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PAPER for an Educational Digital Library

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Abstract. GeogDL is a digital library of geography examination resources designed to assist students in revising for a national geography examination in Singapore. As part of an iterative design process, we carried out participatory design and brainstorming with student and teacher design partners. The first study involved prospective student design partners. In response to the first study, we describe in this paper an implementation of **PAPER** – **P**ersonalised **A**daptive **P**athways for **E**xam **R**esources – a new bundle of personalized, interactive services containing a mock exam and a personal coach. The "mock exam" provides a simulation of the actual geography examination while the "personal coach" provides recommendations of exam questions tailored to suit individual ability levels. This paper concludes with findings from a second study involving teacher design partners to further refine GeogDL.

1   Introduction

GeogDL [2] is a digital library of geography examination resources designed to help students prepare for a national secondary-level geography examination in Singapore. GeogDL's collection consists of past-year examination questions, solutions, related supplementary content and user annotations.

With the initial phase of development completed, a first study was conducted to engage a group of intergenerational partners involving designers, secondary school students and usability-trained evaluators for the purposes of reinforcing and refining the initial design of GeogDL [11]. The study revealed that, among other issues, student participants' expectations for GeogDL went beyond the initial design goals for the system, which were to provide an environment for users to access past-year examination questions, view their solutions, explore related content and discuss with other users.

In response to the first study, we describe in this paper an implementation of **PAPER** – **P**ersonalized **A**daptive **P**athways for **E**xamination **R**esources – an assessment and coaching module, consisting of two major components:

- **Mock Exam.** Provides a timed and scored test that reflects the structure and content of the actual geography examination.
- **Personal Coach.** Provides recommendations of examination questions to attempt based on performance in previous mock exam sessions.

PAPER is built using the generic services of GeogDL and draws content from GeogDL's repository of examination questions and solutions.

The remainder of this paper discusses the design and implementation of PAPER. Section 2 describes PAPER's underlying educational design rationale and contrasts PAPER with related work in general computer adaptive testing systems and geography-oriented educational digital libraries. Section 3 provides an in-depth treatment of PAPER including its architecture and usage. A second study of PAPER involving teacher design partners is described in Section 4.

2   Related Work

In contrast to traditional computer adaptive testing systems attempting to replicate the expertise of a human teacher who can diagnose and respond to the needs of individual students [10], PAPER is designed based on analyses of students' individual and group performances. The underlying educational design rationale in PAPER is inspired by "successful learning experiences" theory postulated by Ellington, Percival and Race [6] in the provision of instant feedback and guidance to students' learning paths.

PAPER's main objective is, therefore, to supplement classroom teaching with a wider and appropriate range of assessment techniques to support individualised student learning and to record achievement, hence achieving one of the main goals of teaching in that performance of students undergoing a given educational system should improve in some desired way [8].

GeogDL's PAPER is also different from more recently developed geography-oriented educational digital libraries (e.g. ADEPT [3] and DLESE [4]) in that students can freely explore geography concepts but also utilize services that offer a more structured yet personalized approach to studying geography. In addition, while the mock exam shares similarities with existing online testing tools such as QUIZIT [12] and PILOT [1] in that all provide a Web-based environment for testing and grading, our approach differs in that the mock exam is integrated with GeogDL's other tools thus offering various interrelated avenues for learning and exam preparation. For example, because the mock exam operates in conjunction with the personal coach, students are not only able to ascertain their areas of weaknesses through their scores but also receive recommendations of topic areas and hence, exam questions, that should be explored further.

3   PAPER's Usage and Architecture

PAPER consists of two major components, the mock exam and personal coach. This section describes these components and their implementation, focusing on the adaptive aspects of the system to create a personalized learning experience for users.

3.1   Mock Exam

Figure 1 shows PAPER's mock exam interface for multiple-choice questions. It has a deliberate minimalist design to focus users on the content. Upon reading a question,

users select an answer and proceed to the next question. Users may also revisit previous questions to modify their answers. PAPER monitors the time taken for each question to give an indication of how difficult a particular question is to a student.

