

## **DESIGNING INFORMATION VISUALIZATION FOR HIGHER EDUCATION INSTITUTIONS: A PRE-DESIGN STUDY**

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### **ABSTRACT**

The multidimensionality of students' data and the limitations of the currently-used data management tools in higher education institutions (HEIs) have been identified as causes of constrained decision-making process in the domain. This, therefore, necessitates a pre-design study for the HEI students' data-focused InfoVis. The objectives of this study are to identify the prevailing practices of HEI data management, the data analytics methods that are generally employed by HEI data analysts and the comprehensive dimensions that are related to HEI students and adequate for conveying the domain explicit knowledge preferences. A mixed method approach with survey questionnaire and interview as data collection methods, is used. The contributions of this study, among others, are: (i) identification of the pattern and relationship of the domains explicit knowledge preferences; and (ii) the elicitation and description of students' data dimensions. These are expected to form the basis for the choice and implementation of the content delivery techniques in designing the domain-focused InfoVis. Our future works therefore entail developing the HEI InfoVis conceptual framework, designing the HEI students' data-focused InfoVis and conducting its users' experimental evaluation.

**Keywords:** Information visualization; pre-design study; data-driven decision making; multidimensional datasets; higher education institutions.

### **INTRODUCTION**

The ever-growing nature and multidimensionality of students' data of Higher Education Institutions (HEIs) have resulted in constraints being experienced in decision-making processes of the domain. This experience has restricted HEIs'

decision-makers and administrators in making good use of the students' data (Semiu & Zulikha, 2014). In view of this, information visualization (InfoVis) – an arguably suitable tool for gaining insights into large multidimensional datasets – is suggested, because of its strength in aiding decision-making through visual exploratory ability (Ware, 2000; Spence, 2007).

Notably, InfoVis is a research domain on data analysis and knowledge discovery through visual exploration (Fekete & Plaisant, 2002; Shneiderman & Plaisant, 2010). It aids cognition and therefore supports decision-making. However, it is argued that InfoVis cannot be functional without a pre-design stage that thoroughly investigates the work practices of the domain actors and identifies the explicit knowledge expected to be delivered through it (Delavari & Phon-Amnuaisuk, 2008; Lam, Bertini, Isenberg, Plaisant & Carpendale, 2012; Koh, Slingsby, Dykes & Kam, 2011). Understanding the work practices of the domain actors will inform the InfoVis' designers of the necessary information architecture and interface content that are needed in the design and implementation of the InfoVis. Also, identifying the explicit knowledge involved in the application areas of InfoVis can guide the transformation of the raw data (structured or unstructured) into meaningful information that can assist in decision-making and creation of knowledge and wisdom (Stasko, 2008). The transformed data can therefore produce explicit knowledge that fairly encapsulates what the InfoVis' users are eager to detect during the exploration of the massive datasets.

Considering the limitations in the currently-used data management tools in HEIs, it is necessary to have a specific InfoVis for the domain. Our on-going research is aimed at developing a HEI students' data-focused InfoVis. This paper discusses its pre-design study conducted mainly to investigate the work practices of the domain's actors – HEI decision-makers, data administrators and data analysts, and identify the explicit knowledge preferences of the domain's policy-makers.

## **DECISION SUPPORT AS THE GENERAL THEME OF INFOVIS STUDIES**

On a general note, the need to transform large and multidimensional datasets to knowledge that can support decision-making through visualization, has resulted in continuous research on InfoVis. In this regard, creation of new visualization techniques, especially visual dynamic queries' mechanism, visual encoding methods, visual data mining techniques and conceptual design frameworks, have been the focus ([Rogers et al., 2011](#); [Sheinerderman & Plaisant, 2010](#); [Spence, 2007](#)).

