

Assessing Mechanical Engineering Undergraduates' Conceptual Knowledge in three dimensional Computer Aided Design (3D CAD)

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Abstract

Research on the relation between conceptual and procedural knowledge has shown that interaction between them will enhance understanding of domain knowledge. Several tools and methods have been developed to assess undergraduates' understanding of conceptual knowledge. In the teaching and learning of CAD, in higher education, there is more emphasis on procedural knowledge. The knowledge is emphasized when generating 3D CAD models with the objective of achieving outcomes of domain subjects, such as technical drawing. Some students might not be aware that there are concepts underlying the procedure they are using. As such students' conceptual knowledge in 3D CAD is as important as their procedural knowledge. The question now arises as to whether the students acquire the conceptual knowledge through a formal and informal learning process in Universiti Teknologi Malaysia (UTM) before they are employed by manufacturing industries. In order to assess their level of 3D CAD conceptual knowledge, capabilities of students should first be explored. This article discusses the concept of developing 3D CAD models, identifies different categories of the concepts and provides assessment method for teaching and learning. It will address the implementation of Concept Map to assess students' conceptual understanding on 3D modeling technique. The use of a concept map as the assessment tool reported here formed part of a larger study. A group of final year Mechanical Engineering students at UTM will be assessed on their understanding of 3D CAD conceptual knowledge. The results of this research would bridge the gap between institutions of higher education and manufacturing industries.

Keywords: Conceptual Knowledge, 3D CAD, Concept Map, Mechanical Engineering

Introduction

CAD software has been the prime tool to support Mechanical Engineering course in higher institutions throughout the world. It was initially used only as a tool to replace hand drawn engineering drawing. Then, as the software and hardware further developed, this has made the systems more affordable and higher institutions started incorporating the system into their curriculum. Extensive use of the system to support teaching and learning in Mechanical Engineering programme materialize as the systems are capable of producing three dimensional virtual objects. 3D models developed by the system are used in teaching engineering design subjects whereby graduates can visualize and present their design ideas. Mechanical Engineering undergraduates at Universiti Teknologi Malaysia (UTM) use the software throughout their years at the faculty. They employ the software in producing engineering drawing at freshmen year, presenting design ideas

during second year of study (introduction to design), presenting and representing design project in Engineering design subject in third year of study and using the software for capstones design project. Learning of these domain subjects utilizes the utilization of this software as supporting tools.

Similarly, other higher institutions also integrate the software to their Mechanical Engineering curriculum. For instance, Hamade et al.(2008) and Garcia et al. (2005) reported that they have CAD subjects in their mechanical engineering curriculum, whereas some other faculties teach them as Engineering Design or Computer Graphics subjects (Sung et al. 2002, Devon 2007, Sorka-Bizon 2007). However, this is not the case in UTM. Knowledge in the use of CAD software are taught along with Engineering drawing subject without any dedicated time for teaching and learning of the software. It is due to the fact that curriculum is packed with engineering sciences and other related domain subjects. Two dimensional CAD software

were initially employed for teaching engineering drawing at the faculty. The system was later upgraded to 3D CAD system as the software and hardware becomes affordable. CAD software is taught in parallel with engineering drawing subject. The undergraduates are taught the principles of engineering drawing and consequently producing the relevant output in the form of CAD generated drawings. Procedures and methods in developing 3D CAD models are explained in dedicated CAD computer laboratory. Engineering drawings are generated from the models and presented to instructors for assessment. This assessment is only based on students' understanding of domain subject matter.

The teaching and learning process in developing the models are primarily focused on procedural knowledge where uses of related commands are emphasized. It is due to the fact that the emphases of the instructors are in assessing students' outcomes in engineering drawing subject. The students are not assessed on their knowledge or skills in developing 3D CAD models. Nevertheless, this is the only experience that the students are formally trained to use the software, where they are required to use the software to solve problems in other domain subjects. This leads to the following study: What is the students' level of understanding on the fundamental concepts in the process of developing 3D CAD models? It will be a significant effort in identifying the possible conceptual knowledge requirements of 3D CAD tasks. Implications from this study will be beneficial to instructors where they can assist students by providing adequate support of model development techniques within product development activity. As Perkins (2007), defined Conceptual knowledge as an understanding of principles governing a domain and interrelation between units of knowledge in a domain.