Upon completion of the mock exam, PAPER grades it and displays a performance report (Figure 2). The report contains a summary of the results and includes the total score and total time taken. Performance data for individual questions are also provided. This includes the correct answer, time taken, question topic and difficulty level. Students and teachers may use the performance report to gauge mastery of geography concepts as well as areas for further improvement. Users may also review the solutions and explore supplementary resources from the report interface.
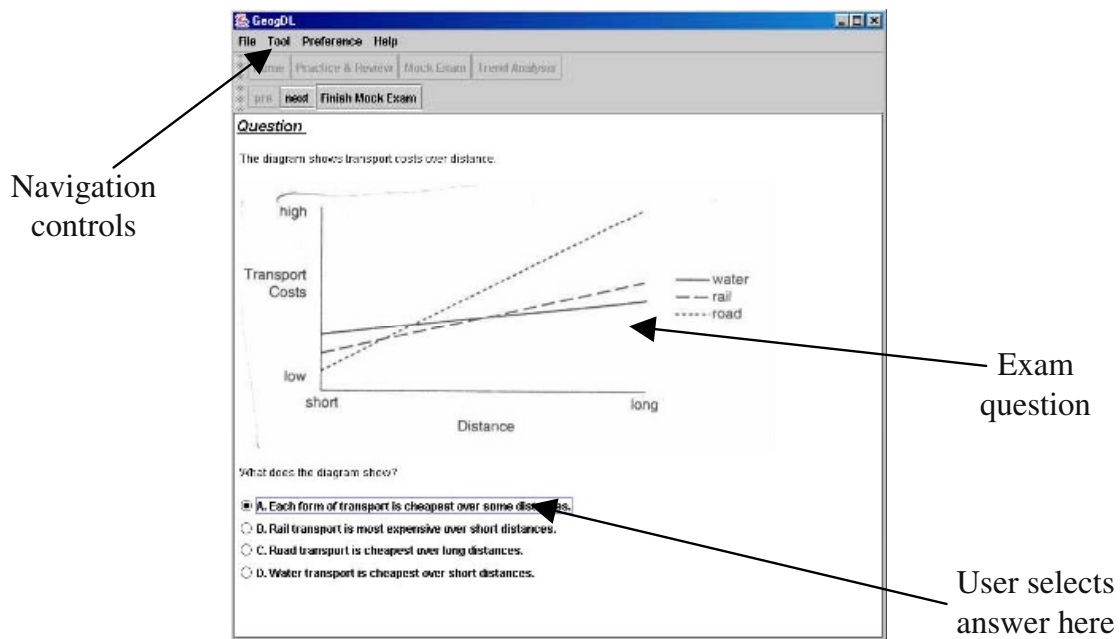

