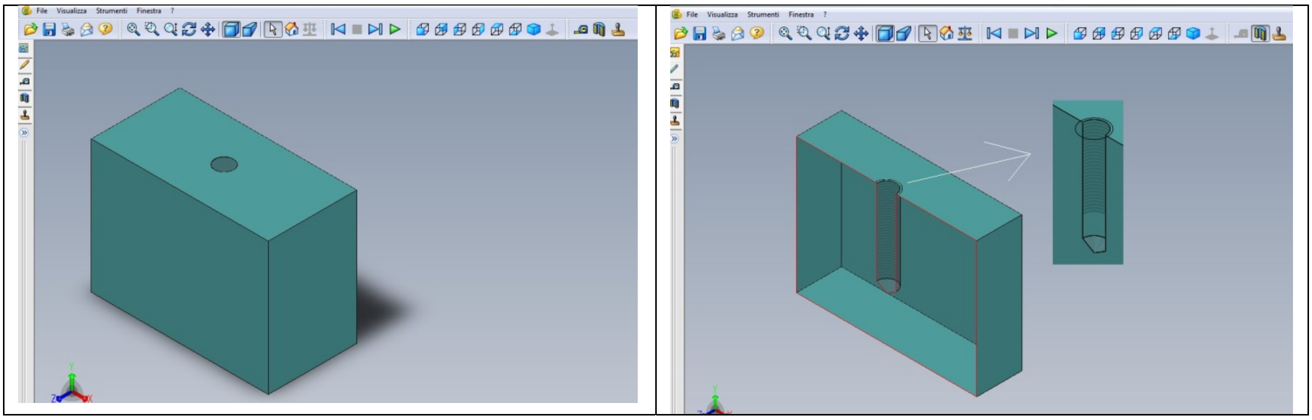

Figure 4 – 3D interactive threaded hole

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 replacingthe 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 outcomesare different in relation to type of concept mapused ($F= 169 >> F_{crit} =18.51, Pr< 0.05$) and level of spatial ability ($F=289 >> F_{crit} =18.51, Pr< 0.05$).

Table 3 - Two-way ANOVAresults

	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-ascompensatorhypothesis. High spatial ability helpslearners to handle 2D concept maps as well as 3D concept maps, whereaswith 2D concept maps, learners with low spatial abilityperform worse than with 3D concept maps. In terms of Salomon's SupplantationTheory, high spatial abilitycan be expected to be able to supplant missing characteristics ofthe 2D concept map (i.e., the interactivity thathelps to build a dynamic mental model), whereas the interactivity can supplant low spatial-ability(i.e., with the interactivity, learners with low spatial-visualizationability 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 andshowthat some learners (learners low with spatial ability) seemingly learnbetter with 3D interactive concept mapcompared to 2D concept map and other learners (those with high spatialability) 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 individualdifferences when administering different types of visualizationsis 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 worththe 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.Thegraphical representation of conceptual knowledge provides a concise and aesthetic format fordescribing concepts and relationships between them [16]. Theyallow abstractions, eliminate unnecessary details and allow readers to focus on critical components. The concept of using chart-basedlearning 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 abilityplays a crucial, butalso 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 anddiscovering concepts, understanding of the abstract and difficultconcepts, enhancing student'sknowledgeand attractinguser'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.