Related Research in knowledge of CAD

Research on CAD education began when two dimensional version of the software were introduced. Advances of computer software and hardware pushed the 2D CAD technology into 3D CAD capabilities that shift the research to focus on utilization of 3D CAD tools in design and product development process (Wang et al., 2002). Researchers start examining students' skills and capabilities in using the software while producing computer generated engineering models (Hamade and Artail 2008).

Lang et al. (1991) identified knowledge in CAD as declarative and procedural knowledge. They state that declarative knowledge consists of the facts of the situation and would include

knowledge on the object being drawn and knowledge about the particular commands which can be used on particular CAD system. They further elaborated that users should have access to facts about the objects being design such as the mechanical properties of the object, good engineering principles which can be applied to the object, and knowledge about other designs for similar kinds of objects which can be used as a reference for the designed object. In addition, the users must have declarative knowledge about the particular system such as syntax of the commands and the particular commands which can be used. Bhavanani et. al. (2000), explained the meaning of declarative knowledge in CAD as knowing what the software is all about and what it can produce. While Chester (2006), proposed a *declarative command knowledge* which is concerned with specific procedures used by individuals to secure familiar objectives such as extrude and revolve. He states that it is knowledge about the commands or algorithms that are available within 3D CAD.

CAD procedural knowledge as mentioned by Lang et al. (1991) is similar to a subroutine that processes the particular information in the same way each time depending on the situation. They further explain that the strategies or procedures used for CAD tasks should be independent of the CAD platform and this should be usable on virtually any of the machine. Chester (2006), proposed quite similar meaning but in different term as specific procedural command knowledge which is concerned with specific procedures used by individuals to secure familiar objectives such as extrude and revolve

Bhavanani et al. (2000), used the term *command knowledge* which refers to knowledge of the commands (algorithms or tools) and procedures to be adopted by those tools within CAD software. It is related to knowledge of knowing the relevant software command to achieve desired output. Meanwhile Chester (2006), reconceptualized command knowledge as *specific procedural command knowledge* which is the knowledge of how to execute the commands by the system to get desired output. He explains that this knowledge enables the operator to execute the necessary commands within specific CAD software.

Bhavanani et al. (2001) stated that expertise in complex computer applications such as CAD may be differentiated on the basis of 'command' and 'strategic' knowledge with expert employing greater amounts of the later knowledge. He explained that strategic knowledge is concerned with knowledge of the alternative methods by which specific tasks may be achieved and the process by which a choice may be made. Chester (2006), refers to strategic knowledge as the

knowledge necessary to choose and apply the appropriate command knowledge in a manner that efficiently produces model and allows future design variation.

As CAD system becomes more complicated and various methods of developing virtual models emerged, essentials concepts on how to develop the models need to be recognized. Thus apart from procedural knowledge, conceptual knowledge is also essential. However, there has been little study of conceptual knowledge in 3D CAD modeling and the emerging requirements of the knowledge. Therefore, this research introduces conceptual knowledge in 3D CAD modeling. The advantages of understanding this type of knowledge, according to Tabaran et al. (2007), are longer-term retention of information due to more elaborated cognitive representation of the knowledge, and the ability to transfer the knowledge to novel situation because the knowledge is not tied to specific rote situations and procedures. Adopting such a perspective, fundamental concepts in developing 3D CAD models will be addressed, specifically in Mechanical Engineering domain.

Concepts of Model Construction in 3D CAD

Construction of 3D CAD models involved numerous steps that the user should understand as it is concerned with the development in virtual environment. The models are developed by understanding and employing set of concepts along with utilizing the right command of the software. Basically, general shapes of the models are initially identified. Then, two dimensional projection profiles are drawn on a construction plane (or working plane) for the formation of basic structure or part of the model to be drawn. Applying suitable procedures to the profile will produce a basic feature of a model to be drawn. This semi-completed model is then further developed by adding desired features. The model and their associated features can be modified or manipulated by using appropriate procedures. Combinations of models or parts are then assembled to form complete assembly visualization. Mechanical engineers use these virtually assembled products for the purpose of evaluating and examining design ideas. The models can also be utilized by other downstream activities.