Fig. 1. PAPER's mock exam interface

The structure and content of a mock exam is defined by a **mock exam paper** – a virtual collection of examination questions. The paper is virtual because questions are not predefined. Instead, an author (e.g. a teacher) indicates the characteristics of questions that should appear. These include question type (e.g. multiple choice, essay), topic area (e.g. "natural vegetation"), number of questions and level of difficulty (as indicated by the questions' metadata). When a mock exam session is initiated, PAPER selects questions using the characteristics set in the paper. Students are thus presented with a unique exam each time a session is run, allowing them to attempt a wider variety of questions. Authors may also create static mock exam papers so that each session results in the same set of questions. This feature would be useful in situations when a teacher wants to measure the performance of his/her class, when a teacher wants students to attempt certain questions that are deemed important in the geography examination, or to emphasize a certain topic learnt in class.
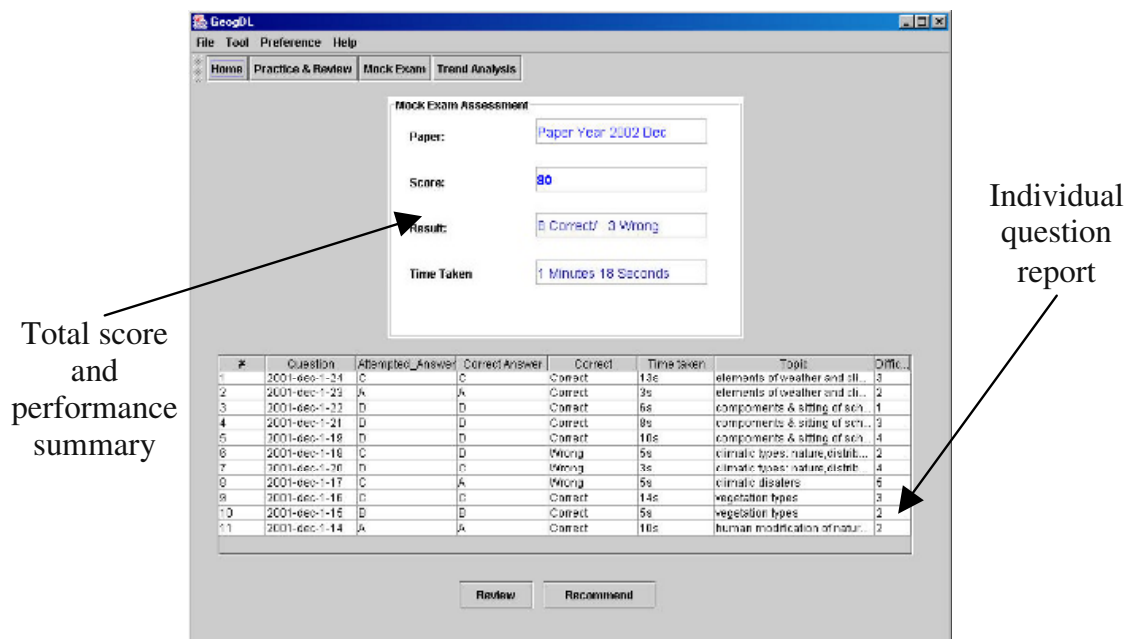
Fig. 2. The mock exam report

3.2   Personal Coach

Upon completion of one or more mock exams, students may wish to attempt more questions for further practice. With print, teachers would typically help their students identify such questions – a time-consuming, manual task. PAPER assists in this process through the personal coach which analyzes a student's performance in previous mock exams and then recommends questions pitched at appropriate levels of difficulty. Questions are thus tailored to individual abilities.

The personal coach may be invoked from the mock exam report (Figure 2). The interface consists of two major sections as shown in Figure 3. The panel on the left provides a list of recommended questions organized into topics as described in the geography syllabus [7]. The panel on the right presents a question selected by the user and also allows users to attempt it. The solution may also be viewed and users may explore any related supplementary resources found there. Currently, these resources are Web sites identified by experienced geography teachers.

Questions are recommended based on a user's past performance in the mock exams. Specifically, each question in a mock exam is associated with one or more topics in the geography syllabus. The personal coach calculates a competency level for each topic based on a user's performance for that topic in previous mock exam sessions. This is a weighted score involving the most recent mock exam and a cumulative score from previous sessions (see Section 4.2 for details of calculation).

Using this approach, the personal coach adapts to the student as he or she interacts with PAPER. For example, if a student consistently answers questions correctly in a topic such as "Agricultural systems", the personal coach will recommend questions with a higher level of difficulty. Conversely, if a student performs poorly in a topic such as "Elements of weather and climate", easier questions will be recommended. Recommendations may change each time a mock exam is completed, and is dependent on the student's topic scores. Difficulty levels range from 1 (easiest) to 5