Tan et al. (2006) pointed that InfoVis research needs to attend to challenges of data transformation and creation of new visualization techniques. To achieve this, an appropriate combination of visual data mining algorithms, dynamic queries’ mechanisms and the visualization techniques must be accomplished. Numerous studies (Quigley, 2002; Robinson et al., 2005; Lee et al., 2005; Ziegler et al., 2008; Faisal el., 2008; Tory & Staub-French, 2008; Oelke et al., 2008; Strobel et al., 2009; Mansmann et al., 2009; Wanner et al., 2009; Hao et al., 2010; Keim et al., 2010; Johansson et al., 2010; Wu & Ren, 2010; Roth et al., 2010; Kohlhammer et al., 2010; Yu et al., 2010; Stoffel et al., 2010; Zheng et al., 2011; Koh et al., 2011; Schaefer et al., 2011; Lirong et al., 2011; Simon et al. 2011; Meyer, 2012; Wang et al., 2012; Krstajic, 2012; Stoffel et al., 2012; Zhong et al., 2012; Ning et al., 2012; Pinto et al., 2012 Bowen, 2013) in different domains have been undertaken, concerning design of InfoVis frameworks, but none addresses the data on HEIs students’ explicit knowledge. Table 1 summarizes these previous studies into domains and references with their respective contributions.

Table 1

*Summary of Previous Studies on Domain, References, Niche and the Contributions*

| Domain  | References               | Contribution  |
|---|--------------------------|---|
| Genomes   | Meyer (2012)             | A visualization techniques to aid the exploration of genetic data by biologists                     |
|   | Simon et al. (2011)      | A visualization that detects overlapping genes in bacterial genomes                                 |
| Information Retrieval                                     | Wang et al. (2012)       | A visualization that enhances information retrieval process in PLM                                  |
|   | Lirong et al. (2011)     | A novel visualization technique for web retrieved credit information                                |
|   | Tekir et al. (2011)      | A visualization for web document clustering   |
| Public and business administration through opinion mining | Kohlhammer et al. (2010) | A visual analytics that helps in policy and administrative decision-making                          |
|   | Wanner et al. (2009)     | Visual sentiment analysis of the RSS News feeds for monitoring the US Presidential election of 2008 |
|   | Oelke et al. (2008)      | An InfoVis’ technique that visually represents customers’ feedback data                             |
|   | Hao et al. (2010)        | A geo-temporal visualization on customers’ feedback stream, and for product marketing               |
|   | Krstajic (2012)          | An InfoVis work on visual text analytics of news story development for policy assessment            |

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| Domain                            | References  | Contribution   |
|-----------------------------------|---|--|
| Software engineering              | Harrison et al. (2010)                            | InfoVis software for visualizing chemical structure.   |
|                                   | Stoffel et al. (2012)                             | A web-based visual query analysis system for the simulation of micro-grid energy mix   |
| Financial and investment analysis | Ziegler et al. (2008)                             | A pixel-based visual analytics that supports investors in making financial market-related decisions.   |
|                                   | Schaefer et al. (2011)                            | A novel explorative tool for the analysis and visualization of financial time-series data.   |
| Community informatics             | Lee et al. (2005)                                 | An InfoVis tool that shows trend and activity of a conference community.   |
|                                   | Bowen (2013)                                      | Visualization that uses network technique to show the co-authorship connection among the academic community.   |
| Public health                     | Robinson et al. (2005)                            | A geo-visualization tool that explores geographic health data  |
|                                   | Sopan et al. (2012)                               | A geospatial and multivariate data visualization tool for public health datasets   |
|                                   | Koh et al. (2011)                                 | An InfoVis tool as a support system for the wide range of decision-making processes.   |
|                                   | Ning et al. (2012)                                | An InfoVis application used to support doctors' diagnosis through intuitive ways of learning about the patients' condition.                            |
|                                   | Yu et al. (2012)                                  | An exploratory visual approach to aid the analysis of temporal patterns of eye movement.   |
| Geography and Climatology         | Johansson et al. (2010)                           | An InfoVis tool that evaluates climatic conditions   |
|                                   | Wu and Ren (2010)                                 | An InfoVis mechanism with augmented reality for the representation of spatial data.  |
|                                   | Roth et al. (2010)                                | InfoVis tool for crime analysis and control.   |
|                                   | Zhong et al. (2012); Tory and Staub-French (2008) | An interactive dymaxion map and web-based InfoVis interface which are tools for conveying research output to practitioners in the building industries. |
| Library and information science   | Stoffel et al. (2010)                             | Novel visual analytics indexing techniques for libraries to aid information retrieval  |
|                                   | Oelke et al. (2008); Strobelt et al. (2009)       | Visualization of document summarization and analysis   |