Conceptual Knowledge and 3D CAD

Conceptual knowledge is defined by Groth and Bergner (2006) as a connected web of knowledge; a cognitive network in which relations between nodes are as important as the discrete

pieces of information constituting these nodes. While Bloom defined conceptual knowledge as the interrelationships among the basic elements within a larger structure that enable them to function together. In the case of 3D CAD, the technology itself has become more complicated by having various modeling techniques with different capabilities to carry out different functions. Knowledge in the interrelationships of this technology within and between them is important as the systems are nowadays being used as essential tools in product development process. According to Hiebert and Lefevre (1986), this knowledge is needed to identify problems and generate new strategies or adapt known strategies to solve original problems.

Constructivism and *Schemata* are two important ideas that underpin learning issues in relation to conceptual knowledge (McCormick, 1997). Constructivisms in 3D CAD focus upon individuals building up representation of their understanding of the systems' model development process. Students gradually developing their understanding of model development process by initially building up basic models of part to a more complicated model structure, and eventually form complete assembled models. They will attempt to fit their understanding of the concepts during model development process. Prior conceptual knowledge is essential during this process as it develops over time.

Schemata described by cognitive psychologists as the knowledge structures that exist in students' memory which they construct from experience and instruction (McCormick, 1997). Students were generally taught how to develop basic 3D CAD models in computer laboratory by means of some command and procedural knowledge. They are further required to develop complete models as an exercise. Requirements of related domain subjects such as engineering design to produce and present design ideas using CAD models generate deeper understanding of the system. Some students may even develop their own models out of interest by acquiring knowledge through their peers or the internet. Through these experiences that their concepts of model development process were constructed that structured within their engineering domain.

In mathematic education, research has shown that understanding concepts of domain subject may enhance procedural knowledge and performance (Rittle-Johnson et al. 2001, Nevin Mahir 2008). It helps students to identify key features in a problem based situation. Students' understanding of the domain subject would improve in a sense that they can determine or identify problems and subsequently produce successful

solution (Hiebert and Lefevre, 1986). According to Fisher and his colleagues (1993) effective problem solving is closely associated with concept learning, making inferences and categorization, which represent distinct components of engineering skill. Tabaran et al. (2007) stated that conceptual and procedural knowledge are two mutually-supportive factors associated with the development of engineering skill. McCormick (1997) explained that conceptual knowledge consists of ideas that give some power to think about technological activity.

Concept Map for the assessment of Conceptual Knowledge

Concept maps visually represent students' knowledge structures and meanings in a particular knowledge domain (Jonassen and Merra, 1994). It was initially introduced by Novak and Gowin (1985) to represent how students linked hierarchical material together in the domain of biology. According to Nicoll (2001), the use of concept mapping is becoming an increasingly important technique for analyzing student understanding in other disciplines. He further explain that concept maps are built by placing terms, which represent the concepts to be mapped, in structures called nodes. The nodes are then linked together into propositions to show how students connect or link the concepts.

This research is intended to have a better understanding of how Mechanical Engineering undergraduates represent their 3D CAD knowledge structure in relation to their domain using concept map. According to Biggs and Tang, (2007) the map can serve as an indication of how the student sees the way in which individual concepts relate to each other and how it presents an overall picture, a holistic representation of a complex conceptual structure. It provides rich insights into organization and cognitive structure (Kinchin et al., 2000; Hay and Kinchin, 2006). Zele and his colleagues (2004) explained that a concept map represents a person's structural knowledge about a certain concept or subject. They further explained that a qualitative analysis of the data, presented more informative and complete picture of students' understanding. Upadhyay et al.(2007) reported that concept map methodology has been integrated successfully to develop a visual pattern of structure of various pre-identified concept elements for a quality engineering education. Application of the method help decision-makers, planners and administrators understand the necessary linkages in the complex and co-evolving system of engineering education.

Categories of 3D CAD Conceptual Knowledge

In order to identify essentials concepts of 3D CAD in mechanical engineering domain, categories of concepts are developed for this study. The research classifies the conceptual knowledge into five major categories: Model Creation, Manipulation, Exploratory Visualization, Model Transfer and Collaboration. The following explains the meaning of each category:

- Concepts of 3D CAD *Model creation* process. Understanding of the system models creation techniques to develop models in virtual environment.
- Concepts to *manipulate* modeled object to produce alternatives and preferred solution. Knowledge on the systems' capabilities that facilitate variations to be explored would enhance creativity and support problem solving activity.
- Concepts to *Visually Explore* models during the process of models development. This knowledge would enhance models creation process by assisting the users to visually navigate through complex models structure.
- Concepts to share data (*model transfer*) for the purpose of obtaining the desired output. Understanding availability of this function to perform proper data exchange across various platforms or downstream requirements.
- Concepts of *collaboration* in model development process. Understanding or recognize that internet and intranet technology has transformed the system to facilitate concurrent engineering in product development process.

