Predicting Students' Examination Performance with Discovery-embedded Assessment using a Prototype Diagnostic Tool

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Abstract: Early detection and provision of feedback on learners' performance are essential mechanisms to allow learners to take prompt action to improve their approach to learning. Although students may learn how they perform in mid-term quizzes, the results cannot reflect how they might perform in the final examination. However, quiz results with set answers cannot illustrate the comprehensive skills and knowledge that are expected in university study. This paper reports on the use of a diagnostic tool to analyse the process of students working on a discovery-embedded assessment task in the collaborative learning environment of a microbiology course. The diagnostic tool identified that those learners who performed less well in the assessment tasks also performed less well in the final examination. This tool can provide early detection of those facing learning challenges in comprehensive assessment tasks, so that educators can provide appropriate support.

1 INTRODUCTION

Learners nowadays have had a range of experiences of using digital technology since they were very young (Prensky, 2001). Although many of the devices used have been for entertainment, information retrieval and social networking, they have also been widely used for educational purposes. Technology has been widely used in universities in Hong Kong, and all universities have had institution-wide platforms that enable teaching faculty to communicate and share resources with their students. This allows educators to consider alternative learning experiences so that they can be better engaged and have more opportunities to demonstrate intended learning outcomes for courses. Using technology for assessment, such as online quizzes, is becoming more popular, because these can be used to measure breadth of knowledge and can provide feedback quickly to students (Bierer et al., 2008), and this undoubtedly provides timely feedback to students (Brady, 2005; Nicol, 2007). Although online quizzes may give teaching faculty some indication of student performance, students cannot demonstrate skills in explanation, analysis, evaluation or creating new concepts through quizzes. Teaching faculty therefore design assessment tasks that facilitate the demonstration of higher-order thinking by students, as required in university study. Unlike with online quizzes, the initial challenge for teaching faculty is the lack of resources to provide timely feedback to individual students. Feedback through peer assessment may be incorporated so that students can provide comments and suggestions for individuals or peer groups on their performance (Hodgson and Chan, 2010). However, good preparation and training of students is necessary if reliable peer rating and feedback is to be expected (Xiao and Lucking, 2008).

In considering alternative options for engaging learners and providing feedback for collaborative learning, Web 2.0 tools such as blogs, wikis and forums are often used in university courses. These social media support personalization, collaboration, social networking, social presence and collective wisdom when participants interact with one another (Dabbagha and Kitsantas, 2012). Many different successful cases of social media adoption have been reported in the literature across different disciplines, including business (Barczyk and Duncan, 2012), medical and veterinary (Coe et al., 2012), and science, technology, engineering, and maths (STEM) education (Ahrama et al., 2011). The Committee of Inquiry into the Changing Learner Experience (2009) found that although learners are

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expected to be participatory and deploy appropriate technical competence in using the applications for academic purposes, some may not have the essential digital literacy or may lack cognitive capabilities such as critical evaluation and therefore adopt a casual approach to evaluating information. Therefore, it is necessary for teaching faculty to make early diagnosis of student learning behaviour.

Different technical solutions have been developed to help teaching faculty to detect students who encounter learning challenges at an early stage so as to provide just-in-time supportive measures. Patterns of individual student activity working through the e-learning platform can be tracked through the system log. Student behaviour is determined by a number of quantitative indicators, such as frequency of log-in, and frequency of various online activities such as postings contributed to online discussions, blogs and wikis. Jong et al. (2007) analysed learners' behaviour, including time spent reading discussion postings, the number of articles submitted and frequency of log-in. In some sophisticated learning diagnostic systems, accuracy of content contributed by learners is evaluated (Hwang et al., forthcoming).

IT solutions can be implemented to analyse learners' behaviour and visualize interactions between individuals and groups. Arnold and Paulus (2010) identified a number of metrics that impact on learning performance: the number of postings in forums, modelling and feedback (i.e. replying to postings), and interactions (i.e., replying to replies, which pertains to various forms of collaboration). One feasible solution is to measure and interpret these metrics to construct a quantitative index to identify students with learning challenges.

In addition, factors such as user-friendliness and timeliness of analysis should be considered when designing a diagnostic tool to predict student performance. Perceived usefulness and perceived ease of use are postulated as critical factors in the Technology Acceptance Model (Davis, 1989), and the latter determines the readiness of users to accept adoption of the system. Timeliness of analysis is equally important, because supportive actions should be provided at an early stage. However, timeliness may be compromised by the analytical accuracy of a diagnostic tool. Lui et al. (2009) assert that timeliness should be emphasized more than accuracy, because decision making on types of support provided can be estimated through the broad prediction of levels of student performance attained.