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| Domain                       | References           | Contribution  |
|------------------------------|----------------------|---|
| Higher Education Institution | Pinto et al. (2012), | (i) U-Map 2, an InfoVis tool used for classification of European HEIs. It aids in updating information for institutional participation; (ii) University Autonomy in Europe3, an InfoVis tool for the ranking of countries based on financial, staffing, organizational and academic autonomy; (iii) U-Multirank4, an InfoVis tool used as ranking tool for institutions; and (iv) MAUNIMO5, an InfoVis tool used for drawing attention to the varieties of academic mobility. |

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However, based on the review of the available previous works on InfoVis design, as presented in Table 1, there is yet an InfoVis tool that can be specifically used to explore the students' data, in view of conveying the preferred knowledge of the domain actors through an interactive and communicative interface. Due to its fast growing pace, HEIs' data is becoming increasingly difficult to analyse so as to detect previously unknown information that could assist policy and decision-making in the education sector (Oracle Data Sheet, 2011; Yanosky, 2009). The currently used data management systems by the HEIs are the traditional management information systems and data mining technologies which are saddled with problems of money and time wastage, loss of scientific and industrial opportunities and inability to exploit its hidden information (Sarker et al., 2010; Pocius & Reklaitis, 2000; Bresfelean et al., 2009). Other recorded cases are the use of static statistical graphics like pie chart, bar chart and line chart (Ehlers et al., 2009), occasional deployment of popular statistical tools like SAS and software systems, like Tableau for the HEIs' operational data analysis (Conrad et al., 2013). However, the multidimensionality of these datasets has limited the success of these traditional data management systems and data representation using the static graphics.

As shown in the diverse areas where InfoVis' adoptions have been made, InfoVis' value lies in its ability to solve problems of information overload, hence, assisting in decision-making through its information filtering and visualization features. It has also been shown that each of the domains reviewed has the design of its InfoVis framework in alignment with the practices of the domain and its peculiar decision-making support – through the systematic combination of the visualization, interaction and visual data mining techniques (Keim et al., 2008). Having understood the diverse applicability and indispensable usage of InfoVis, this study is thus motivated by the lingering problem of information overload in managing the data of HEI students and the consequent constraints in related decision-making (Semiu & Zulikha, 2014).

## **LITERATURE REVIEW**

Most previous InfoVis pre-design studies ([Robinson et al., 2005](#); [Isenberg et al., 2008](#); [Hinrichs et al., 2008](#); [Mansmann et al., 2009](#); [Roth et al., 2010](#); [Grammel et al., 2010](#); [Huang et al., 2010](#); [Jung et al., 2011](#); [Koh et al., 2011](#); [Zhong et al., 2012](#)) have extensively employed qualitative method for users' studies; while [Tory et al. \(2008\)](#) used mixed methods. All these studies designed their research process to cater to the objectives of their studies and answer their research questions.

As argued by [Creswell \(2009\)](#), mixed method has the ability to provide a deeper insight to answering research questions. Our study also employs mixed method so as to adequately accomplish our research objectives, which are:

- i. To identify the prevailing practices of HEIs' data management;
- ii. To identify the data analytics methods that are generally employed by HEIs' data analysts; and
- iii. To identify the comprehensive dimensions related to HEI students which are adequate for conveying the domain explicit knowledge preferences.

## **METHODOLOGY**

Due to the nature of the work of HEI data analysts and administrators, understanding their administrative activities to identify the prevailing practices of HEI data management and data analytics methods is better done through a qualitative method. Therefore, interview, as supported by [Rogers et al. \(2011\)](#) and [Sheinerderman and Plaisant \(2010\)](#), is employed.