In order to further develop this conceptual model, we need to operationalize and define the categories. Each category is discussed next in detail.

Model Creation

In 3D CAD, modeling activity usually starts with defining datum or construction plane that serves as the base plane to create the base profile. The construction of the base profile utilizes geometric entities, such as lines, arcs, splines, which are drawn as vectors in a single open or closed profile that will form base part (Silva et al., 2002). Constraints are added at this point to the profile if parametric modeling is chosen for the modeling techniques. Further development on the models' subpart are constructed by employing the same part creation sequence through creating and positioning the construction plane at appropriate location. The user can add features to the parts'

features. Completed model are treated as a single part in assembly modeling and additional parts can be further developed either in the same or separate files. In addition standard engineering part can also be constructed through third party software or special programming script by specifying required parameter. These parts are then assembled using suitable software's specific command procedures. Models are regularly rotated and positioned in preferred location during the development process to assist interaction between the user and the models. Items associated with this category are as listed in Table 1.

Manipulation

Manipulation is a modeling activity which variations on the models is developed (Baba et al., 1998). The models is manipulated by means of modifying their geometry or features. Making use of the systems' facilities has great potential on reducing design time and design mistakes, enhancing consistency and ease of documentation. Acquiring this knowledge gives the advantage by reducing the amount of time spend modifying designs ideas, subsequently helping design to manufacture more quickly (Wang et al. 2008). Any change made on any part or assembly is automatically generated in all associated parts and drawing sheet, so that all the related files will simultaneously been changed as the main part is being manipulated. Items for this category are as listed in Table 1.

Exploratory Visualization

Understanding of CAD systems' visualization facilities would help users to speed up model development process (Fitzmaurice et al., 2008). It is necessary for the user to be able to navigate through simple or complex models structure such that features can be added or modified to form complete object (Jong et al. 2008). For instance, users can make use of feature manager to select directly desired entities in a complex model structure which would enable users to speed up modifying or correcting unintentional error. Concepts included in this category are as listed in Table 1.

Data Transfer

Understanding and knowing data transfer in 3D CAD models development process is essential to every CAD users as created models are used for downstream applications (Kim et al., 2008; Pratt et al. 2001). The process of developing the models should include the needs of other users.

Models would not be useful if it cannot be transferred to another platform. For example, related software system could not read the data due to inappropriate use of geometry or topology to develop a 3D model. Therefore, it is important to develop models that can be in greater use throughout the organization. Table 1, illustrate essential concepts for to this category.

Collaboration

The framework of collaborative CAD in product development facilitates creation of a hierarchical product structure, with single and compound components by assigning tasks to team members (Janardanan et al. 2008). Each team member can have his own specific view on the product which is kept consistent by using a central product model. The actual design of a single component is supported by a web-client specialized in part design, whereas the specification of assembly relations among components is supported by a web-client specialized in assembly design (Bidarra et al. 2002). Some commercial CAD systems are incorporating functionality for multi-user facilities using client-server architecture in collaborative modeling. Items related to this category are as shown in Table 1.

Method

The participants of this study were 33 final year Mechanical Engineering undergraduates from UTM. All of the participants are studying Mechanical Engineering as their domain courses without any specific subjects on CAD or CAM. Procedures for Concept map assessment test were based on steps proposed by Ruiz-Primo et al. (2001). Students were taught the basic structure and classifications of concept map the first twenty minutes followed by a simple exercise. They were asked to develop a simple concept map as an exercise such that they are familiar with the method. The students were then provided with a sheet of A3 paper with the following instruction printed along the top edge of the page: "What do you know about three dimensional Computer Aided Design (3D CAD)?" Five categories of the conceptual knowledge were labelled along 3D CAD word with linking lines. No propositions were labelled along these lines. A set of essential concepts randomly arranged in A4 page was attached to the sheet. The total number of listed items for each category is as shown in Table 1. This list of concepts was given such that their internal knowledge representation would converge as

anticipated by the researcher. The tasks were administered in a normal lecture day for the duration of thirty minutes. Most students only come across the construction of concepts maps once the researcher introduces it.