Considering both the user-friendliness and timeliness of a diagnostic tool, we report the development of a prototype that can be used to diagnose and predict learners' performance. The objectives of the prototype are to (1) evaluate learner contributions in collaborative work, (2) analyse learner engagement in the process during online activities, (3) predict learner performance at the end of the course through visual presentation of diagrams, and (4) alert teaching faculty to take action early for learners who may encounter learning challenges.

2 DEVELOPMENT OF DIAGNOSTIC TOOL: AN ACTION DESIGN RESEARCH APPROACH

Agile methodologies are commonly adopted as the development model for providing 'quick-and-dirty' solutions because of rapid solution delivery, efficient evaluation, instant modification and ease of maintenance (Beck, 1999). Combining action research and design science (Hevner and Chatterjee, 2010) methodologies, Action Design Research (ADR) (Sein et al., 2011) provides the agility and capability for extensive user input from different stakeholders, in which an iterative process takes a holistic view from the perspectives of educators, technologists and stakeholders with dual roles, e.g., teaching staff with strong technology backgrounds. It is essential to have iteration of modifications based on feedback from various stakeholders, given the exploratory nature of the development of the prototype, in order to truly deliver a solution to solve the problems faced by stakeholders.

Analysis, design and development of our diagnostic tool follows the set of guidelines postulated in the ADR approach. Discussion on the four interconnected stages and seven underlying principles, as suggested by Sein et al. (*ibid.*) are presented in the subsections.

2.1 Stage 1: Problem Formulation

The first stage of ADR involves identification of problems by the researchers, often from the practitioners' perspectives. Stage one involves two principles, as described below.

Principle 1: Practice-inspired Research. The research originates from a problem or an issue that has practical value. This usually involves attempts to solve problems happening in real life by developing IT solutions.

In the case of teaching and learning in an institutional context, large class size (often involving more than 100 students) is at the root of many issues that arise (Gleason, 2012). Providing timely and in-depth formative feedback to individual students, especially during the continuous assessment process, becomes difficult for instructors (Cole and Spence, 2012). Moreover, it is extremely difficult to monitor the progress of individual students' learning.

Principle 2: Theory-ingrained Artefact. The researchers then aim to structure the problem. Afterwards, they identify solution possibilities and suggest design guidelines to deliver the solution.

In this case, the problem is structured more accurately: the development of a prototype diagnostic tool to predict students' examination achievements. Most possibly, this prototype makes use of social networking analysis techniques and should be relatively easy for use. Results of the diagnosis should be easy to read and interpret, even for educators without a technical background.

2.2 Stage 2: Building, Intervention and Evaluation

The second stage in ADR involves generating the initial design of the IT artefact, i.e., a holistic view on IT and its application for socio-economic activities that extend beyond the IT solution itself (Orlikowski and Lacono, 2001). This stage involves three principles: guiding participation from different stakeholders, and continuous evaluation and input from these stakeholders.

Principle 3: Reciprocal Shaping. The organizational and technical domains exert inseparable influences on each other. This implies that the organizational settings (e.g., culture and practices) have a significant impact on the technical design of solutions. Similarly, technical solutions have a long-term impact on organizational culture and practices.

In this case, departmental settings and subject-specific settings play an important role in the design of technical solutions. For example, in an academic department with a strong technical background, sophisticated functionalities offered by the system would be dominant. On the other hand, educators' usage experience (UX) would be more favoured than 'geek' functionalities without good UX.

Principle 4: Mutually Influential Roles. The stakeholders in an ADR project should learn from others with different roles. Stakeholders often carry more than one identity, e.g., as a researcher and a practitioner conducting front-line duties.

In the development of the prototype diagnostic tool, stakeholders had different roles: a subject-domain expert in microbiology, an educational practitioner, an e-learning consultant, a technical developer, an educational researcher and an information systems researcher. Some researchers had multiple roles: the subject-domain expert in microbiology was also an educational practitioner and educational researcher, while the e-learning consultant was also an educational practitioner and information systems researcher.

Principle 5: Authentic and Concurrent Evaluation. Instead of evaluating software development at fixed milestones under traditional software engineering models, e.g., waterfall model (Pressman, 2010), evaluation and modification of the prototype should be 'interwoven' at every stage of software development, carefully taking feedback from different stakeholders.