References

1. van Riel, C., Y. Wang, and A. Eliëns, *Concept map as visual interface in 3D Digital Dossiers: implementation and realization of the Music Dossier.* Proceedings of CMC2006, 2006: p. 5-8.
2. Jonassen, D.H., K. Beissner, and M. Yacci, *Structural knowledge: Techniques for representing, conveying, and acquiring structural knowledge.* 1993.
3. Novak, J.D. and D.B. Gowin, *Learning how to learn*. 1984: Cambridge University Press.
4. Tripto, J., O. Assaraf, and M. Amit, *Mapping what they know: Concept maps as an effective tool for assessing students' systems thinking.* American Journal of Operations Research, 2013. **3**: p. 245-258.
5. Hao, J.-X., Y. Yu, and R.C.-W. Kwok, *The Learning Impacts of a Concept Map based Classroom Response System.* 2013.
6. Gürbüz, R., E. Erdem, and S. Fırat, *The Effect of Teaching Mathematics Performed in Cooperative Groups with Computer-Supported Concept Maps on Conceptual Learning.* AWERProcedia Information Technology and Computer Science, 2013. **1**.
7. Chmielewski, T.C. and D.F. Dansereau, *Enhancing the recall of text: Knowledge mapping training promotes implicit transfer.* Journal of Educational Psychology, 1998. **90**(3): p. 407.
8. Constantinou, C., *Concept mapping for performance assessment in physics.* Cognitive Support for Learning: Imagining the Unknown, 2004: p. 155.
9. Fernandez, H., P. Kommers, and M. Asensio, *Conceptual representation for in-depth learning.* Cognitive support for learning, 2004: p. 229-240.
10. Novak, J.D., *Learning, creating, and using knowledge: Concept maps as facilitative tools in schools and corporations*. 2010: Taylor & Francis.
11. Weber, S., *Evaluating structural knowledge with concept mapping.* Cognitive support for learning, 2004: p. 123-136.
12. Gulmans, J., *Mapping for the constructivistic acquisition of concepts?* Cognitive support for learning, 2004: p. 31-45.
13. Jonassen, D.H., *Learning to solve problems: An instructional design guide*. Vol. 6. 2004: John Wiley & Sons.
14. Lumer, J. and M. Hesse, *Concept mapping in the teaching of biology.* Cognitive support for learning, 2004: p. 81-89.
15. Kommers, P.A., *Cognitive support for learning: imagining the unknown*. 2004: IOS Press.
16. Yen, J.-C., C.-Y. Lee, and I.J. Chen, *The effects of image-based concept mapping on the learning outcomes and cognitive processes of mobile learners.* British Journal of Educational Technology, 2012. **43**(2): p. 307-320.
17. Kamble, S. and B. Tembe, *The Effect of Use of Concept Maps on Problem Solving Performance and Attitude in Mechanical Engineering Course.* Procedia-Social and Behavioral Sciences, 2013. **83**: p. 748-754.
18. Novak, J.D., *Concept mapping: A useful tool for science education.* Journal of research in science teaching, 1990. **27**(10): p. 937-949.
19. Willerman, M. and R.A. Mac Harg, *The concept map as an advance organizer.* Journal of Research in Science Teaching, 1991. **28**(8): p. 705-711.
20. Bruillard, E. and G.-L. Baron. *Computer-based concept mapping: a review of a cognitive tool for students*. in *Proceedings of Conference on Educational Uses of Information and Communication Technologies (ICEUT 2000)*. 2000. Publishing House of Electronics Industry Beijing.
21. Star, J.R. and G.J. Stylianides, *Procedural and conceptual knowledge: Exploring the gap between knowledge type and knowledge quality.* Canadian Journal of Science, Mathematics and Technology Education, 2013. **13**(2): p. 169-181.

22. Turns, J., C.J. Atman, and R. Adams, *Concept maps for engineering education: A cognitively motivated tool supporting varied assessment functions.* Education, IEEE Transactions on, 2000. **43**(2): p. 164-173.
23. Morsi, R., W. Ibrahim, and F. Williams. *Concept maps: Development and validation of engineering curricula*. in *Frontiers In Education Conference-Global Engineering: Knowledge Without Borders, Opportunities Without Passports, 2007. FIE'07. 37th Annual*. 2007. IEEE.
24. Korakakis, G., et al., *3D visualization types in multimedia applications for science learning: A case study for 8th grade students in Greece.* Computers & Education, 2009. **52**(2): p. 390-401.
25. Liu, S.-H. and G.-G. Lee, *Using a Concept Map Knowledge Management System to Enhance the Learning of Biology.* Computers & Education, 2013.
26. Jack, G.U., *Concept Mapping and Guided Inquiry as Effective Techniques for Teaching Difficult Concepts in Chemistry: Effect on Students' Academic Achievement.* Journal of Education and Practice, 2013. **4**(5): p. 9-15.
27. Khalil, M.K., et al., *Interactive and dynamic visualizations in teaching and learning of anatomy: A cognitive load perspective.* The Anatomical Record Part B: The New Anatomist, 2005. **286**(1): p. 8-14.
28. Paivio, A., *Dual coding theory: Retrospect and current status.* Canadian Journal of Psychology/Revue canadienne de psychologie, 1991. **45**(3): p. 255.
29. Catrambone, R. and A.F. Seay, *Using animation to help students learn computer algorithms.* Human Factors: The Journal of the Human Factors and Ergonomics Society, 2002. **44**(3): p. 495-511.
30. Spotts, J. and F.M. Dwyer, *The Effect of Computer-Generated Animation on Student Achievement of Different Types of Educational Objectives.* International Journal of Instructional Media, 1996. **23**(4): p. 365-75.
31. Yang, E.-M., et al., *Spatial ability and the impact of visualization/animation on learning electrochemistry.* International Journal of Science Education, 2003. **25**(3): p. 329-349.
32. Lewalter, D., *Cognitive strategies for learning from static and dynamic visuals.* Learning and Instruction, 2003. **13**(2): p. 177-189.
33. Mayer, R.E., et al., *When static media promote active learning: annotated illustrations versus narrated animations in multimedia instruction.* Journal of Experimental Psychology: Applied, 2005. **11**(4): p. 256.
34. Swezey, R.W., R.S. Perez, and J.A. Allen, *Effects of instructional strategy and motion presentation conditions on the acquisition and transfer of electromechanical troubleshooting skill.* Human Factors: The Journal of the Human Factors and Ergonomics Society, 1991. **33**(3): p. 309-323.
35. Rasch, T. and W. Schnotz, *Interactive and non-interactive pictures in multimedia learning environments: Effects on learning outcomes and learning efficiency.* Learning and Instruction, 2009. **19**(5): p. 411-422.
36. Lowe, R. and W. Schnotz, *Learning with animation: Research implications for design*. 2008: Cambridge University Press.
37. Tversky, B., J.B. Morrison, and M. Betrancourt, *Animation: can it facilitate?* International journal of human-computer studies, 2002. **57**(4): p. 247-262.
38. Höffler, T.N. and D. Leutner, *The role of spatial ability in learning from instructional animations–Evidence for an ability-as-compensator hypothesis.* Computers in human behavior, 2011. **27**(1): p. 209-216.
39. Höffler, T.N. and D. Leutner, *Instructional animation versus static pictures: A meta-analysis.* Learning and instruction, 2007. **17**(6): p. 722-738.
40. Ayres, P., et al., *Learning hand manipulative tasks: When instructional animations are superior to equivalent static representations.* Computers in Human Behavior, 2009. **25**(2): p. 348-353.
41. Gero, A. and W. Zoabi, *LONG-TERM EFFECT OF ANIMATION-BASED LEARNING: THE CASE OF ELECTRONIC DEVICES.* INTED2013 Proceedings, 2013: p. 3710-3713.
42. Violante, M.G. and E. Vezzetti, *Implementing a new approach for the design of an e-learning platform in engineering education.* Computer Applications in Engineering Education, 2012.
43. Wu, C.-F. and M.-C. Chiang, *Effectiveness of applying 2D static depictions and 3D animations to orthographic views learning in graphical course.* Computers & Education, 2012.