Scoring Method

A criterion from Blooms' (1956) characterization of conceptual knowledge which was reported by Nightingle et al. (2007) was used to form the basis of the assessment. The assessment criteria are on the understanding of items

		Concepts/Items	Total No. of Items
Categories of 3D CAD Conceptual Knowledge	1. 3D CAD Model Creation	1. Drawing 2. Parts 3. Assembly 4. Modeling Techniques 5. Geometrical Entities 6. Reference plane 7. Sketch profile 8. Free form geometry 9. Surface creation methods 10. Rules for the creation of surface 11. Models Translation and Rotation 12. Model position and orientation 13. Parametric Layout to capture design intent 14. Standard parts in assembly modeling 15. Programming	15
	2. Manipulation of Modeled Object	1. Sub-model 2. Engineering Drawing 3. Dress-up features 4. Connections of edges 5. Level of model manipulation 6. Manipulation of non-geometric entities 7. Parent-child relationship 8. Perform design changes 9. Exploration of design	9
	3. Exploratory Visualization	1. Model viewpoint 2. Switching between 2D and 3D mode 3. Appearance of surface 4. Interaction with geometric entities 5. Producing 3D CAD layout 6. Visualizing features 7. Models hierarchies 8. Features manager 9. Navigation 10. Expand and Collapse	10
	4. Model Transfer	1. Handling of geometric and non-geometrical entities 2. Different CAD platform 3. Data throughout company 4. Data to related company 5. Data as communication with consumers 6. Data as design review 7. Data as design verification 8. Data as illustration 9. Data as sharing of design	9
	5. Collaboration	1. Formal design report 2. Visual output 3. Reverse engineering 4. Use of internet 5. Concurrent engineering 6. Implement Real-time design 7. Perform on-line design 8. Design activity of different time zones	8

Table 1. List of items in each category.

classification, formation of logical conceptual *model* and the *structure* of the items forming the model. Briefly, maps were scored with the following point assignment for each valid component:

- item links to categories (1 point each)
- 3 connected items forming logical conceptual model (3 point each)
- logical structure of the model (3 point each)

This marking scheme is used to measure students' understanding of components of conceptual knowledge categories as described in previous section. A table of scored marks for each student was established to identify their level of knowledge. The table consists of criteria of conceptual knowledge at one end (Classifications, Models, Structure) against the knowledge categories (Model Creation, Manipulation, Exploratory Visualization, Model Transfer and Collaboration). All the data were then statistically examined and analyzed y using SPSS version 13.

Results of Study

The purpose of this study was to examine students' understanding of 3D CAD modeling techniques through the construction of concept maps. Scoring procedures were applied to assess the relationship of the students' concept maps to a reference map developed by the researchers. The data set used here is the outcome of concept map scores outlined previously (n = 33). Descriptive statistics were used to describe distribution of Scores. The data were also assessed for normality and nonparametric means of Spearman's rho and Friedman's test were used for skewed distribution in comparisons of the scores.

There are three criteria in this dataset that address undergraduates' conceptual knowledge: score on Classifications (scale), score on developed Models (scale) and score on the models' structure (scale). Preliminary examination on the concept maps reveals that majority of the students were

unable to construct logical structured models of the concepts as most of the items were drawn in a chain like connections. The connections were drawn

without any linking words in almost all the maps. Initial investigation of the data indicates that all five categories of the conceptual knowledge received

		Criteria of Conceptual Knowledge											
		Classification				Models				Structure			
		Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum
Attributes Of Conceptual Knowledge	Model Creation	3.90	1.86	.00	8.00	.73	1.51	.00	6.00	.52	1.15	.00	4.00
	Manipulation	1.94	1.27	.00	6.00	.00	.00	.00	.00	.00	.00	.00	.00
	Exploratory Visualization	1.33	.92	.00	3.00	.00	.00	.00	.00	.00	.00	.00	.00
	Model Transfer	.38	.66	.00	2.00	.00	.00	.00	.00	.00	.00	.00	.00
	Collaboration	1.39	.92	.00	3.00	.48	1.56	.00	8.00	.30	1.05	.00	5.00

Table 2. Descriptive statistics of the concept map scores.

low or zero scores for all the criteria, as illustrated in Table 2. Criteria for classification demonstrate some variation of scores for all the categories. Therefore, only results of this criteria will be presented in the following section.

