A Theoretical Approach Towards Designing InfoVis for Decision Support Effectiveness

Semiu A. Akanmu, Zulikha Jamaludin
School of Computing, Universiti Utara Malaysia, 06010 Sintok, Malaysia.
zulie@uum.edu.my

***Abstract*—Information Visualization (InfoVis) as information systems used in gaining insights of large and multidimensional dataset has gained interest of human computer interaction researchers. The researchers have also craved for more theory-based design models to support designing InfoVis and to enhance its decision support effectiveness. This is a result of the observed insufficiency in the theoretical explanation and model of InfoVis design generally, and its decision support effectiveness, specifically. Extant literature reviewed showed that there is lack of studies that explicitly state the linkage between InfoVis design techniques and respective supporting theories, and how this translate to decision support design of InfoVis. This study therefore employs an unobtrusive research method that involves thematic analysis of InfoVis design and related theoretical literatures, to characterize, categorize and link the InfoVis theories with their respective design techniques. The result is a proposed theoretical design model. The model is therefore used, as a validation process, in the design of StudentViz – an InfoVis to support the multidimensionality of students' dataset.**

***Index Terms*—InfoVis Design Techniques; InfoVis' Theories; Decision Support Effectiveness; Students' Dataset; Multidimensionality.**

I. INTRODUCTION

Information Visualization (InfoVis) is a tool suitable for gaining insight from large and multidimensional datasets through users-control visual exploration [1] [2]. One of the appealing InfoVis' research areas is building the theoretical base for its design guide generally, and its decision support specifically, due to the reported insufficiency of studies in the area. As Fekete and Plaisant [3] stated, for InfoVis' decision support functionality to be actualized, its perception-gaining and cognition-amplifying qualities must be achieved with design models. Such design models must be built base on deep theoretical explanations of the evolving abstract human consciousness –like perception and cognition, and their linkages with InfoVis' techniques. However, studies that border on the theoretical linkage between InfoVis' techniques and their corresponding InfoVis' support are still lacking. The few recorded theoretical works are on the need to investigate potential InfoVis' users [4], internalization and externalization of data representation to support cognition [5], and InfoVis' evaluation [6], among others.

This study, through a thematic analysis of selected InfoVis' literatures, characterizes and categorizes InfoVis' support and techniques, and establishes their linkages with due theoretical explanation. This is presented as a theory-based design model. From theoretical perspective, we propose that InfoVis' decision support effectiveness can be designed by ensuring that the choice of the InfoVis' techniques addresses all the InfoVis' support –perceptual, cognitive and decision. As an evaluation process, we employed the proposed design model in our design project: *StudentViz*, an InfoVis to support the multidimensionality of students' datasets. The implementation success of the proposed model validates its applicability.

II. PAST RELATED STUDIES

Previous studies that explained InfoVis from a theoretical perspective are Li, Hook, Dey, Forlizzi and Medynskiy [4], Benoit [5], Crapo, Waisel, Wallace and Willemain [7], Yi [8], Liu, Nersessian, and Stasko [9], and Teets, Tegarden, and Russell [10]. Others, Purchase et al. [11] and Graham [12], advocated for extended works on InfoVis' theoretical foundation.

Li, Hook, Dey, Forlizzi and Medynskiy [4] explored behavioural theories, and proposed that understanding InfoVis must be based on understanding the individual users. This proposition is opined to be more fitting into the pre-design phase of InfoVis, and possibly its users' evaluation phase. The authors suggested that users' behavioural antics give better design concept, and this should be attended to by focusing on their domain needs and goals. The work did not state how the users' needs will inform the choice of the InfoVis techniques in manner that is appealing to the studied behavioural antics, and in the light of theoretical explanation. On another hand, Benoit [5] which extended Li, Hook, Dey, Forlizzi and Medynskiy [4] work, also solely discussed the needed perception to be derived from the information displayed on InfoVis as a design guide for its decision support. The study did not consider other InfoVis supports – like cognitive- that are necessary for InfoVis decision support design.