(most difficult) and are stored in each question's metadata. These are once again assigned by experienced geography teachers to ensure validity.
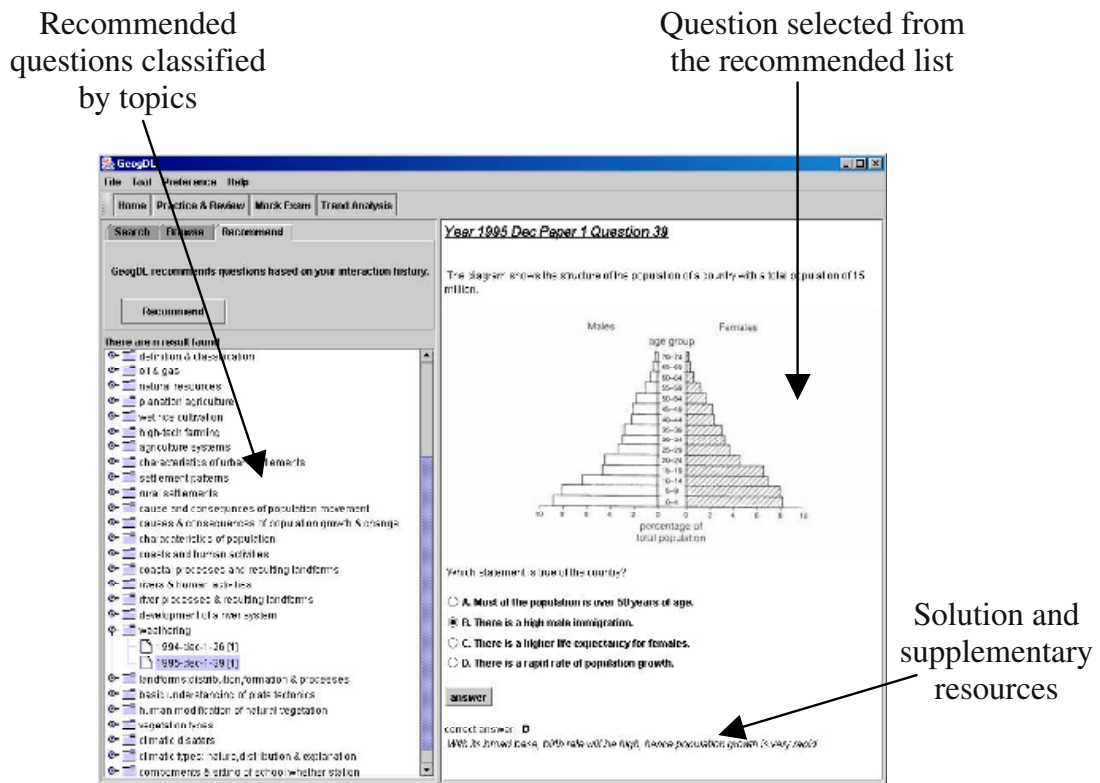
Recommended
questions classified
by topics

Question selected from
the recommended list

Solution and
supplementary
resources

Fig. 3. The personal coach

We term this approach **personalized adaptive pathways**, to refer to the ability of the personal coach to adapt to the changing needs of students by recommending learning paths in the form of examination questions, solutions and supplementary resources. It is hoped that this approach will better cater to the learning needs of individuals by providing challenging questions for familiar areas in geography while asking easier, confidence boosting questions for more problematic areas.

4   Implementation

4.1   Architecture

The major components of PAPER are shown in Figure 4. The collection of the digital library is maintained in the **question database** and contains examination resources (questions, solutions, supplementary content and mock exam papers) as well as their associated metadata.