Further analysis on classification criteria were carried to give an impression of the diversity within the group of students. The relative frequencies of the criteria were tested for normality with Kolmogorov-Smirnov procedure. All the attributes were found to be not normally distributed, however attribute of Model Creation is fairly close to a normal distribution. This give an impression that most of the students only being able to classify the items into this variable, which indicates that the students were only familiar with concepts of developing 3D CAD models within the boundary of a single basic CAD system. The highest score in this category is 8 with a mean of 3.90 and a standard deviation 1.86. Figure 1 shows the frequency distribution of this variable. Other variables show distribution of scores skewed (i.e. positively skewed) toward the low end of the scale.

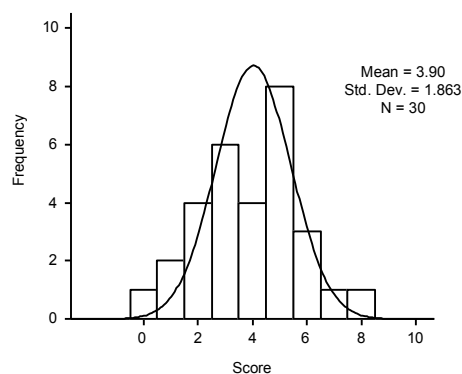


Figure 1. Frequency distribution for Model Creation.

The frequencies of the various categories of classification criteria were determined in order to give an impression of the diversity within the students. Figure 2 shows the cumulative percentage distribution of classification criteria. From the chart it was found that the scores of all the attributes were evenly distributed at low marks. More than three quarter of the students' scored below 3 for all the attributes except for the category of model creation.

This indicates that students tend to understand more concepts or items for models creation compared with the other attributes. They were inclined to utilize all available items for this category. This suggested that they are quite comfortable utilizing the software only to achieve desired objectives. In other word, they still regard the system as basic supporting tools in their own domain subjects.

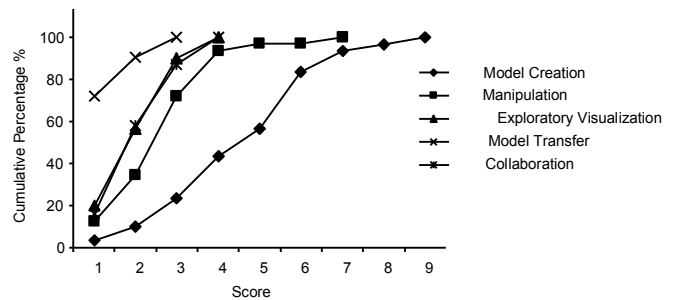


Figure 2. Cumulative Percentage of scores.

Non parametric test of the variables revealed that the correlation between Manipulation and Collaboration was found to be significant (Spearman's rho=0.096, n=30, p=0.049). This monotonic relationship means that the two variables are associated but only in a general sense. It give insight that the students did not understand the meaning of manipulation by not manipulating modeled object for the purpose of finding alternatives and they did not have any ideas on how to develop CAD models collaboratively.

Friedman's test for comparison of scores resulted in $\chi^2(3) = 63.61$ and $p < 0.001$. The lowest score was *Model Transfer*. Multiple comparisons indicate that there was no significant difference of scores in *Model Creation* and *Model Transfer*, but there were significant difference between *Manipulation* and *Exploratory Visualization*, *Manipulation* and *Collaboration*, and *Exploratory Visualization* and *Collaboration*. This gives an indication that the students appreciate the items used in *Model Creation* and *Model Transfer*, but not in the other variables. The result indicates that there are some patterns of students' understanding of the software which will be further investigated.

Discussions

This study explains how concept map might be used to explore students' understanding of essential concepts in 3D CAD. Initial results of the map have provided the researcher understanding of the undergraduates' knowledge structure about the software. The results have shown a relatively low understanding of 3D CAD modeling within their own domain area. Understandings of the concepts are found to be scattered across multiple components of the knowledge. Further investigation of the constructed concept maps reveals that the students were unable to form logical structured models of the concepts.