In another study, Liu, Nersessian, and Stasko [9] proposed distributed cognition as a theoretical framework for InfoVis. Contrary to Benoit [5], the study highlighted internalization and externalization of data presentation as theoretical constructs that aid distributed representation in human cognition. This process, with the support of propagation by coordination through the interaction process, is argued to be the process that led to cognition amplification during the use of InfoVis. The work essentially acknowledged interaction techniques as aid of InfoVis' cognition support. Also, Crapo, Waisel, Wallace and Willemain [7] emphasized the role of computational modelling in knowledge discovery through InfoVis, and cited cognitive theories as design guide. The study lists sketches through diagrams and charts as knowledge creation models that amplify cognition. Though this aligns with Benoit's [5] internationalization and externalization of data representation, the theoretical

explanation that guides the perceptual support of sketches, as a requisite to the cognition amplification, is exempted. Teets, Tegarden, and Russell [10], by building on Benoit [5] and Liu, Nersessian, and Stasko [9], proposed that evaluation of InfoVis' effectiveness in decision making can be rightly done using cognitive fit theory. It is argued that cognitive fit theory addresses the visual presentation (perceptual) phenomenon which is associated with InfoVis data representation.

From InfoVis' decision support perspective, Yi's [8] suggested using normative and descriptive models as frameworks. This, as entrenched in decision science, is opined to be befitting for InfoVis decision support design. However, the limitation of the work is that it addressed InfoVis' decision support as a concrete functionality that depends not on human-based abstract actions like perception and cognition.

In attending to the limitations of these previous works, as highlighted, this study therefore presents a theoretical design model. The model highlights a theoretical linkage between InfoVis' supports and their respective techniques.

III. Methods

We used an unobtrusive method of data gathering which involves open coding [13] [14] of published works on theories that were adapted or adaptable into the InfoVis research area. In doing this, a total collection of nine (9) works and seventeen (17) theories were chosen for fitting into InfoVis theoretical works. These works were analyzed to identify their common and recurring theoretical themes. After the identification of the theoretical themes, descriptive interrelationship and knowledge operationalization [13] with review of Spence [1] and Cooper, Reimann, Cronin, and Noessel [15] are used to categorize the supports enshrined in the analyzed theories and their corresponding InfoVis' techniques. By matching the description made by the theoretical themes with its respective InfoVis' supports, the interconnections between the theories, supports and users' control activities form the proposed theory-based design model. Table 1 below presents the works analyzed, themes and InfoVis' supports identified, and the corresponding InfoVis' techniques.

The available themes, as shown in the review of these InfoVis' works suggest that perceptual, cognitive and decision making supports are the prominent InfoVis' supports. InfoVis must be designed to aid these supports through corresponding InfoVis' techniques and theoretical justifications. Pre-attentive processing theory, cognitive and normative and descriptive theories are chosen from theories analysed and presented in Table 1 because they best represent the core value of their respective themes. The selected theories form the base for the proposed design model presented in Figure 1.

IV. Result: Proposed Theoretical Design Model

The proposed theoretical design model presents the linkage between InfoVis' theories (Pre-attentive processing theory, cognitive-fit theory, and normative and descriptive theories), its supports (Perceptual, Cognition and Decision support), and the involved human-computer activities (visualization, data exploration and interaction). The model states that the explanations of Pre-attentive processing theory, cognitive-fit theory, and normative and descriptive theories must influence the design of visualization, interaction, and data exploration activities to achieve InfoVis' perceptual, cognitive and decision supports, respectively. The collectivist effect of these theories-based and human computer interaction activities is to actualize InfoVis' decision support effectiveness. Pre-Attentive processing theory [6] is chosen because it reflects the essence of colour scheming in interaction and visualization techniques. Cognitive fit theory [9] also highlights reduction of cognitive load for effective decision making purpose, and this resonates with the need for InfoVis in addressing data's multidimensionality. Normative and Descriptive theories from decision science address the need to establish relationship between data variables and the presentation of their quantifying values. Figure 1 presents the theoretical design model for InfoVis' decision support effectiveness.

