Supporting Classroom Instruction with Data Visualization

Chia Pei Xian
Ministry of Education
chia_pei_xian@moe.gov.sg

Thong Chee Hing
Ministry of Education
thong_chee_hing@moe.gov.sg

Qiu Yiru
Ministry of Education

Kang Eng Hiok Zachary Dexter
Raffles Institution

ABSTRACT: This paper elaborates on our understanding of data visualization and efforts to empower teachers by providing information to support just-in-time instruction in the context of an inquiry-based lesson with a game on identifying the names and formulae of ionic compounds (wRiteFormula). It highlights the process of identifying the data teachers need to gauge student learning and determining how to visualize the data appropriately. It also describes the efforts taken to ensure a high degree of accuracy in the data visualization, and usability and customizability for teachers. It concludes with suggestions on how teachers can use the visualized data in class.

Keywords: data, visualization, teachers, classroom, instruction, accuracy, customizability

1 INTRODUCTION

Data visualization has been described by Few (2013) as “the graphical display of abstract information for two purposes: sense-making (also called data analysis) and communication,” and by Assam, Evergreen, Germuth, and Kistler (2013) as “a process that (a) is based on qualitative or quantitative data and (b) results in an image that is representative of the raw data, which is (c) readable by viewers and supports exploration, examination, and communication of the data (adapted from Kosara, 2007).”

In both definitions, raw, non-visual data is processed to create an image that can be used and communicated more easily than the original raw data. This may seem like a self-evident definition, especially with the increasing pervasiveness of visualizations like infographics, and may seem easy to do – a few steps are all it takes to select a set of data and create a graph in a spreadsheet programme. But the full process is more complex; much thoughtful consideration is required to identify the necessary data, determine how to collect, organize, and visualize the data, and ensure that the output is valid and accurate. And finally, from the end-users’ perspective, the real test of a successful visualization is whether it empowers them to explore, examine, make sense of, communicate and easily utilize the information therein.

In this project, the end-users were teachers, and data visualization was introduced to enhance an existing content management system (CMS) from an earlier project. The earlier project involved the development of wRiteFormula, a tile-matching game to motivate and help students learn ionic compound nomenclature. To play wRiteFormula, students freely select cations and anions to form a binary ionic compound, and then identify the correct chemical formula and name of the compound. Figure 1 shows an example for the compound potassium sulfide, K_2S. The combinations were limited to binary ionic compounds in order to build students' foundational knowledge of ionic compound nomenclature. The game has a customised feedback system, and an accompanying CMS that allows teachers to access records of game moves made by students (Chia & Sivaram, 2016; Thong, Chia, & Kang, 2015). In a typical lesson, students play the game, have a group discussion to compare observations made during the game, and then a class discussion facilitated by the teacher to deduce the relevant nomenclature rules encountered (Thong, Qiu, & Chia, 2016).

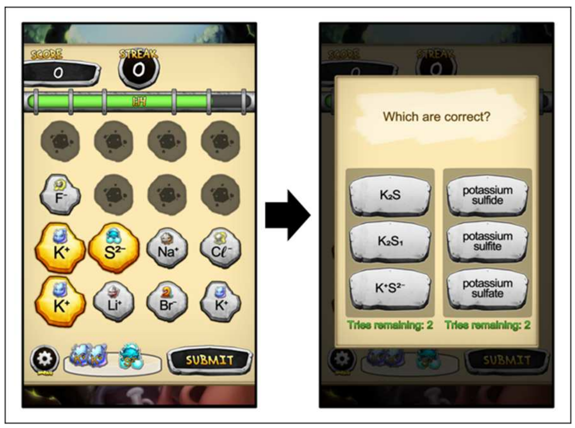


Figure 1: Screenshots of typical in-game screens

Feedback from teachers during the first project revealed that they had difficulty locating and interpreting information presented in the CMS data tables. For instance, they could not easily determine how well their class was performing from the Class Summary table (Figure 2), and much effort was required to determine the frequency of a type of mistake from the Class Errors Analysis table (Figure 3).

Player List			Class Games Analysis					
	Idx No.	Username	Games Played	Highest Score	Highest Streak	Mastery Level	Level (Exp)	Highest Compound (Score)

Figure 2: Class Summary table headings

Count	Game Mode	Index No.	Name	Game Time (+8 GMT)	(Dissoc. Ion) Selected Cations	(Dissoc. Ion) Selected Anions	Symbol Recognition Error	MCQ Formula Errors	Synthesis / MCQ Formula Feedback	MCQ Name Errors	MCQ Name Error Feedback

Figure 3: Class errors analysis table headings

2 WRITEFORMULA DATA VISUALIZATION JOURNEY

To empower teachers to make sense of the CMS information and support just-in-time instructional decisions backed by the information about students' performance, the team (more than half of whom were teachers) decided to incorporate data visualization into the CMS. The key work to be done was identifying useful information about student performance to support classroom instruction more effectively, and identifying, reorganising, and analysing the game moves to obtain the desired information. Since the wRiteFormula game data is quantitative, the team's working definition of data visualization was: Data visualization is the graphical display of quantitative data that is representative of the data, and readable and usable by teachers (adapted from Assam et al., 2013; Few, 2013; Kosara, 2007).