Evaluation of this prototype has been conducted continuously during the development cycle. Typically, the user interface has been optimized to cater for the needs of subject-domain experts in microbiology, who are usually from non-IT backgrounds by presenting controls and results in a graphical format. The metric for evaluating the social networking strength of students was fine-tuned during development to provide more accurate predictions, e.g., the effect of lurking behaviour in the online activities (Weller et al., 2005).

2.3 Stage 3: Reflection and Learning

The third stage of ADR extends the solutions built in the previous stage from a specific problem to a more generalized context. It should be noted that this stage is not linear with the previous stage but happens in parallel with the previous two stages. One important task in this stage is to modify the whole ADR process and future directions continuously according to the experience and lessons learned from the previous two stages.

Principle 6: Guided Emergence. The deliverable combines the continuous effort by all stakeholders and reflects the design that iteratively consolidates the input from concurrent evaluations in the previous stages. The final deliverable, therefore, reflects the organizational use, perspectives and stakeholders' preferences.

During the development stage of this prototype, different stakeholders provided continuous effort in testing and evaluating, similar to the prototyping model adopted in software engineering (Pressman, 2010). Extensive input having been received and reflected in the prototype, this was then ready for trial on additional courses.

2.4 Stage 4: Formalization of Learning

The final stage of ADR formalizes the learning in the whole ADR project and presents knowledge in the form of general solutions to a wider set of problems. Often, the experience and lessons learned are presented to the researchers' and the practitioners' community in the form of IT artefact and research papers.

Principle 7: Generalized Outcomes. Sein et al. (2011) explicitly recommend three deliverables in this stage: (1) generalization of the problem instance, (2) generalization of the solution instance, and (3) derivation of design principles from the design research outcomes (p.44). These are presented in the form of technical solutions (e.g., systems), documents (e.g., best practice and guidelines) and research papers.

In the context of this ADR project on diagnostic tool development, the solutions are presented as (1) a prototype that can be fitted into similar courses that include similar teaching and learning activities; (2) sharing in formal and informal sessions, institutionally and externally; and (3) presentation of research findings in conferences and journals.

The prototype diagnostic tool has been adopted in one microbiology course. The tool should fulfil the objectives as identified in the first stage of the ADR process. It should be able to predict student performance and provide a relatively easy-to-use tool for educators. The next section presents the background of this course.

3 BACKGROUND OF MICROBIOLOGY COURSE

This study was conducted with 77 students in a first-year course on microbiology. Among a variety of assessment tasks in this course, a four-week discovery-embedded assessment task was designed to enhance the engagement of students in their learning of microbiology and was weighted 20 percent of the coursework, compared with 55 percent for the final examination. In the task, students were asked to identify activities or through exploration and observation from their daily lives that were connected with microbiology. They were expected to work in groups to describe the connection between the identified activities or observations with the activity of microbes in comprehensible English and evaluate the positive or negative effects of the activities or observations in relation to the microbes.

To complete the coursework, students had to submit six cases, including three photos and three video clips, each clip lasting no longer than 30 seconds. They had to write some notes (between 30 and 80 words) to describe the activity or observation, stating the relationship between the subject matter in each case with a brief description of the outcome (positive or negative impact) of the activity being observed. In addition to posting all cases to a blog, students had to provide comments to six peer submissions so as to build critical evaluative skills and broaden the scope of their experience.

After the deadline for postings, having made discoveries, observations from their daily lives and critiquing peers on their submissions, the diagnostic tool was used to examine the interactions between students in the blog, and charts were generated to identify active and less active students.

4 ANALYSIS IN AN INTERACTIVE AND VISUAL WAY THROUGH THE PROTOTYPE DIAGNOSTIC TOOL

To fulfil these objectives, the tool analysed interactions between students in the online collaborative activities and presented the analysis in the form of an index and interactive maps.

Figure 1 presents the networking diagram showing the overall connectivity of students in the online activities in the microbiology course. The lines show the pattern of interactions between students. The interconnection between individual students in the online activities are displayed when the node is clicked, showing the nature of collaboration between students. All interactions between students are displayed as light grey lines in the system. Activities performed by an individual student would be displayed when the mouse cursor pointed to his/her name. A red line connecting two students implies that the other student made a comment to the student being analysed (inbound). A green line denotes that the student being analysed made a comment to the other student (outbound). When two students had both inbound and outbound activities, the line is displayed in yellow (bi-directional). Student identities cannot be disclosed due to the privacy legislation in Hong Kong. Therefore, parts of student names have been blurred in the figures shown here.