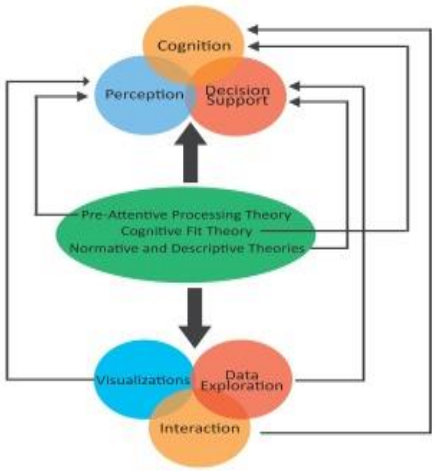

Figure 1: Theoretical Design Model for InfoVis Decision Support Effectiveness

V. Evaluation

The proposed model is validated using Prototyping. According to Rogers et al. [23], prototyping, which is a process of turning a conceptual diagram to a physical artefact, validates the applicability of the said conceptual diagram. For the development of the prototype codenamed StudentViz, an open source Google API for interactive chart built with Adobe Flash framework is used. The open source API is embedded in a web-based system developed using Hyper Text Markup Language (HTML), Cascading Style Sheet (CSS) and JavaScript.

The core functions of StudentViz, which are also described as the human-computer interaction activities of the InfoVis, are visualization, interaction, and data exploration. Visualization implies the display of information sought by the user through the communicative statistical graphics. In this study, scatter plot, line chart, bar chart and geo chart are employed. The interaction is the mode and process that the user takes in interacting with the InfoVis, and by extension, the data to be visualized, and vice versa. This study employed check boxes, mouse on-drag, and drop down menu, push button, and dynamic hinting. For the data exploration which influences the form and type of data to be displayed, zooming, scrolling, exploration and overview with details are the distortion techniques. All these are included in the development of StudentViz and the details of the InfoVis' techniques are according to the proposed theoretical design

model. The visualization is guided by the pre-attentive processing theory through the use of colour for distinctive representation and data communication appropriateness of the statistical graphics. The interaction techniques are guided by the cognitive-fit theory and data exploration is guided by the normative and descriptive theories.

As suggested by the proposed theory-based design model, each of the functions of StudentViz, as designed for by their respective InfoVis' techniques, are influenced by the underlying theoretical provisions. According to pre-attentive processing theory, informative graphics must be represented by distinctive colours and/or shape. This will aid user's pre-attentive processing of the particular information. As shown in Figure 2, the data dimensions can be explored using the drop-down menu (indicated by the arrows). The data exploration activity is critical in InfoVis' decision support. It allows users to deal with manageable data dimension and insight at a point in time.

By implementing normative theory, the user can relate the ordinal data types of the data dimensions –which are placed in the x and y axes –with each other. The descriptive implementation affords the user to represent any picked categorical data in quantity. This is the panel labelled 'size' on the right side of the interface (as shown in figures 2 and 3). In sum, the data exploration is influenced by the normative and descriptive theories using drop-down menu and check boxes as interaction and distortion techniques. The check boxes, as designed in StudentViz and shown on the right panel of the interface, are to pick any of the entities (nationalities of the students, in this instance) for further detailing. The ability to reduce cognitive load, as suggested by the cognitive fit theory, is supported by the users' control mechanism of choosing the particular data dimensions during the data exploration exercise. Snippets of the screenshots of the system are further presented in figures 2 and 3.

Figure 3 presents a rendered scatterplot which is one of the visualization techniques.

Visualization techniques are the media through which the domain explicit knowledge is presented [1]. This largely depends on the nature of the information to be represented. In our case, scatter plot, bar char and line charts are chosen. As shown in figure 3, the relationship between internship length (on y axis) and CGPA (on x axis) is sought. The rendered scatter plots show this relationship on country-by-country basis (on the average), with different colours for distinction. The visualization is to give perceptual support, and this is designed with due consideration to the explanation of pre-attentive processing theory. The choice of all the visualization techniques is also based on the details of the data-driven decision making framework [24].