The first step was to identify and articulate what constituted essential information about student learning. The discussion started with the teachers listing questions that were important to them, then determining which questions were essential to answering the overarching question of whether students had learnt ionic compound nomenclature. Next, the team identified the data needed to answer the essential questions, and discussed how to present that information to make it usable by teachers (Figure 4).

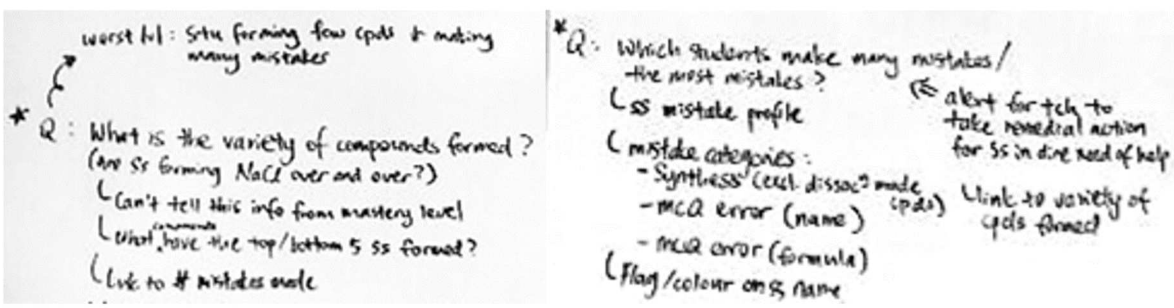


Figure 4: Example of notes from a preliminary discussion

In some instances, combinations of data from the game moves were needed to answer one question. For example, to determine students' proficiency in identifying the chemical names and formulae of compounds, the team concluded that the information about students' game mastery level would need to be supplemented by other indicators like the percentage of correct answers, the streak of correct answers, and the variety of compounds formed. This information was eventually presented on the Class Summary page (Figure 5) as a pie chart to illustrate the proportion of students at each game mastery level block, and an accompanying table (the Alert System) that aggregated the three indicators and sorted students into three bands: exceeding expectations; meeting expectations; approaching expectations.

The Alert System was created to display and help teachers monitor students' level of mastery of ionic compound nomenclature. When discussing the criteria for the Alert System indicators, the team agreed that customizability was necessary as different schools, classes and teachers would have different standards, and those standards might change over time. Thus the Alert System criteria was made adjustable, and the percentiles of 54,000 game moves for each indicator (obtained from the first project) were used to guide the choice of the default values. Figure 6 shows the Alert System's default values (Example 1) and the effect of lowering the default values (Example 2).