The interview sessions for the data administrators and data analysts are of approximately thirteen (13) and eleven (11) minutes, respectively. The interview sessions were recorded using an audio tape recorder, and subsequently transcribed. The transcription is manually coded to inter-relate themes and their descriptions. These themes practically address the questions asked during the interview sessions. Table 2 presents the code tags, terms, quoted comments and themes.

The code tags are the identities given to the interviews conducted. The term is the participant's category while the theme is the unifying idea from the quoted comments which are excerpts from the transcribed texts.

Table 2

*Code Tags, Terms, Quoted Comments and Themes*

| Code tags | Term            | Quoted Comments  | Themes   |
|-----------|-----------------|--|--|
| 1.        | Data Management | <p><i>“But at the moment, what we do right now is to check the data needed and extract the data, put in one place and use what we use now..”</i></p> <p><i>“There are two databases for the students. One is for the undergraduate, and the second one is for the post graduate. Staffs have another database.”</i></p>  | <p>Adhoc data extraction practice</p> <p>Decentralised data storage</p>                                    |
| 2.        | Data Analytics  | <p><i>“We extract from system, from data warehouse, then we analyse, do statistics in Microsoft Excel”</i></p> <p><i>“Yes, PowerPivot. Ok. My team, we extract the useful data from our operational database, and then provide same to UPK.”</i></p> <p><i>“And for the reporting, it is quite easy. We have to use SQL Server Reporting System.... Microsoft Excel, PowerPivot”</i></p> <p><i>“If they need the total of students, we just figure out. We don’t use any analysis that is complicated, or with complicated tools. We just use Microsoft Office; Excel and Access. The data warehouse converts to Access, and we analyse using Excel. Just Microsoft, Microsoft products”</i></p> | <p>Traditional descriptive statistical graphics</p> <p>Utilization of data administrative technologies</p> |

On the other hand, to identify the comprehensive dimensions related to HEI students and adequate for conveying the domain explicit knowledge preferences, a survey questionnaire is designed and administered to a total number of thirty (32) respondents chosen among HEI decision-makers, as a purposive sample. The respondents are Assistant Registrars, Registrars, Deans, Deputy Deans, Program Coordinators and Heads of Departments. The survey questionnaire (Items are presented in Table 3) contains twenty-nine (29) HEI decision-makers’ explicit knowledge preferences which had earlier been elicited from literature review (Semiu & Zulikha, 2016).

Table 3

*Identifying the HEI-Focused Explicit Knowledge from the Students' Data*

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S/N Items:

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At my institution, we seek to know...

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1. The pattern of various groups of students based on their race, religion, sex and nationality.
2. The pattern of previous graduates based on their race, religion, sex and nationality.
3. The pattern (course of study, CGPA and nationality) of the Alumni who are responsive to the university's invitation.
4. The relationship between the students' performance and their gender, race and nationality.
5. The trend of the students' enrolment based on their nationality and sex.
6. The trend of the students' enrolment based on their mode of admission and gender.
7. The relationship between students' mode of entry (foundation, matriculation, credit transfer), criteria set for admission, and their academic performance.
8. The pattern of the students' economic status (self/family sponsored and scholarship) per enrolment.
9. The performance of students with disabilities.
10. The performance of students with unfavourable health history.
11. The trend and pattern of the university's graduating students based on gender, race and nationality.
12. The relationship between the graduating students' performance with their gender, race and nationality.
13. The relationship between students' course of study and their employability.
14. The relationship between students' course majors and their employability.
15. The relationship between students' performance and their lecture venue and time.
16. The relationship between students' course majors and their performance.
17. The trend of the students' performance in relationship with number of semesters used.
18. The relationship between the students' performance and their programme of study (degree & graduate).
19. The relationship between the students' performance and their mode of study (full time & part time).
20. The pattern of students in a particular department, school or college based on race, gender and nationality.
21. The courses that are majorly or otherwise enrolled by the students.
22. The relationship between the majorly (or otherwise) enrolled course and the students' performance in the said course.
23. The relationship between the students' performance and their English language proficiency.
24. The pattern of the drop-out students.
25. The relationship between drop-out students and their economic status (self/family sponsored and scholarship) and health history.
26. The pattern of the drop-out students based on their gender, nationality and marital status.
27. If there is impact of soft skills acquisition on the students' academic performance.
28. The significance of internship on the students' employability.
29. About the students' deferment history and its relationship with students' performance.