Supplementary items/concepts which were made accessible by providing students with a random list of crucial concepts have proved to assist evaluators to investigate certain aspects of domain subject appropriately. Structural elements, generated by a numerical analysis of generated map were found to create important qualitative data about how the students construct their understanding of anticipated concepts. The maps also provide manageable means of generating qualitative data about 3D CAD abstract concepts. The results point out what the students know about

References

- Baba, Y., and Nobeoka, K. (1998). Towards knowledge-based product development: The 3D CAD model of knowledge creation. *Research Policy*, Vol. 26, Issue 6, pp.643-659.
- Bhavnani, S. K. (2000). Design conducive to the use of efficient strategies. *Symposium on designing interactive systems*. USA.
- Bhavnani, S. K., Garrett, J. H., and Shaw, D.S. (1993). Leading Indicators of CAD Experiences. *CAAD Futures*, pp 313-334.
- Bhavnani, S. K., John, B. E., and Flemming, U. (1999). The strategic knowledge use of CAD: An empirically inspired Theory-Base course. *Proceedings of CHI*, pp.42-49.
- Bhavnani, S. K., Reif, F. and John, B. E. (2001). Beyond Command knowledge: Identifying and Teaching Strategic Knowledge for Complex computer applications, *Proceedings of CHI*, pp.229-236.
- Bidarra, R., Kranendonk N., Noort A., Bronsvort W. F. (2002). A Collaborative Framework for Integrated Part and Assembly Modeling.

3D CAD and how they construct the knowledge in their learning experiences. These insights are useful for educators to introduce conceptual knowledge within the systems' procedural, command or strategic knowledge while delivering instruction to students.

This study is largely explanatory, attempting to build foundation on which to base more comprehensive investigations with larger student samples for future work. A more complete picture of each student's understanding might emerge by incorporating aspects such as the shortcomings and considering the content and structure of the concept map. It will assist researchers to comprehend potential misconception about the utilization of software within a specific domain.

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Transactions of the ASME, Vol. 2, Issue 4, pp. 256-264.

Biggs, J. and Tang, C. (2007). *Teaching for Quality Learning at University, What the Student Does*. Third Edition, McGraw-Hill Education.

Bloom, B., Englehart, M. Furst, E., Hill, W., & Krathwohl, D. (1956). *Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain*. New York, Toronto: Longmans.

Chester, I. (2007). Teaching for CAD expertise. *International Journal of Technology and Design Education*, 17(1):23-35.

Devon, R., Okudan, G., Nguyen, H., Gordon, A., Bilen, S., Wa, X., and Sathianathan, D. (2007). Decision making models for choosing CAD software. *World Transaction on Engineering and Technology Education*, Vol. 6, No.2.

Fitzmaurice, G., Matejka, J., Mordatch, I., Khan, A., and Kurtenbach, G. (2008). Safe 3D Navigation. *Symposium on Interactive 3D*:

Proceedings of the 2008 symposium on Interactive 3D graphics and games, Redwood City, California.

Garcia, R. R., Santos, R. G., Quiros, J. S., and Penin, P. A. (2005). Present state of CAD teaching in Spanish universities. *Computers & Education*, Vol. 44, Issue 3, pp. 201-215.

Groth, R. E., & Bergner, J. A. (2006). Preservice elementary teachers' conceptual and procedural knowledge of mean, median and mode. *Mathematical Thinking and Learning*, 8(1), 37–63.

Hamade, R. F., and Artail H. A. (2008). A study of the influence of technical attributes of beginner CAD users on their performance. *Computer Aided Design*, 40, pp. 262-272.

Hay, D. and Kinchin, I. M. (2006). Using concept maps to reveal conceptual typologies. *Education + Training*. Vol. 48, pp. 79-83.

Hay, D. and Kinchin, I. M. (2008). Using concept mapping to measure learning quality. *Education + Training*, Vol. 50, No. 2, pp. 167-182.

Hiebert, J., & Lefevre, P. (1986). Conceptual and procedural knowledge in mathematics: An introductory analysis. In J. Hiebert (Ed.), *Conceptual and procedural knowledge: the case of mathematics*, (pp. 1–28). Hillsdale, NJ: Erlbaum.

Jonassen, D. H., and Marra, R. M. (1994). Concept Mapping and other formalisms as mindtools for representing knowledge. *ALT-J Research in Learning Technology*, Vol. 2, Issue 1, pp.50-56.