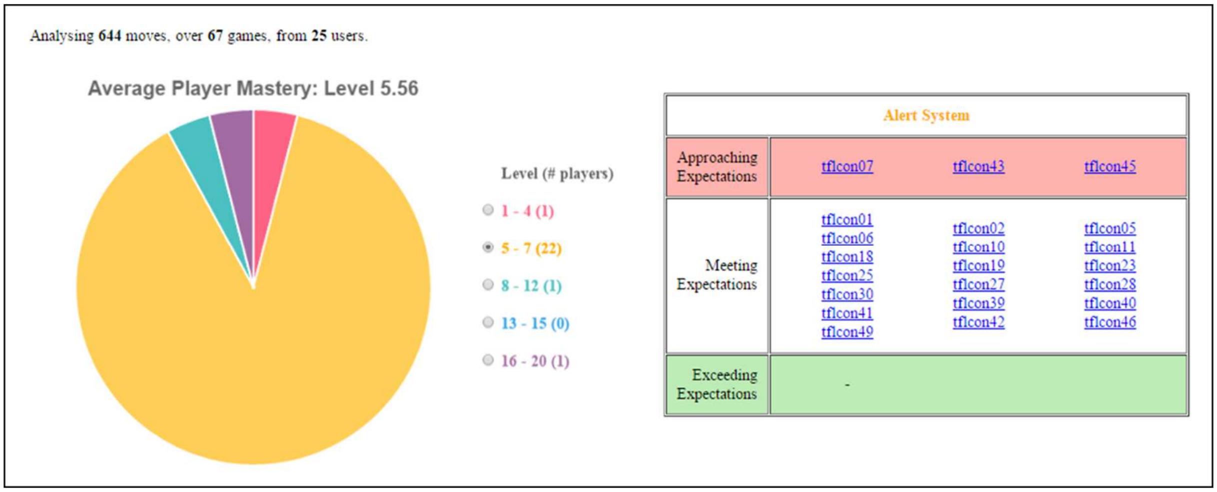


Figure 5: Sample class summary page

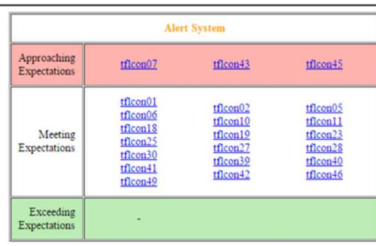
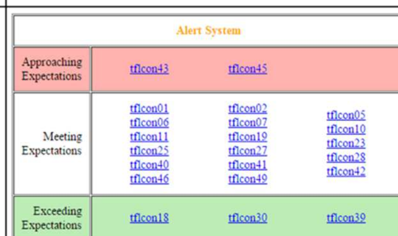
Example	**1 (Default)**		**2 (Adjusted)**	
Alert System				
Criteria to Use	**Boundary Conditions**		**Boundary Conditions**	
	Lower Boundary	**Lower Boundary**	**Lower Boundary**	**Upper Boundary**
☑ Variety of Compounds Formed	≥ **4** Categories of Compounds	≥ **6** Categories of Compounds	≥ **2** Categories of Compounds	≥ **4** Categories of Compounds
	≥ **1** Compound(s) per Category		≥ **1** Compound(s) per Category	
☑ Percentage of Correct MCQs	> **75** %	> **85** %	> **50** %	> **75** %
☑ Maximum Streak	≥ **2**	≥ **6**	≥ **2**	≥ **4**

Figure 6: Example of the effect of a change in the alert system criteria

To allow teachers to make sense of students' common mistakes quickly, the team explored how to present information on the frequency of mistakes made meaningfully. After much discussion, the team grouped the seventeen types of mistakes into four major categories. The mistakes in each category were presented as a pie chart to indicate the proportion of each mistake at a glance, with an accompanying table to provide further details for each of the top three types of mistakes in that category (Figure 7).

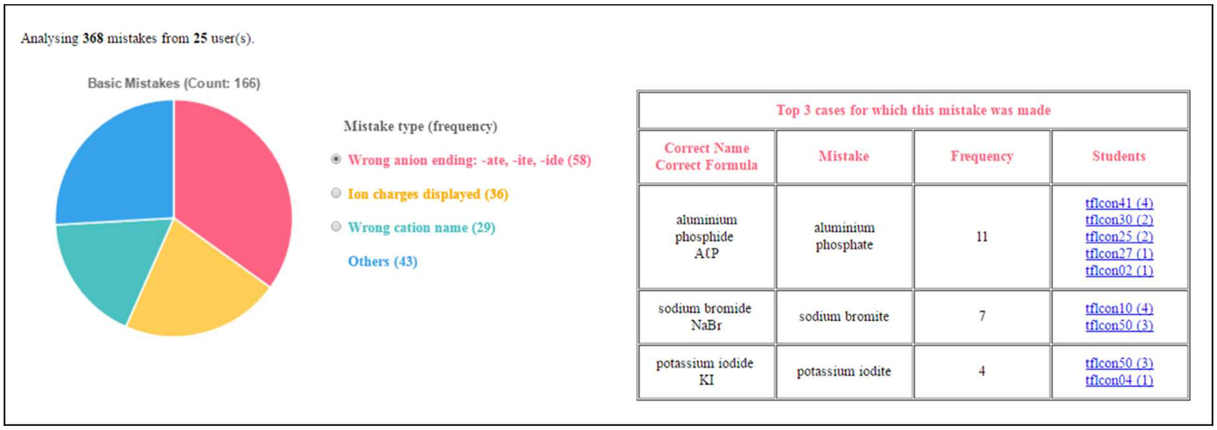


Figure 7: Sample class errors analysis page

An underlying consideration throughout the project was the validity and accuracy of the data visualization. To ensure all game moves were accounted for, and that the graphical image was representative of the raw data, a range of games was played to cover commonly expected scenarios, and the data generated from those games was analysed through a variety of manual and automated methods. The output of the different methods of analysis was compared to verify the accuracy of each method, and ultimately, of the CMS.

