Development and validation of an essential three dimensional Computer Aided Design Conceptual Knowledge (3D-CAD-CK) questionnaire

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ABSTRACT

Three dimensional CAD technologies have been an engine for new product development process and appropriate exploitation of the knowledge on the use of the technology can be valuable to expedite the process. This article presents the development and initial validation of a questionnaire to assess conceptual knowledge for 3D CAD among practicing mechanical engineers in the manufacturing industries. The study introduces and empirically explores essential 3D CAD conceptual knowledge (3D-CAD-CK) within manufacturing firms. In particular, the concepts of model manipulation, exploratory visualization, data exchange and collaboration activity in the development of 3D CAD models will be examined. The level of importance of this type of knowledge is analyzed through the use of factor analysis conducted on survey pilot study data of 31 companies representing metal, metal processing, mould and die, and plastic manufacturing industries in Malaysia. Two to three sub-categories were extracted and reliabilities were calculated. An exploratory factor analysis provided evidence of construct validity, revealing several level of importance of the categories. Our initial findings indicate all the categories are imperative and related to the construction of essential conceptual knowledge in the development of 3D CAD models. This pilot survey has provided valuable insight into essential attributes of the knowledge to educators in higher education institutions. The paper finally reports important concepts related to 3D-CAD-CK as perceived by practicing Mechanical Engineers in the Manufacturing industries.

Keywords: *Conceptual Knowledge, 3D CAD, Survey Questionnaire, Mechanical Engineering*

INTRODUCTION

CAD systems have generally been used as designer's everyday tools and have helped drive the concurrent engineering (CE) practice (Nahm & Ishikawa, 2006). Designers are able to create virtual parts and assemble parts through the use of geometric features for digital mockup in the CAD environment (Silva & Chang, 2002). Effective means of employing the technology has greatly simplified iterative design process (Abdel-Malek et al., 2001) and it has been widely used due to its importance in manufacturing by improving design quality, reduce design cost, and shorten the development time of new product (Robertson & Allen, 1993). 3D CAD is no longer mere product design tool, instead it is becoming a firm's competitive weapon (Park, et al. (2007). Under such circumstances industry is becoming more and more dependent on CAD technology to enhance productivity (Wen & Kobayashi, 2002).

Pilot survey research reported in this article sought to represent the perceptions of practicing mechanical engineers on the related 3D CAD key concepts of developing 3D models based on 4 measures of categories: 1. Manipulation of Modeled object, 2. Exploratory Visualization, 3. Data Exchange, 4. Collaboration. The purpose of the present study is to examine vital concepts in the utilization of 3D CAD software by investigating the psychometric properties of 3D-CAD-CK questionnaire and provide evidence of its construct validity with practicing mechanical engineers in the manufacturing industries. Result of this study is an important step in the process of providing CAD instructors valuable information for assessing, understanding and improving Mechanical Engineering undergraduates' knowledge in using CAD in their course.

CATEGORIES OF 3D CAD CONCEPTUAL KNOWLEDGE

In order to identify essentials of conceptual knowledge for 3D CAD in mechanical engineering domain, categories of concepts are developed for this study. Items related to the categories are as listed in Table 1. The following section explains the meaning of each category.

Manipulation: Concepts to manipulate modeled object to produce alternatives and preferred solution. Knowledge on the systems' capabilities that facilitate variations to be explored which would enhance creativity and support problem solving activity. As Baba et al. (1998) explain that manipulation is a modeling activity on which variations on the models are developed.

Exploratory Visualization: Understanding of CAD systems' visualization facilities that help users to speed up model development process (Fitzmaurice et al., 2008). It is an activity that would enable user to navigate through simple or complex models structure such that features can be added or modified to form complete object (Jong et al. 2009).

Data Transfer: The rationale to share data (model transfer) for the purpose of transferring models for downstream applications (Kim et al., 2008: Pratt et al.

2001. Model creator should take to account the process of developing 3D models to include the needs of other users.

Collaboration: Knowledge of various means of communication and collaboration to develops models within any distributed teamwork environment. Users should recognize the framework of collaborative CAD in product development which facilitates the creation of a hierarchical product structure, with single and compound components by assigning tasks to team members (Janardanan et al. 2008) which is supported by a web-client specialized in part design, supported by a web-client specialized in assembly design (Bidarra et al. 2002).

METHODOLOGY

Participants

This article reports on a pilot study data (n=31), exploratory factor analysis study that determined the underlying constructs or sub-categories of 3D-CAD-CK, sought to represent the perceptions of practicing Mechanical engineers from various manufacturing industries. The respondents were identified based on the Federation of Malayisan Manufacturer (FMM) 2009 directory listing which provides profile of leading Malaysian industries.