The **mock exam module** extracts questions from the question database given a mock exam paper, and displays them to the user. Upon completion of a paper, the module grades it, generates the performance report and updates the user's profile through the **profile manager**. All profiles are maintained in the **user profile database** which keeps track of users' competencies in the various geography topics.
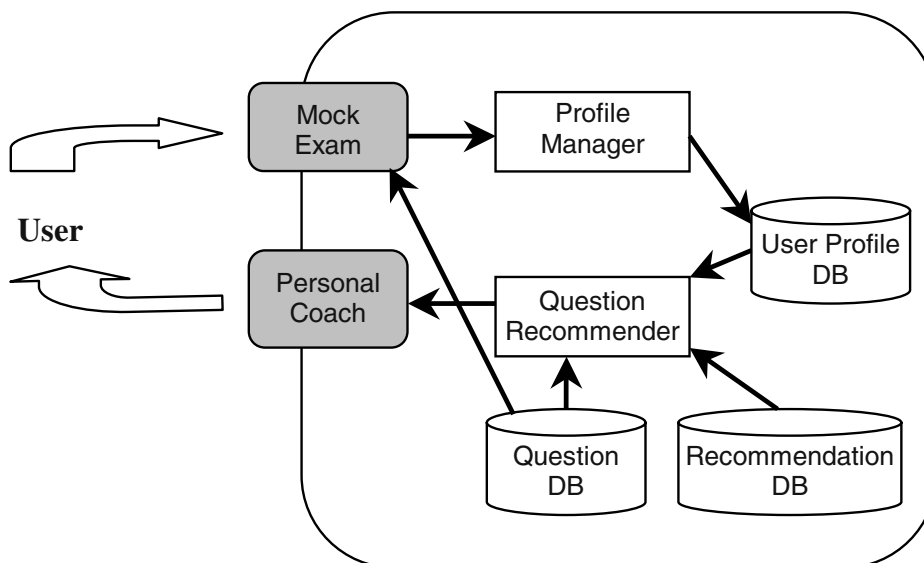
Fig. 4. Architecture diagram of PAPER.

When the user requests the **personal coach** to recommend suitable examinations questions for further practice, the **question recommender** will be invoked. This component retrieves the user's profile from the user profile database, determines the competency level of each geography topic and then consults the **recommendation database** for a list of questions matching each competency level. The question recommender then extracts the questions from the question database and delivers it to the personal coach for formatting and presentation to the user.

4.2   Profile Manager

PAPER's profile manager is responsible for updating a user's profile or topic competency scores. Each profile is a vector of values, with each value representing the competency score of a user in a particular geography topic. The profile is updated each time a user completes a mock exam.

The formula used for computing each new topic competency score ($\mathbf{h}_{new}$) is shown below. Each new topic competency score in the profile is a weighted sum of the existing topic competency score ($\mathbf{h}$, based on past mock exams) and the topic performance score ($\mathbf{p}$) in the current mock exam. Topic competency scores range from 0 (lowest competency score) to 1 (highest competency score). The rationale behind the formula is that the topic performance score in the current mock exam ($\mathbf{p}$) reflects the user's mastery of geography concepts more accurately than his/her previous performance ($\mathbf{h}$). Consequently, a higher weight ($\mathbf{W}$) should be assigned to the current mock exam topic performance score.

$$h_{new} = \begin{cases} p \times \dfrac{n_m \times W}{n_m \times W + n_t} + h \times \dfrac{n_t}{n_m \times W + n_t} & \text{if} \quad \dfrac{n_m \times W}{n_t} >= T \\ \\ p \times T + h \times (1 - T) & \text{otherwise} \end{cases} \tag{1}$$

where

h_{new}: the new topic competency score

h: the existing topic competency score prior to the current mock exam

p: the topic performance score for the current mock exam

n_m: the number of questions in the current mock exam on a particular topic

n_t: the number of questions previously attempted on a particular topic

W: the weight assigned to the current mock exam

T: the minimum weight assigned to the current mock exam

The value **p** is the percentage of the number of questions answered correctly over the total number of questions attempted on a particular topic in the current mock exam. **W** is a weight that determines the contribution of the current topic performance score in the calculation of a new competency score. To favor current topic performance over past performance, **W** is assigned a number greater than 1. **T** is the threshold of the minimum contribution of the current mock exam topic performance score **p**. In cases where **n_t** is very large, the contribution of the current performance is very small and cannot affect the calculation of a new competency score that adequately reflects the user's mastery of the topic. Therefore, there is a need to maintain a minimum contribution factor and this is denoted by **T**. Note that the parameters **W** and **T** are user defined.