In the illustration given in Figure 3, with pliant response hinting as an interaction technique, the user can mouse-hover a selected scatter plot and the detail becomes glaring. This aids both perceptual and cognitive supports. The cognitive support, as expected from an InfoVis, is explained by cognitive fit theory. The theory emphasizes the ability to select minimal data portion for detailing as a viable way of reducing cognitive load, hence achieve cognitive and decision supports.

We propose that InfoVis' decision support effectiveness as a design construct for InfoVis can be achieved through theory-based design for perception, cognition and decision supports.

VI. Conclusion and Future Work

This study presents a theory-based design model for InfoVis decision support effectiveness. It argues that for InfoVis' decision support effectiveness to be actualized, the perceptual, cognitive and decision making supports must be designed for, with due attention to their respective theoretical imports. Pre-attentive processing theory, cognitive theory and normative and descriptive theories should respectively dictate the perception, cognition and decision making design.

This study aims at contributing to the theoretical discussion of InfoVis design by presenting an explicit linkage between theories, InfoVis' techniques and their corresponding human-computer interaction activities. As earlier reviewed, previous related studies have only concentrated on units of the InfoVis' supports by evaluating either of perceptual, cognitive or decision support through chosen theories. Through prototyping method, the proposed model is implemented in the development of StudentViz which is an InfoVis developed to support the multidimensionality of students' datasets. The applicability of the model in the practical design process of the prototype validates its essence.

Our future work is to evaluate the developed prototype through a user experience experiment. In the experiment, the higher education institutions' policy makers would be the prospective participants. This will empirically present the evaluation of the prototype's decision support effectiveness, and its comparison with related previous studies.

Table 1
Works Analyzed, Theories Involved, Themes and the Corresponding InfoVis' Techniques

Works	Theory	Themes	Category of Support	Corresponding InfoVis' Techniques
Triesman & Gormican [16]	Pre-Attentive processing theory	Preattentive Visual Property	Perceptual	Visualization
Triesman [17]	Extension of preattentive processing theory: Feature integration theory and Texton theory	Preattentive Visual Property		
Quinlan & Humphrey [18]	Similarity theory	Visual representation		
Wolfe & Cave [19]	Guided search theory	Visual Search		
Ware [20]	Information Theory	Visual representation		
Discussed by Fekete, van Wijk, Stasko & North [21]	Gestalt theory: proximity, similarity, continuity, symmetry, closure, relative size, and theory of graph comprehension	Visual perception		
Hutchins [22]	Distributed cognition framework	Human mind and cognition	Cognitive	Interaction and Distortion
Teets Tegarden, & Russell [6]	Cognitive fit theory	Human cognition	Decision making	Visualization and Distortion
	Normative theory	Data exploration		
Yi [8]	Descriptive theory	Statistical formulation		