3 TEACHING AND LEARNING WITH WRITEFORMULA DATA VISUALIZATION

While the CMS was being developed, the team concurrently discussed how the data visualization would impact teaching and learning. In the earlier project, the team had adapted the discovery-learning approach from Wirtz, Kaufmann, and Hawley (2006) to incorporate the use of wRiteFormula (Thong, Qiu, & Chia, 2016). In this project, the team reviewed the earlier lesson design, and looked at which sections of the lesson that could be strengthened by the use of data visualization. For example, during the class discussion phase of the lesson, teachers could refer to the Class Errors Analysis page (Figure 7) to identify common mistakes, decide which examples to use for the classroom discussion, or which students to call on to respond to questions. After a lesson, teachers could review the Class Summary page (Figure 5) to identify which students might need more support in the subsequent lesson.

4 CONCLUSION

Having teachers participate actively in the project was critical in creating a reliable and relevant educational resource with just enough features and options for teachers to make just-in-time instructional decisions supported by information about students' performance. Along the way, the team acquired a greater understanding of proficiency profiling through the work on the criteria and mechanisms of the customizable Alert System. While the team's data literacy has definitely improved as a result of all the discussions, other teachers who wish to use wRiteFormula may not be as proficient, thus the team will include a data literacy component in workshops to train teachers who intend to adopt the use of wRiteFormula for learning and teaching.

At the time of writing, the development work has just been completed, and the team is in the process of deploying wRiteFormula to local schools. The team is excited about the prospect of making wRiteFormula available to more students. However, due to funding constraints, and lack of manpower and experience in managing and supporting large scale adoption of this innovation, the team hopes to work with others who can assist in the scaling up effort.

5 ACKNOWLEDGEMENTS

This project (NRF2015-EDU001-EL025) was part of the eduLab programme jointly managed by the Educational Technology Division, Ministry of Education, Singapore and National Institute of Education, Singapore, and funded by the National Research Foundation, Singapore. The authors would also like to acknowledge the significant contribution of each team member: Ang Xiu Qin, Kevin Andrew Thesman, and Lee Sin Yen Joselyn from Ang Mo Kio Secondary School; Asmahan binte Aman and Tan Kee Sing from Chua Chu Kang Secondary School; Addie Siew Chin Hoong, Alan Teo Boon Hwee, and Seow Tzer Yeun from Edgefield Secondary School; Conrad Zheng and Phua Zhengjie from Raffles Institution.

REFERENCES

Azzam, T., Evergreen, S., Germuth, A. A., & Kistler, S. J. (2013). Data visualization and evaluation. *New Directions for Evaluation, 2013 (*139*),* 7-32. http://dx.doi.org/10.1002/ev.20065

Chia, P.X., & Sivaram, H. (2016). Developing and using wRiteFormula to teach ionic compound nomenclature. In J. Lavonen, K. Juuti, J. Lampiselkä, A. Uitto, & K. Hahl (Eds.), *Electronic Proceedings of the ESERA 2015 Conference. Science education research: Engaging learners for a sustainable future*, Part 4 (co-ed. E.A. Kyza, & C. Malmberg), (pp. 624-633). Helsinki, Finland: University of Helsinki.

Ixora Studios Pte Ltd. (2016). wRite Formula (Version 32) [Mobile application software]. Retrieved from http://play.google.com/store

Few, S. (2013). Data Visualization for Human Perception. In M. Soegaard, & R.F. Dam (Eds.), *Encyclopaedia of Human Computer Interaction.* (2nd ed.). Retrieved from https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/data-visualization-for-human-perception

Kosara, R. (2007). Visualization criticism – the missing link between information visualization and art. *Proceedings of the 11th International Conference on Information Visualization,* 631-636. http://dx.doi.org/10.1109/IV.2007.130

Thong, C.H., Chia, P.X. & Kang, Z. (2015). The making of wRiteFormula: Issues and considerations for a chemistry nomenclature app. In S. Carliner, C. Fulford & N. Ostashewski (Eds.), *Proceedings of EdMedia: World Conference on Educational Media and Technology 2015* (pp. 215-221). Waynesville, NC: Association for the Advancement of Computing in Education.

Thong, C.H., Qiu, Y.R., & Chia, P.X. (2016). Learning chemical formulae and names through discovery-learning. In S.Y. Foo, C.C.C. Ong, & L.L.M. Chia (Eds.) *i in Practice Volume 4* (pp. 1-5). Singapore: Educational Technology Division, Ministry of Education, Singapore. Retrieved from http://ictconnection.moe.edu.sg/publications/i-in-practice/articles&func=view&rid=217

Wirtz, C. M., Kaufmann, J., & Hawley, G. (2006). Nomenclature made practical: Student discovery of the nomenclature rules. *Journal of Chemical Education, 83(*4*)*, 595-598. http://dx.doi.org/10.1021/ed083p595