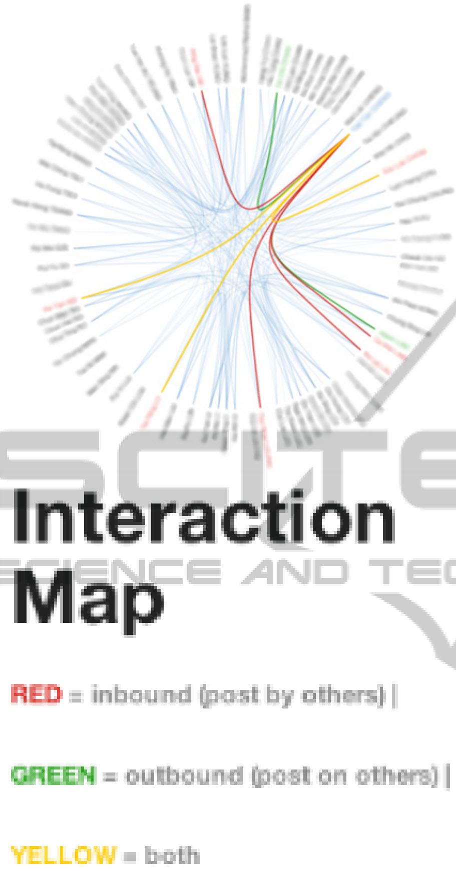

Figure 1: Connectivity of students on the microbiology course.

Apart from showing the nature of connectivity, the system can show the 'intensity' (i.e., number of postings) of student participation. When an individual node is clicked, the social network of the student will be displayed. Figure 2 shows the initial interaction network generated by the tool. The size of a node indicates the intensity of student participation in the online activities. The small nodes at the middle indicate 'disconnected' students. Different colours are used to indicate students with similar intensity of participation.

Figure 3 shows a display of the direction and nature of posts. The same colour notations (red, green and yellow) are used to represent inbound, outbound and bi-directional comments made in Figure 1. Similarly, the size of each node indicates the intensity of student participation in the online activities.

Figure 2: Intensity of student participation.

Dawson (2010) acknowledges that monitoring and visualizing the student online community would be an effective way to identify "at risk" students. Early and effective detection of these "at risk" students allows educators to prepare better remedial actions before it is too late for the final major assessment task. The "disconnected" students (i.e., students who seldom take part in the online collaborative activities) may represent those who are less engaged in a course, and will probably be those who require more attention from educators.

5 DIAGNOSTIC RESULT OF THE MICROBIOLOGY COURSE

The metric adopted to evaluate the accuracy of the diagnostic tool is the percentage of 'at risk' students identified by the tool. These students we describe as less engaged for the paper. Theoretically, the tool

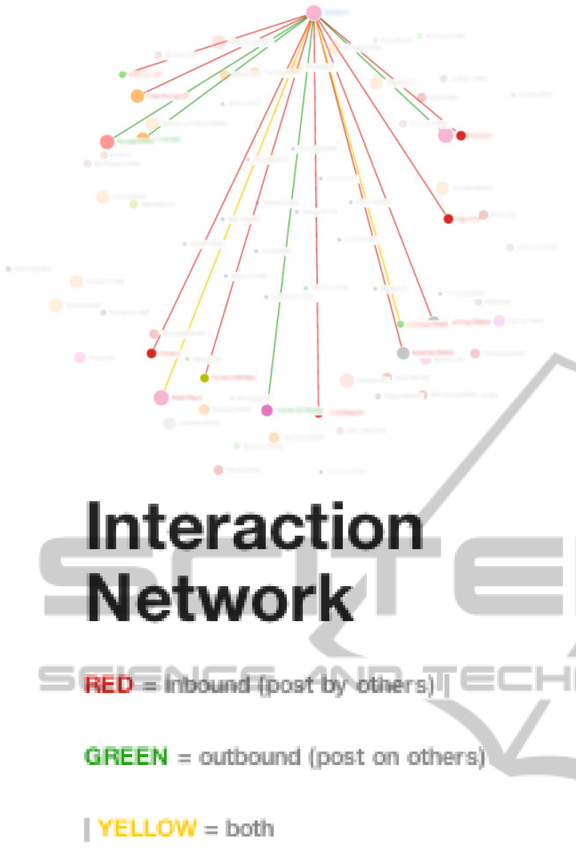

Figure 3: Direction and nature of posts contributed by individual students.

should be able to predict those students who achieve below the median score in assessment tasks if no action is taken. The result of the final open-book examination was used as the benchmark, as the coursework component was related to the online activities.

