An empirical study of user perceived usefulness and preference of open learner model visualisations

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***Abstract*—Many higher education institutions have reformed their academic programmes to adopt unit learning outcomes. It is essential for effective learning management tools to support this fundamental transformation. We see the need for a tool that provides visualisations of Open Learner Models (OLM) and associated e-portfolio content to guide students in achieving intended learning outcomes, help evidence their learning and keep them engaged in their study. OLMs surface the relationship between learning activities and tasks, formative and summative assessment, and intended learning outcomes. We have developed and validated a set of candidate visualisations for such OLMs. We report key findings from our study in terms of potential users' feedback on our tool's support for tracking learning progress against learning outcomes. Our findings can inform and refine learning management systems.**

Keywords—education, open learner model, e-portfolio, formative assessment, information visualisation

I. Introduction

Teaching and learning have been undergoing a transformation from an input-based to a more outcome-based paradigm. Educators are now confronted with the challenge of creating an optimal learning environment to not only engage students in the subject learnt but also to guide them in taking greater ownership of their learning. Students are now also increasingly required to accumulate their learning artefacts to evidence their achievements. An Open Learner Model (OLM) is a computer-based representation used to indicate a learner's progress and achievements. Many types of learning data are of interest to teachers and learners and have been externalised through OLM visualisations. A key motivation is to improve learners' meta-cognitive activities [1] such as self-assessment and self-reflection through formative assessment.

Doubtfire, a web application tool has been designed to facilitate the Task Oriented Portfolio teaching and learning approach to guide students in managing their learning [6]. To better support student learning in outcome-based paradigm, we aim to enhance it with OLM visualisations to provide direct support for linking assessment tasks and the intended learning outcomes (LO).

A wide range of representations have been adopted and adapted from information visualisation system to OLM to suit diverse user information needs [2, 3]. However, there is no empirical study on how useful these visualisations are from the user perspective nor if there are any preferred visualisation formats in presenting a learner model. In addition, not many visualisations are provided to facilitate meta-cognitive activities supporting LO achievement through assigned learning tasks.

In this study, we test various prototype visualisations for capturing students' learning task progress towards achieving LOs. We adopt some existing OLM visualisations and propose some new visualisations based on existing visualisations from other domains [4]. We validate from user perspective if these visualisations are likely to be useful and accepted by the potential users through a detailed survey and interviews.

This paper presents the analysis results of potential users' perceptions of these visual representations. Section II provides background and motivation to our research. Section III shows our proposed visualisations and Section IV outlines the methods used to investigate user perceived usefulness and their preference on the proposed OLM visualisations. Results obtained are reported and discussed in Section V, followed by the threats to validity in Section VI. We conclude with a summary and key future research directions in Section VII.

II. Background and Motivation

A. Learning Tasks and Learning Outcomes

A "learning outcome" represents knowledge, skill or experience acquisition that is demonstrated and assessed during an individual course or degree programme. LOs play a key role in defining what a learner knows, understands and is able to do on completion of a learning process [5]. Linking learning tasks to LOs has become popular in course and programme design.

B. Doubtfire Learning Management Tool

Doubtfire has been used to support portfolio-based constructive alignment approach in which students progress through a series of unit tasks [6]. The tool supports students in monitoring their progress through two visualisation formats: a *task list* and *burn down chart*. The task list exploits different colours to display various task statuses, while the burn down

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chart, adopts the Agile Scrum technique that uses line graphs to show progress over time with work remaining decreases as tasks are completed, see Fig. 1. Doubtfire enables students to create a portfolio that demonstrates they have met unit LOs. Although existing LMSs have been used to link learning activities with institutional missions and program goals, the linking is mainly to fulfil the reporting purposes [7] and has limited support for student learning. Extending learning management systems with visualisations that show progress toward achieving unit and course LOs is hoped to help motivate students during their studies.

C. Open Learner Models (OLM)

The OLM concept originated from intelligent tutoring systems, where students' learning models are stored in a machine-usable format for the system to provide individualised instruction to students. Traditionally, the learner models are invisible to the students. Due to great potential educational benefits, Self [8] has proposed to expose students to their learner model which contain their knowledge level and misconceptions in a computer-based representation.

Bull [9] found that many students were receptive to use OLMs. This idea has been applied in the development of tools that is believed to support and profit both the teaching staff and students with the bunch of information and data in the form of multiple analyses and visualisations [10]. The main benefit reported is OLM can improve learners' meta-cognitive activities and for them to take control over their learning [1].

One key challenge is to create an effective interface to present the learner model and to support user interaction [11]. Many representations have been adopted and adapted from information visualisation system to present OLMs such as skill meter [12], pie chart [13], tables [14] and many more. There is no empirical study on how useful these visualisations from the user perspective and if there are any preferred visualisations for presenting a learner model. Besides that, while OLM literature includes a substantial body of research focusing on inspection of individual data, there is limited work exploring the group statistics and provision of comparison features [15].