Instruments

31 pilot survey questionnaires were collected from the companies representing metal, metal processing, mould and die, and plastic manufacturing industries in Malaysia. The respondents were asked to evaluate the level of importance of the items of 3D-CAD-CK at their organization. Items were rated based on a 1 to 5 Likert Scale (from "Not important at all" to "Extremely Important", respectively). They had the option to tick a "Don't Know" check box if they were not familiar with a particular item.

The first part of the questionnaire was designed to collect respondents' demographic information such as, length of service in industry, age, experience in using CAD, position with respect to the use of CAD and training experience. The second part of the questionnaire consists of 41variables or essential 3D-CAD concepts, which were obtained from published literature. The variables were group under 4 categories of 3D-CAD-CK (or construct), which were identified as (a) manipulation of modeled object, (b) Exploratory Visualization, (c) Data Exchange, and (d) Collaboration in model development.

RESULTS

Most of the respondents came from medium sized companies with more than 500 employees (57%). The distribution of the respondents' role in CAD operation was CAD operator (37.9%), Supervisory (13.8%), and downstream CAD user (48.3%). It was also observed that more than 65% of all the industry participated in the survey were manufacturers. About 90% of the respondents involved in this study perceived their CAD skills level to beintermediate to advanced user. The distribution of the respondents' length of service in industries was, more than 10 years (19.4%), between 5 to 10 years (35.5%), between 2 to 5 years (25.8%), between 1 to 2 years (12.9%) and below 1 year (6.5%). The results also indicate that most of the respondents have undergone intermediate training in solid modeling (51.6%) and basic course in Surface modeling (53.8%).

Adequacy of Correlation Matrix of Items

A principal component factor analysis (PCFA) with Oblimin rotation was used to determine the underlying structure of the data. Results of Chi-square test by means of a Bartlett's test of sphericity for each category are within acceptable range. It was also found items for each construct were not highly correlated indicating multicollinearity would not be a problem. All the statistical analyses were carried out using SPSS version 17.

Factor Loadings

The factor loadings from the principal component analysis with the Oblimin solution are as shown in Table 1. All the items met the criterion of loading at least 0.4 on their respective factor as suggested by Worthington and Whittaker (2006). The eigenvalue associated with each factor, the percent of variance explained by each factor and the Cronbach coefficient alpha for each factor are as shown in Table 1. The Cronbach coefficient alphas for all factors ranged from good to excellent, except the one associated with *data exchange* where item of "handling of geometric and non geometric entities" removed.

Factor interpretation from factor analysis

Factors extracted by using exploratory factor analysis helped us to interpret the underlying structure of essential 3D-CAD-CK as perceived by practicing mechanical engineers. The following section will describe the factors that were identified in the analysis.

Manipulation

Overall Design Stage of Manipulation – This group of factor consists of essential concepts on the application of the software to manipulate modeled object by exploring potential design solution to solve design problem after parts were assembled. Models of assembled parts are further explored by performing relevant procedures enabling assessment of alternative solutions.

Significant Level of Manipulation- Items in this group represent concepts of model manipulation in which completed models are continuously being modified to achieve specific objective. Models are usually particular parts which need to be altered to solve design problems. Changes made to these parts would require the production of new set of engineering drawing.

Secondary Level of Manipulation- Manipulation of modeled object in this group is related to the activities of performing various procedures at initial stage of developing a model. Strategies used to develop 3D models might use different approach to represent design ideas. The approach employed different modeling strategies at each stage of model development process.

Exploratory Visualization

Primary Visualization for Manipulation- Items in this group are related to concepts of visualization for the purpose of model manipulation, as knowledge of visualization is closely related to the manipulation of modeled objects. Proper execution of this process would promote meaningful manipulation activity as a result of efficient approach of loading and displaying 3D models. Manipulation of modeled object becomes easier once the object can be viewed appropriately that show its most distinguishing features.

Advanced model Visualization-This sub-category primarily concerned with the visualization of parts in details, as modeled parts are constructed by the formation of several features. Visualizing these associations of features would enable designers to identify problematic models and subsequently take appropriate action. The ability to perform model exploration by using proper visualization techniques enables designers to dynamically change a shape model.

Overall model Visualization-Visualizing developed models as a whole in 3D CAD are the main objective of creating models in virtual environment. Activity of examining highly complicated models and subsequently filter visible information are vital concepts in this sub-category. Visualizing by sequent filtering of assembled parts are important concepts in this subcategory as representation of model view are limited to the systems' display devices.

Data Exchange

Direct data exchange-Items in this group are categorized as the concepts of exchanging completed models by generating two dimensional images where the images were then used for particular purpose. This category does not involve the sharing of complicated geometric data of modeled object, it is only apply to exchanging extracted 2D layout generated from the 3D models.