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Frequency distributions are calculated for each of the explicit knowledge items to weigh their preferences using a dichotomous response (Yes and No) (Neuman, 2007; Pallant, 2010). Items with more than eight (8) “No” responses are invalidated, using the Quartile approach to Item weighting. Note: 8 is approximately the lower quartile (Q1) of 32 (Total number of the respondents). It is derived from this formula:  $1/4 (n + 1)$ , where  $n = 32$ . From the analysis, items 3 and 15 are invalidated.

## **FINDINGS**

### *Identifying the prevailing practices of HEIs’ data management*

The data administrator’s department of the institution handles the extraction of any requested data. The request and usage of the data is mostly done by the university’s corporate planning unit. From the information provided, it is evident that the presently used data management tools, like Microsoft SQL Server for data warehousing, can be easily linked to visual exploratory system, using a suitable Application Programming Interface (API).

### *Identifying the currently-used data analytics methods in HEI*

We find that Microsoft Excel and Excel Power Pivot are the most used data analysis tools. The usual descriptive statistics is done by Microsoft Excel while bar chart, pie chart and line chart are preferred statistical graphics to data analysts due to their data communicative abilities. Both the data administrator and analyst positively review the presently used tools but wish to explore better ones that could ease their work practices and enhance their experiences.

### *Identifying the comprehensive and adequate dimensions related to HEI students for conveying the domain’s explicit knowledge preferences*

The validated items of the HEI policy-makers’ explicit knowledge are summarized as follows:

- i. The patterns of: various groups of students based on their race, religion, sex and nationality; colleges; previous graduates based on their race, religion, sex and nationality; course of study, and Cumulative Grade Point Average (CGPA);
- ii. The relationship between the students’ performance and their gender, race and nationality; mode of entry; disabilities; health history; course major; number of semesters used; program of study; mode of study; intensively enrolled courses; English language proficiency; soft skills acquisition; and deferment history;

- iii. The relationship between drop-out students and their economic status; gender, nationality and marital status;
- iv. The relationship between students’ employability and internship record; course major; course of study; and
- v. The students’ enrolment pattern based on nationality, gender; sex; mode of admission.

Based on the validated explicit knowledge preferences, we elicit the comprehensive data dimensions that must be modelled into the InfoVis domain for adequate conveyance of the intended knowledge. This can also guide the choice and implementation of the visualization, interaction and analytics techniques. Table 4 presents the data dimensions of HEI students and their description:

Table 4

*HEI Students’ Data Dimensions and their Descriptions*

|   | Data Dimensions         | Class | Data Type   | Descriptions  |
|---|-------------------------|-------|-------------|---|
| 1 | Gender                  | Basic | Categorical | This represents the students’ gender, i.e., Male or Female.   |
| 2 | Nationality             |       | Categorical | The citizenship identity of the students. E.g., Malaysia, India, Nigeria, etc.  |
| 3 | Race                    |       | Categorical | Continent-based identity. E.g., African, Asian, American, etc.  |
| 4 | Religion                |       | Categorical | The faith identity of the student. E.g., Islam, Buddhism, Christianity, etc.  |
| 5 | Course of Study         |       | Categorical | The course that the student is taking. E.g., Information Technology (IT), Business Administration, etc.   |
| 6 | Specialization          |       | Categorical | When applicable, this describes the area in which the student is specializing. E.g., Artificial Intelligence as a specialization for IT students. |
| 7 | Year of Entry           |       | Numeric     | The year that the student entered the university. E.g., 2010, etc.  |
| 8 | Year of graduation      |       | Numeric     | The year that the student graduated (or will graduate) from the university. E.g., 2010, etc.  |
| 9 | Number of Semester Used |       | Numeric     | The number of semesters used by the student. E.g., 2, 3, 4, etc.  |