Information visualization systems consist of two main components: representation and interaction. While computer graphics underpin the representation component, that is, to map data to the display of graphical representation, the interaction component concerns the direct involvement of the user with the system to explore the data set to uncover insights [16]. Therefore, it is important to investigate effective OLM representation formats from user perspective to guide the design and development of the OLM tool.

III. Visualising Progress on Learning Outcomes

This work aims to examine if additional visualisations of student progress toward achieving unit LOs can help support student learning by making adjustments to the existing Doubtfire tool to an enhanced version, called Doubtfire++ for the purposes of this paper. Visualisations capturing students' learning task statistics and LO achievements are proposed. We use existing OLM visualisations, and trial some new visualisations from information visualisation literature. Fig. 2 shows several examples – table listing, bar graph and pie chart, intended for inspecting learning task statistics.

Fig. 3 shows ten visualisations for inspecting individual LOs. Six – skill meter, spider plot, tree map, smiley face, table and word cloud – were adopted from [3]; grid plot from [17]; and the other three – bar graph, target plot and star pictogram – from common statistical representations.

We enrich the current OLM for users to inspect data statistics of a class or parts of a class, see Fig. 4. The boxplot is a popular graphical form for displaying data distribution and has been widely used in exploratory data analysis [18]. We also propose alternatives – ladder, fan and line scales for inspecting these data based on how a boxplot can graphically depict a summary of the data distribution. We allow users to make comparison of their achievements by adapting the visualisations from Fig. 3 and Fig. 4 to accommodate the comparison features, see Fig. 5.

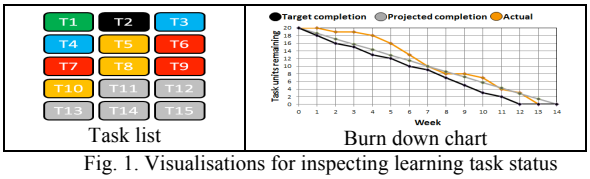
IV. Methods

A. Evaluation Strategy

The OLM prototype tool design has been built through the video simulation using Macromedia Captivate to test a variety of visualisation options for use in Doubtfire++. We created mock-up of each visualisation with sample scenarios for potential users. They were introduced to this tool through this simulation about the features of the tool and how to use it.

B. Experimental Procedure

This study applied an explanatory sequential design methodology [19] for collecting, analysing, interpreting, and reporting data regarding initial user opinions and requirements and reactions towards our proposed visualisations. The research design started with the collection of quantitative data through an online survey for respondents to rate each visualisation on a five-point Likert scale from 1=not useful to 5=very useful. They were also asked to select their most preferred visualisations from five aspects as illustrated in Fig. 2 to Fig. 5. For visualisations in Fig. 2, 4 and 5, participants were asked to select one of their preferred visualisation whereas for Fig. 3, respondents were asked to select three of their preferred visualisations. This was followed by subsequent collection of qualitative data through face-to-face interviews. The interview protocol was designed so that some questions were fixed and some were followed from the results of the quantitative phase. These interviews were used to triangulate, cross-validate and explain the initial quantitative results obtained from the questionnaires in more depth.