Jong, W. R., Wu, C. H., Lin, H. H., and Li, M. Y. (2008). A collaborative navigation system for concurrent mold design. *The international Journal of Advanced Manufacturing Technology*, Vol. 40, No. 3-4.

Kim, J., Pratt, M., J., Iyer, R. G., and Sriram, R. D. (2008). Standardized data exchange of CAD models with design intent. *Computer-Aided Design*, Vol. 40, pp. 760–777.

Kinchin, I. M., Hay, D. B. and Adams, A. (2000). How a qualitative approach to concept map analysis can be used to aid learning by illustrating patterns of conceptual development. *Educational Research*, Vol. 42, No. 1, pp. 43-57.

Lang, G. T., Eberts, R. E., Gabel, M. G., Barash, M. M. (1991), Extracting and Using Procedural Knowledge in a CAD Task. *IEEE Transaction on Engineering Management*, IEEE, 38(3).

Mahir, N. (2008). Conceptual and procedural performance of undergraduate students in

Integration. *International Journal of Mathematical Education in Science and Technology*, pp.1–11.

McCormick, R. (1997). Conceptual and Procedural Knowledge. *International Journal of Technology and Design Education*, Vol. 7, pp. 141-159.

McCormick, R. (2004). Issues of Learning and Knowledge in Technology Education. *International Journal of Technology and Design Education*, Vol. 14, pp. 21–44.

Miller, R. L., Streveler, R. A., Olds, B.M., Chi, M. T. H., Nelson, M. A., and Giest, M. R. (2006). Misconceptions about Rate Processes: Preliminary Evidence for the importance of Emergent Conceptual Schemas in Thermal and Transport Sciences. *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, Chicago, IL.

Nicoll, G. (2001). A three-tier systems for assessing concept map links: A methodological study. *International Journal of Science Education*, Vol. 23, Issue 8, pp.863-875.

Nightingale, S., Carew, A., and Fung, J. (2007). Application of Constructive Alignment Principles to Engineering Education: Have we really changed? *Proceedings of AaeE Conference*, Melbourne.

Pratt, M. J., and Anderson, B. D. (2001). A shape modelling applications programming interface for the STEP standard. *Computer-Aided Design*, Vol. 33, pp. 531-543.

Rittle-Johnson, B, Seigler, R. S., and Alibali, M. W. (2001). Developing conceptual understanding and procedural skill in mathematics: An iterative process. *Journal of Educational Psychology*, 93, (2), 346-62.

Sorka-Bizon, M. (2007). Geometry and Engineering graphics in engineering education illustrated by example of advanced 3D modeling course. *International conference in Engineering Education*, Coimbra, Portugal.

Sung, W. T., and Ou, S. C. (2002). Web-based learning in the Computer-Aided Design curriculum. *Journal of Computer Assisted Learning*, Vol. 18, pp. 175-187.

Taraban, R., DeFinis, A., Brown A. G., Anderson E., E., and Sharma, M. P. (2007). A Paradigm for Assessing Conceptual and Procedural Knowledge in Engineering Students. *Journal of Engineering Education*, 96(4), pg. 335.

Taricani, E. M. and Clariana, R. B. (2006). A Technique for Automatically Scoring Open-Ended

Concept Maps. *ETR&D*, Vol. 54, No. 1, p. 65–82, Association for Educational Communications and Technology.

Upadhyay, R.K., Gaur, S. K., Agrawal, V. P. and Arora, K.C. (2007), ISM-CMAP-Combine (ICMC) for hierarchical knowledge scenario in quality engineering education. *European Journal of Engineering Education*, Vol. 32, No. 1, 21–33.

Wang, L., Shen, W., Xie, H., Neelamkavil, J., and Pardasani, A. (2002). Collaborative Conceptual Design – State of the art and future trends. *Computer Aided Design*, Vol. 34, Issue 13, pp. 981-996.

Wang, S. H., Melendez, S., and Tsai, C. S. (2008). Applications of parametric sketching and Associability in 3D CAD. *Computer Aided Design and Applications*, Vol. 5, Issue 6, pp.822-830.

Zele, E. V., Lenaerts J., and Wieme W. (2004). Improving the usefulness of concept maps as a research tool for science education. *International Journal of Science Education*, Vol. 26, No. 9, pp. 1043-1064.