44. Ainsworth, S. and N. VanLabeke, *Multiple forms of dynamic representation.* Learning and Instruction, 2004. **14**(3): p. 241-255.
45. Hegarty, M., S. Kriz, and C. Cate, *The roles of mental animations and external animations in understanding mechanical systems.* Cognition and Instruction, 2003. **21**(4): p. 209-249.
46. Paas, F., T. van Gog, and J. Sweller, *Cognitive load theory: New conceptualizations, specifications, and integrated research perspectives.* Educational Psychology Review, 2010. **22**(2): p. 115-121.
47. Hegarty, M., *Multimedia learning about physical systems.* The Cambridge handbook of multimedia learning, 2005: p. 447-465.
48. Mayer, R.E., *Multimedia learning.* Psychology of Learning and Motivation, 2002. **41**: p. 85-139.
49. Mayer, R.E. and V.K. Sims, *For whom is a picture worth a thousand words? Extensions of a dual-coding theory of multimedia learning.* Journal of educational psychology, 1994. **86**(3): p. 389.
50. Hegarty, M. and S. Kriz, *Effects of knowledge and spatial ability on learning from animation.* Learning with animation: Research implications for design, 2008: p. 3-29.
51. Höffler, T.N., *Spatial ability: Its influence on learning with visualizations—a meta-analytic review.* Educational psychology review, 2010. **22**(3): p. 245-269.
52. Hays, T.A., *Spatial abilities and the effects of computer animation on short-term and long-term comprehension.* Journal of educational computing research, 1996. **14**(2): p. 139-155.
53. Hari Narayanan, N. and M. Hegarty, *Multimedia design for communication of dynamic information.* International journal of human-computer studies, 2002. **57**(4): p. 279-315.
54. Barbero, B.R., C.M. Pedrosa, and E.G. Maté, *Assessment of 3D Viewers for the Display of Interactive Documents in the Learning of Graphic Engineering.* Educational Technology & Society, 2012. **15**(4): p. 167-180.
55. Hamza-Lup, F.G., et al. *Interactive 3D Web-Based Environments for Online Learning: Case Studies, Technologies and Challenges*. in *Mobile, Hybrid, and On-line Learning, 2009. ELML'09. International Conference on*. 2009. IEEE.
56. Barbero, B.R. and R. García García, *Strategic learning of simulation and functional analysis in the design and assembly of mechanisms with CAD on a professional Master's degree course.* Computer Applications in Engineering Education, 2011. **19**(1): p. 146-160.