Task list Burn down chart

Fig. 1. Visualisations for inspecting learning task status

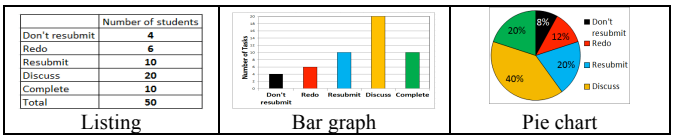


Fig. 2. Visualisations for inspecting task status statistics

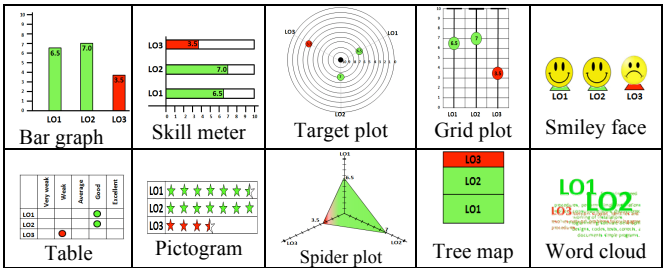


Fig. 3. Visualisations for individual learning outcome achievements

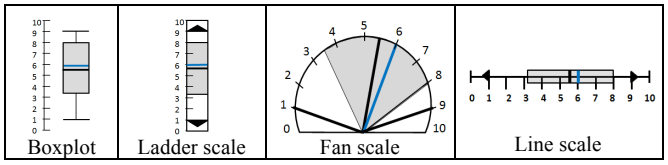


Fig. 4. Visualisations for inspecting group learning outcome achievements

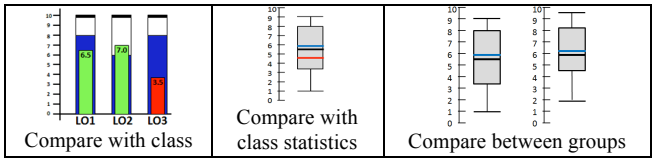


Fig. 5. Visualisations for comparing learning outcome achievements

V. Results and Discussion

108 respondents from Swinburne University of Technology have participated in this study yielding 64 valid samples. 16 of them were teaching staff and 48 were students. Most (59) of them were from Engineering and Science disciplines with 44 were familiar with visualisation techniques. 10 of them volunteered to be interviewed.

Statistical tool, SPSS, was used to generate the descriptive statistics and correlation coefficients. Table II shows respondents' perceived usefulness and individual preferences for inspecting learning task status statistics. Pie chart (μ=3.09) and bar graph (μ=2.98) were rated as more useful visualisations than a textual listing (μ=2.52) with 30 and 24 respondents preferred bar graph and pie chart respectively. Only 10 liked listing. The interview results corroborated this finding:

- *"Bar chart and pie chart are easy to read. Pie chart clearly describes full workload and task breakdown."*
- *"Although listing gives good description of task status, it is dull. We need more time to interpret the data it displays."*
- *"Pie chart is popular and I am familiar with it. It is clear and tells me where more resources should be allocated and motivate me to get the whole chart into green – complete."*

Table III shows summary responses and mean scores for useful forms and preferred view to inspect individual LO achievements. The higher counts cluster in the upper left side

TABLE II. RESULTS FOR INSPECTING LEARNING TASK STATISTICS

Format	Very useful			Not useful		μ	Preferred view
	(5)	(4)	(3)	(2)	(1)		
Pie chart	9	17	16	15	7	3.09	24
Bar graph	8	17	15	14	10	2.98	30
Listing	5	8	19	15	17	2.52	10

TABLE III. RESULT FOR INSPECTING INDIVIDUAL ACHIEVEMENTS

Format	Very useful			Not useful		μ	Preferred view
	(5)	(4)	(3)	(2)	(1)		
Bar graph	20	22	12	9	1	3.80	45
Table	10	19	25	8	2	3.42	34
Skill meter	14	18	18	8	6	3.41	26
Grid plot	6	20	16	15	7	3.05	15
Pictogram	5	14	24	14	7	2.94	12
Textual	6	12	11	24	11	2.66	26
Spider plot	3	12	13	22	14	2.50	13
Target plot	1	6	12	23	22	2.08	5
Smiley face	2	8	13	13	28	2.11	11
Tree map	0	3	12	20	29	1.83	2
Word cloud	0	0	5	19	40	1.45	3

and lower right side of the table implies that certain views have a number of students that consider the visualisations to be more useful or least useful. The most useful representation is bar graph (μ=3.80), followed by table (μ=3.42), skill meter (μ=3.41) and grid plot (μ=3.05). The least useful formats are tree map (μ=1.83) and word cloud (μ=1.45). Word cloud, tree map and smiley face were rated by 40, 29 and 28 respondents respectively as not useful. Interview results confirmed that bar graph, skill meter and table forms were seen as useful representations whereas grid plot was perceived useful for those who have analytical mind. Responses received also revealed why the other forms were perceived as not so useful as follows:

- *"Bar graph is simple, clear, common, concise, easy to read, understand and compare each LO achievement.*
- *"Table form with graphics and simple text is a good representation as it is clear and easy to understand."*
- *"Target plot, spider plot and grid plot are hard to understand."*
- *"Star pictogram might be misleading as star in general means good even with only one star."*
- *"Smiley faces and word cloud are too abstract to indicate achievement."*
- *"Spider plot causes confusion as the points are linked and as if there are relationships among the learning outcomes."*
- *"Grid plot has the racing metaphor. It is useful for people with analytical mind but maybe not for students across all cohorts."*

45 and 34 respondents rated bar graph and table as the two most preferred views respectively. The least preferred views were tree map and word cloud. This is interesting given the adoption of word clouds and tree maps in many domains. Interview details give explanation to this:

- *"Tree map may cause misunderstanding that the increment of one LO will reduce the other."*
- *"I find it hard to determine my achievement level through the font size of the word cloud as it is too abstract."*

Interestingly, although textual form was only rated as moderately useful, 26 respondents liked it, same as the number of respondents who preferred skill meter. Respondents said:

- *"Textual form is important but graphics have better expression power. It is ideal to have a combination of both."*
- *"Pure visual is no good for a colour blind person unless it has alternative textual support."*

So, textual form in simple text or number can be incorporated to increase the expression power of the graphical form.