Interoperability between platforms (Inter-system data exchange) - In practice, 3D data from final models are being shared throughout the organization and related manufacturing companies. Downstream users make use of the models for further action. This subcategory consists of items related to the activities of exchanging and using modeled data either of the same formats (identical system) or standardized format (use of data exchange standard).

Table 1: Descriptive statistics, Factor Loadings and item reliability of instrument items.

Interpretation of the Factors			Secondary level of object Manipulation	Significant Level of Manipulation	Overall Design Stage of Manipulation	Primary Visualization for Manipulation	Advanced model Visualization	Overall model Visualization
		Factor	1	2	3	1	2	3
Categories	Mean	SD						
1. Manipulation (Cronbach's Alpha = **0.88**)								
ManNonGeoEntities	4.414	0.628	0.766					
DressUpFeatures	4.552	0.572	0.836					
SubModel	4.621	0.561	0.892					
Produce Eng Drawing	4.517	0.634		0.502				
ModelManipulation	4.345	0.614		0.845				
Connection of Edges	3.966	0.778			0.868			
Parent-Child Relationship	4.448	0.632			0.763			
To perform Design Changes	4.655	0.484			0.431			
Exploration of Design	4.379	0.677			0.755			
2. Exploratory Visualization (Cronbach's Alpha = **0.95**)								
Switching 2D to 3D	4.423	0.758				0.970		
ApprSurfHiddenLines	4.385	0.752				0.995		
ApprSurfLevelofDetails	4.269	0.827				0.837		
Interact Geometric Entities	4.269	0.778				0.856		
CommToolsDecisionMaking	4.385	0.752				0.798		
CommToolsProblemSolving	4.423	0.758				0.674		
Several Model Viewpoint	4.000	0.849					0.499	
VisFeaturesRecognition	3.808	0.939					0.812	
VisFeaturesCreation	3.962	0.958					0.931	
VisFeaturesRelating	3.923	0.891					0.866	
Vis Hierarchies in Assembly	4.115	0.816					0.598	
Features Manager	3.923	0.688					0.692	
Navigation	4.115	0.711						0.967
Expand & Collapse operation	3.923	0.845						0.857

Table 1: ***Continue*.**

			Direct data Exchange	Inter-system data Exchange	Visual Collaboration	Production – Integrating ICT
			1	2	1	2
3. Data Exchange (Cronbach's Alpha = **0.94**)						
Handling Geo & Non Geo Entities			a			
Comm with Consumer	3.793	0.902	0.553			
Design Review	4.172	0.805	0.968			
Design Verification	4.276	0.751	0.963			
Data as Illustration	3.931	0.998	0.837			
Sharing of Design	4.069	0.753	0.846			
Different Platform	3.552	1.121		0.936		
SharedThroughoutCompany	3.793	0.940		0.872		
Share to Related Company	3.793	0.902		0.844		
4. Collaboration (Cronbach's Alpha = **0.91**)						
Formal Design Report	3.960	0.841			0.943	
Visual output	3.920	0.909			0.879	
Reverse Engineering	2.960	1.306				0.476
Use of Intranet	3.720	1.137				0.510
Concurrent Engineering	3.680	1.108				0.751
Internet Realtime	3.200	1.354				0.934
On-line	3.160	1.248				0.964
Different Time Zones	3.320	1.215				0.951
Eigenvalue			5.677	0.735	1.175	5.038
Variance explained (%)			70.96	9.19	14.690	62.980

a = deleted item after analysis

Collaboration

Production-Integrating ICT-The globalization and the intensive time to market competition have made CAD system becomes vital tools in the manufacturing industries. This subcategory describes essential concepts of adopting ICT in the development of 3D models in general.

Visual Collaboration-Items included in these subcategories yield the meaning of collaboratively develop models by producing or presenting output in a format which would be used in formal discussions. Extracted models' layouts are presented as tools for communications purposes within cooperative working environment.

DISCUSSIONS

This study was conducted to obtain information about psychometric properties of the 3D-CAD-CK Questionnaire and establish evidence of its construct validity with practicing Mechanical Engineers in the manufacturing industries. The questionnaire was designed to identify level of importance of essential concepts in the utilization of 3D CAD system in product development process. It can be useful to CAD instructors in higher intuitions as guidelines for the scope and depth of the knowledge within specified domain knowledge. Generally, the 3D-CAD-CK questionnaires developed in this study exhibits strong reliability and validity. The scales generated strong Cronbach alpha coefficients of internal consistency, had high factor loadings indicating construct validity, met item convergent validity standard and were judged to have content validity. Further analysis on the sub-categories should to be carried out in order determine which group is more important within anticipated categories. Overall, the results of this pilot study provides strong preliminary support for the viability of the questionnaire and it has provided the researchers ground to carry out further investigation with larger respondents in the manufacturing industries. Further investigation with large number of respondents is ongoing.

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