4.3   Question Recommender

The personal coach's question recommender is responsible for recommending suitable questions based on the user's competency profile vector calculated by the profile manager. For example, if a student does not perform poorly in the topic "Elements of weather and climate" (e.g. h=0.4), the system will recommend questions with a lower level of difficulty. In contrast, if another student performs very well in that topic (e.g. h=0.85), the system will suggest more advanced questions.

In the current implementation, we make use of the recommendation database to maintain the set of questions that matches each level of difficulty. Conceptually, the database is a table of values whose columns represent levels of difficulty and rows represent topics. A cell found at the intersection of a row and column contains questions belonging to a particular topic and having a certain difficulty level. To locate a cell, the question recommender first maps a user's topic competency score to a difficulty level. This is done by approximating the competency score to a letter grade as defined by the requirements of the national examination, and using that grade

as a proxy to the level of question difficulty. For example, exam scores of 75 or more are graded as "A" in the national examination, and competency scores within this range are thus assigned the most difficult questions (difficulty level 5). Conversely, competency scores of less than 50 ("F") are assigned the easiest questions (level 1).

5   Participatory Design

PAPER was developed using the participatory design (PD) methodology [5, 9]. In participatory design, a team of people representing the major stakeholders of a product work together to create that product that would reflect the way actual users would use it. In contrast with the first study employing student design partners, this section describes a second study using teacher design partners to carry out participatory design to further refine PAPER.

5.1   Participants

Two design partners (P1 and P2) in the education field were recruited. P1 is a secondary school geography teacher and head of the school's humanities department with over 30 years of experience teaching the subject. P2 is a school psychologist involved in teacher training at a university in Singapore. Both are well-versed in pedagogical theories and methods, and familiar with the intricacies of Singapore's education system.

5.2   Protocol

A facilitator involved in the first study and currently on the development team worked with each design partner in separate sessions to elicit opinions on PAPER. Each session lasted approximately 1.5 hours.

   The session was divided into four parts. Part 1 was a familiarization segment that introduced the design partner to the project. The goals of the project were reviewed and the design partners were given an overview of PAPER's features. In Part 2 of the session, the facilitator provided a guided tour of the mock exam and elicited opinions on four areas: (1) positive aspects of the mock exam; (2) areas of improvement; (3) usefulness of the mock exam in helping students learn and prepare for the geography exam; and (4) usefulness of the mock exam as a tool for helping teacher meet their educational objectives. Part 3 was a repeat of Part 2 except that the focus was on the personal coach. Finally, Part 4 was an open-ended interview whose purpose was to identify, refine and brainstorm further ideas for improving PAPER.

5.3   Feedback on Mock Exam

Design partners were introduced to the three major tasks afforded by the mock exam: selection of static and dynamic papers; attempting questions in the mock exam; and viewing of the mock exam report.

Positive Comments. The design partners' responses to the mock exam were generally positive. P1 liked the dynamic paper concept since it lessened the work required for creating new exam papers. Teachers simply needed to select the desired topics and PAPER would then automatically generate an exam paper for students. P2 also liked the fact that students could review answers after the mock exam and explore supplementary resources as the latter would help reinforce concepts learnt, or elucidate areas of weakness. Both P1 and P2 also felt that the mock exam report was comprehensive and useful for diagnostic purposes. For example, the length of time taken for each question and the topic area would be helpful to identify strengths as well as areas for further revision.

In terms of usefulness to students, P1 thought that it would be a good alternative to print versions of past-year exam questions. For example, after completion of a lesson, teachers could ask students to attempt related questions to assess mastery of the topic. Further, being Web-based, students need not have to bring additional books to school and could access the system both at school and at home.