Table IV shows responses to inspect group achievements. Boxplot is found to be the most useful and most preferred representations with μ=3.63. There was a suggestion to have different visualisations for students and teaching staff. The interview results supported the quantitative finding. Respondents hold different opinions on the fan scale:

- *"Boxplot is widely used and is a familiar representation. It is simple clear, easy to understand. Each line clearly shows one piece of information."*
- *"Fan scale would be easy for students to interpret. Boxplot and line scale would be more appropriate for teaching staff."*
- *"Fan scale is confusing."*

Table V shows summary responses about comparison feature. Respondents felt that comparing individual against group achievement (μ=3.75) is the most useful and preferred view with 37 respondents favoured this view. Respondents' comments explained this point:

- *"It's this (comparing with group achievement) that has pure visual impact and is the most generic for students."*
- *"I can compare with my class without invading privacy. It is a good way to have students evaluate and compare their abilities. It stimulates the competition aspect."*

Mabbott and Bull [20] found that while some students were very interested in comparing features, this is offset by some students who thought that this feature is not useful. Our finding explains this point. For students who always strive to stay competitive, they were very positive towards having this feature. In contrast, students who only care for their own achievement hold a negative perception on it:

- *"I feel that I should always stay competitive. So the comparison features is really good to know your position in class and how the whole class performs."*
- *"I only care for my achievement so this feature is not useful. It may be more useful to teaching staff"*

The interview results show that students as well as some of the teaching staff were receptive to use the proposed tool.

- *"These visualisations give me visual feedback that saves me time to see lecturers for verbal feedback."*
- *I can address issues with students and encourage them to manage their learning. It helps to question the level of their learning, especially their overstated confidence. Seeing the comparative analysis will keep them aware if they are really good. So, it is a "secret tool"!"*
- *"As an instructor, I would access the learning information to understand my students' progress, anything I can do to reinforce their learning or if there is any problem area with myself."*

We further analyse the data to investigate the relationship between perceived usefulness and preferred view by using Pearson product-moment correlation coefficient. We found that there was a very strong, positive correlation between perceived usefulness and user preference, r=0.816, n=21, p<0.01 with higher perceived usefulness ratings correlated with most preferred views. The result suggests a relationship exists between perceived usefulness and preferred views. This finding indicates that users' preferred view is closely related to their perceived usefulness of the visualisations. Representation formats that are useful can increase user preference and thus their experience in using the tool.

Some suggestions received include the use of Stephen Few's bullet chart and parallel coordinate plot to enrich the existing OLM visualisations. For navigation, game metaphor such that having different interaction level to engage users to explore more information was proposed. Another suggestion was to have bifocal technique so that users will have better view with strong visuals. These are all good inputs to expand the use of visualisations in existing OLM research.

While color blind issue was raised, some respondents highlighted solutions to this issue, including providing double visual such as the use of hover text and the use of a single hue with different gradient to represent the qualitative ranges of LOs.

TABLE IV. RESULTS FOR INSPECTING GROUP ACHIEVEMENTS

Format	Very useful				Not useful	μ	Preferred view
	(5)	(4)	(3)	(2)	(1)		
Boxplot	13	29	11	7	4	3.63	40
Line scale	7	19	15	19	4	3.09	11
Ladder	4	11	23	21	5	2.81	7
Fan scale	3	9	16	24	12	2.48	6

TABLE V. RESULTS FOR INSPECTING COMPARISON FEATURES

Format	Very useful useful				Not	μ	Preferred view
	(5)	(4)	(3)	(2)	(1)		
with group	14	32	9	6	3	3.75	37
with group stats.	12	19	15	13	5	3.31	17
sub-groups	6	21	11	15	11	2.94	10

VI. Threats to Validity

So far we have had 64 respondents to our survey and have interviewed 10 people in detail. Most respondents were from Engineering and Science disciplines. We used an Introduction to Programming course and Computer Science degree programme as our example scenarios for our visualisation tool mock-up for which most of them had prior experience using Doubtfire. Thus generalising these results to others is not possible without further feedback from more diverse users. Different visualisations may be preferred for the same models with other kinds of courses, degrees and respondents without prior experience of our tool.

VII. Summary

To facilitate outcome-based teaching and learning, we propose enhanced visualisations to support monitoring student progress. Our approach can help teaching staff to create an environment in which students can better reflect on their achievements. We have identified a set of visualisations that user perceived useful representations of learning data. Our results so far are based on a scenario-based design. We have started to implement these ideas in a more comprehensive prototype for further evaluation. Based on the feedback, we will iteratively enhance the tool and deploy it in several units that have portfolio-based assessment with future work involving analysis of its usage and impact on learning and teaching.

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