Although 77 students enrolled, two students dropped out, and 75 enrolments were recorded at the final examination. Examination results for the whole class were divided into four quartiles in ascending order of scores: Q1 (lowest 25%), Q2 (next 25% below the median), Q3 (next 25% above the median) and Q4 (top 25%). Fourteen out of the 37 (37.8%) less engaged students identified by the tool performed at or below the 50th percentile in the final examination.

The purpose of the prototype diagnostic tool was to provide early diagnosis to educators so that timely action could be taken to address students' learning difficulties. However it was not designed to provide a very accurate prediction of student performance in the final examination. Like many other forecasts,

Table 1: 'At risk' students as identified by the prototype diagnostic tool in different quartiles.

Quartile	No. of students	'Less engaged' students identified
Q1	18	7
Q2	19	7
Q3	19	3
Q4	19	1

false alerts for some outlier cases cannot be avoided, and four students were identified in Q3 and Q4 in this case. Rapid prediction of student performance who fell into Q1 and Q2 would be of significant value to educators, because use of the tool has the potential to reduce significantly the effort needed to identify the less engaged students.

Interpreting the number of posts in the online collaborative activities may provide a quantitative indicator of student engagement and participation. However, it does not provide comprehensive information, because the quality of online postings is not taken into account. For example, some postings on interesting topics may attract more responses for discussion. Therefore, it is necessary to evaluate students' contributions in a more comprehensive way, including evaluating the original posts by students, replies by others, and subsequent responses between students.

6 DISCUSSION

The purpose of designing this system was to provide an efficient way of identifying students with learning needs under tight time and human resource constraints, and to provide them with timely advice and help. This tool can be used primarily for diagnosis and should not be used solely to predict examination performance.

Application of this diagnostic tool extended beyond predicting the less engaged students to tracing interactions of these students in the associated social network in the study. It was observed that the less engaged students had few interactions and fewer students to interact with. This implies that the social network of those students was relatively closed. Educators can make use of the interaction network map generated by the diagnostic tool to trace the social network of the less engaged students, as students in the same social network may also be potentially 'at risk'. They can proactively make use of this tool to provide formative and timely feedback to those students, and to help them to overcome difficulties encountered in learning.

7 LIMITATIONS AND NEXT STEPS

We acknowledge that there are a few limitations on the existing version of the diagnostic tool. This includes no screening for quality of content in the postings, the tool providing only visual analysis of the nature and intensity of postings between students. The tool counts all postings; however, the content of some postings may not have significant value, e.g., postings such as ‘thank you’ or ‘I agree’ with no further explanation or justification. Second, it does not analyse when postings are submitted. It was observed that many postings were submitted shortly before the cut-off time for the online activities. Active learners may consider various learning opportunities and show engagement across the study period, and they would contribute postings during the whole period of the online task. Subsequently, students had multiple moments of engagement that would allow them to think, reflect on and review the discussion.

8 CONCLUSIONS

Teaching large classes is common in universities, and educators are expected to provide timely feedback. Automated computer-generated feedback may be perceived as a plausible option. However, educators may not be able to identify the less engaged students before the marking of final term papers. Emerging from the educational practitioner’s needs, a diagnostic tool for predicting student academic engagement was developed iteratively using the ADR approach. The pilot run of the tool showed the connections between students in the online activities. It successfully predicted 37.8% of the less engaged students who performed below the median in the final examination. However, the use of the diagnostic tool should provide timely assistance to those students, and to further identify other potential less engaged students through social network analysis. Within the social network of the course, there was a tendency for students producing similar performances to collaborate and connect with each other. This may be explained by the traditional English proverb, ‘*birds of a feather flock together*’, which is also exhibited in users’ blogging activities. Li and Chignell (2010) postulate that bloggers have a tendency to interact with other bloggers (e.g., replying to and continuing discussions) who share similar interests. By engaging active learners, educators can consider involving them to provide early assistance or mentoring to the less engaged students.

The next steps towards improving this diagnostic tool would include fine-tuning the metric for analysis and automatic importation of collaborative content from the learning management system. It is essential to keep track of posting time to the system, so that we can evaluate the effects of last-minute postings. Modification of the existing evaluation metrics would be needed. To further automate the process of importing collaborative data, an application programming interface (API) may be developed to reduce manual data importing before analysis.

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