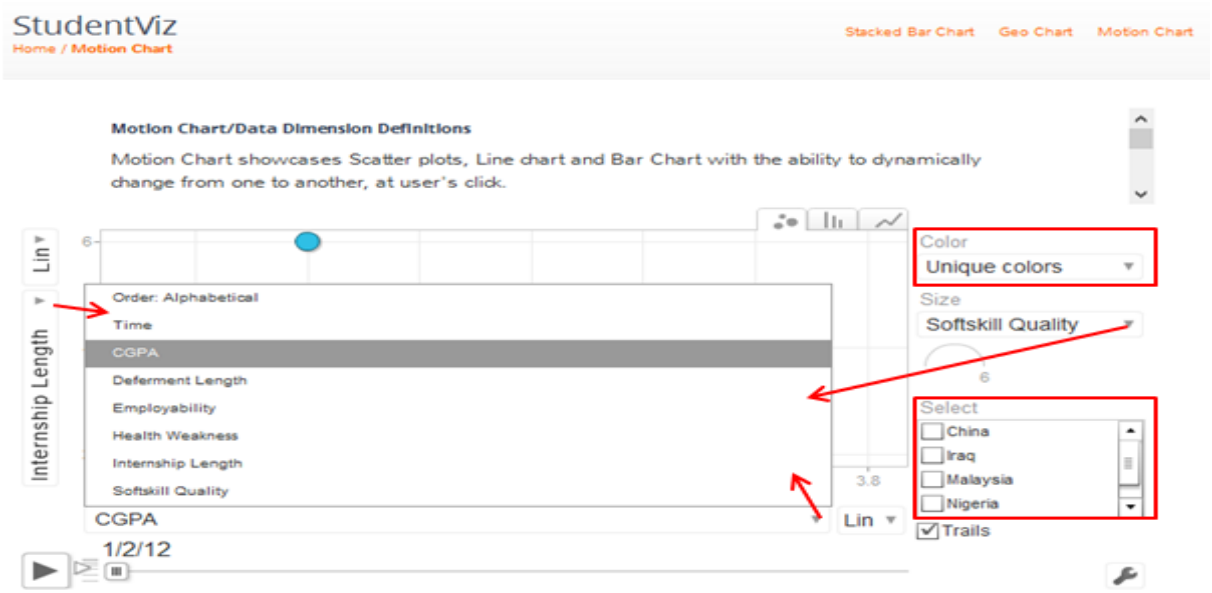

Figure 2: StudentViz's Interface showing the drop-down menu for the exploration of the data variable

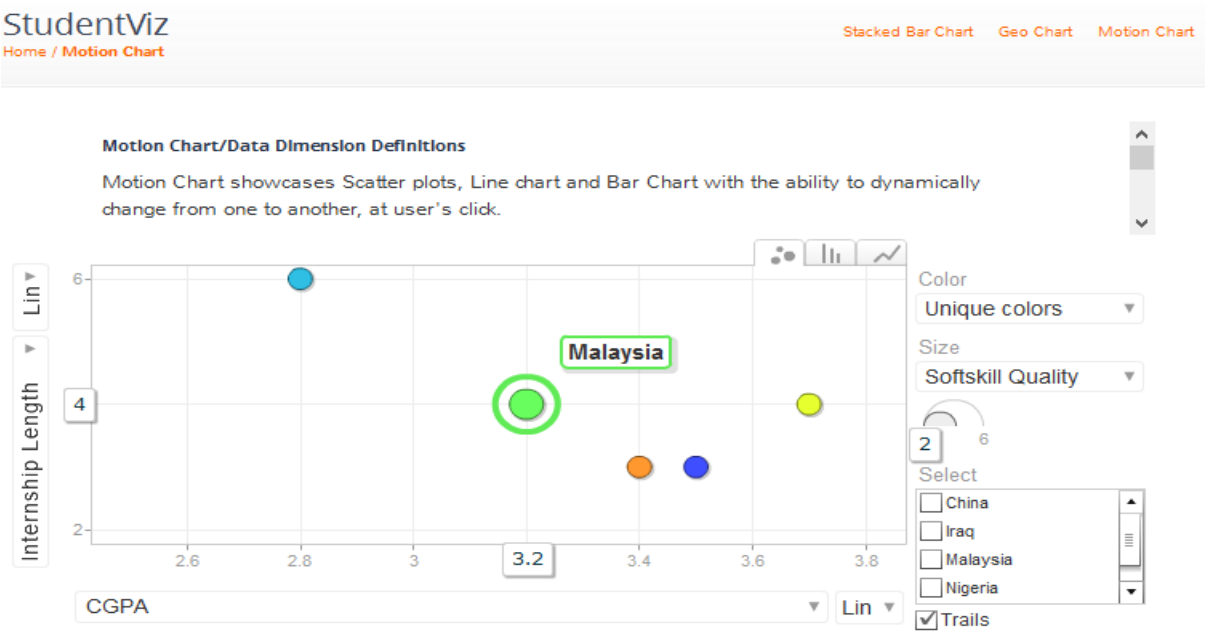

Figure 3: Rendered Scatter Plots

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