(continued)

|    | Data Dimensions              | Class   | Data Type   | Descriptions   |
|----|------------------------------|---------|-------------|--|
| 10 | Mode of Admission            |         | Categorical | This describes the entry method into the university. E.g., SPM, Matriculation, Diploma.  |
| 11 | Mode of sponsorship          |         | Categorical | This describes how the student is sponsoring his or her education. E.g., Loan, Family, Self-Study and Scholarship.   |
| 12 | Current CGPA                 |         | Real Number | The current grade of the student which is normally with fractions. E.g., 3.2, 3.7, etc.  |
| 13 | Studentship Status           |         | Categorical | This is to show the status of the student. E.g., Active, Non-Active, Drop-Out.   |
| 14 | English Language Proficiency |         | Categorical | When applicable, this gives the English language certification record of the student. E.g., MUET, IELTS, TOEFL, etc.   |
| 15 | Disability                   |         | Categorical | When applicable, the disability type of the student is stated. E.g., Physical, Hearing Impairment, etc.  |
| 16 | Mode of Study                |         | Categorical | This is to categorize students on full-time and part-time basis.   |
| 17 | Program of Study             |         | Categorical | The program the student is undertaking. The values here are: BSc, PGD, MSc, PhD and DBA.   |
| 18 | Internship length            | Derived | Numeric     | The total number of months the students used on internship.  |
| 19 | Soft skill quality           |         | Numeric     | The total number of workshops or seminars on soft skills (public speaking, leadership, time management, etc.) acquisition attended.  |
| 20 | Health soundness             |         | Numeric     | This is calculated by the addition of number of times the students visited the hospital and the number of times he/she was medicated, divided by the total number of semesters used. |
| 21 | Employability                |         | Numeric     | The total number of months that graduated students used before being gainfully employed.   |
| 22 | Deferment length             |         | Numeric     | The total number of semesters that the student deferred his or her registration.   |

As shown in Table 4, the derived data attributes are computed (derived) through addition and division operations, as applicable. These derived data variables are products of diligent extraction from their respective information repositories. For example, health soundness which is computed through the addition of number of times a student visited the hospital and the number of times he/she was medicated, divided by the total number of semesters used

- and other derived data variables – are new. They are basically chosen as operational computations to realize atomic data variables that can fit into the students' data analytics and that appeal to the domain's pre-design findings. On the other hand, the basic data variables are fundamentally known units; so, they are with no computational operations.

## **DISCUSSION AND CONCLUSION**

The findings from the interview sessions highlight the necessity for a better tool that can attend to the limitations of the present ones. We opine that a tool, like InfoVis, which shares visualization and presentation similarity with the currently used traditional bar chart, pie chart and line chart of Microsoft Excel, is a good choice. Also, InfoVis' analytical strength can be leveraged with interaction techniques and visual query mechanism. This will make the tool usable to everyone irrespective of their knowledge of statistics.

With the identified and validated explicit knowledge preferences, this study has reliably elicited a comprehensive data dimension expected of each data instance in the HEI students' datasets. Notably, due to the decentralised data storage practice, many of the data dimensions (e.g., Soft skills quality, Internship length, Employability, etc.) are not presently covered by the students' academic record. We therefore posit that for a functional HEI student-focused InfoVis, the elicited data dimensions are the expected data fields of the database table.

The identification of HEI current data management practices and the elicitation of domain policy-makers' explicit knowledge preferences are essential findings from this study. Also, the data dimensions guide the choice of visualization, interaction and analytic techniques which are InfoVis' content delivery techniques and components of its conceptual framework.

Our future works thereby entail developing the HEI InfoVis conceptual framework, designing the HEI students' data-focused InfoVis and conducting its users' experimental evaluation.

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