P2 felt that the mock exam would also be a useful tool for teachers in that "differentiated teaching" can occur, catering to individual differences and abilities. Through the dynamic paper, a teacher could create exams with varying levels of difficulty, and then instruct students to attempt a particular exam given his/her ability level. P1 commented that the mock exam would also help in easing a teacher's workload. In a typical classroom setting, students would attempt print versions of mock exams and upon completion, the teacher would painstakingly go through each solution, answering any questions that might arise during the process. With PAPER's mock exam, students could independently attempt the questions and then peruse the solutions and supplementary resources. The teacher now becomes a facilitator that assists students in interacting with PAPER, and provides additional instruction when students require more information than what PAPER can provide.

Negative Comments. P2 felt that there should be greater use of color and multimedia to take advantage of the digital medium, and differentiate the system from print. The use of such elements would not only help the learning process (e.g. animation depicting ox-bow lake formation) but also maintain the interest level of students. However, these should only be made available during the review phase of the mock exam, and not while students are attempting the questions. It was interesting to note that both P1 and P2 did not like the default grey "theme" of the system – a more colorful user interface would be more appropriate for PAPER's target group of users. P1 also pointed out that content was an integral part of the system and its acceptance by students and teachers would depend very much on the quality of the solutions and supplementary resources. Consequently, while P1 agreed with P2 that the introduction of multimedia would be an improvement to the existing system, content should never be sacrificed.

5.4   Feedback on Personal Coach

While PAPER's mock exam was relatively straightforward to describe since it had a print counterpart, the personal coach required more explanation as there was no physical parallel. Here, the design partners were shown how students could receive

recommendations from the personal coach after the mock exam was completed, and how they could attempt the recommended questions. A non-technical overview of the recommendation algorithms used by the personal coach was also provided to assure the design partners that the questions were not haphazardly selected.

Positive Comments. Since adaptivity is difficult to achieve in print versions of exam questions except perhaps through manual analysis, both design partners felt that the personal coach had good potential as a tool to facilitate exam preparation. Further, they liked the fact the recommendations were fine grained (at the topic level), and that students would be provided with questions that met their ability levels. Both P1 and P2 agreed that this would be something that teachers would not have time to do in a classroom setting with large numbers of students, each requiring individual attention.

P1 felt that students would benefit from the personal coach because they will be able to determine for themselves whether they have grasped the presented concepts. That is, the better students perform in the mock exam, the more likely they will be able to attempt harder questions. Conversely for weaker students, the personal coach will recommend questions that are easier. In all cases, students will be able to find a level of question difficulty they are comfortable with. P2 added that this would be motivating factor since weaker students will not be discouraged and better performing students will be challenged by the more difficult questions. Further, P2 also noted that the personal coach would be useful for students who have just begun their exam preparation and are unsure what questions to attempt first. The system would also be useful for those who do not have the initiative to explore the repository of questions themselves. In both cases, the personal coach would serve as a good starting point.

Both design partners agreed that the personal coach would be useful from the teacher's point of view as well. Specifically, P1 felt that since students can be left on their own with PAPER, teachers would have more time to devote to individual students who are academically weaker or simply have trouble with certain topics or questions. P2 concurred and noted that since the personal coach (and the mock exam) runs without the need for intervention by teachers, there will be less resistance to adopting PAPER in the classroom. Teachers will also spend less time identifying suitable questions for students to attempt.

Negative Comments. P2 argued that one weakness of the personal coach is that it lacks comprehensiveness in terms of question coverage. In the long run, students simply cannot focus only on recommended questions. Instead, they need to attempt as many questions as possible since the actual examination contains both easy and difficult questions. Consequently, students cannot depend only on the personal coach but use features such as search/browse to retrieve and attempt questions that have not been recommended. P2 also felt that the personal coach could be extended to become a recommender system for teachers who are planning lesson materials and authoring exams. Specifically, the system could provide a teacher with the average difficulty level for each topic using the individual topic difficulty levels for each student in his/her class. These average values would serve as an overall performance indicator for the class, allowing the teacher to pitch the lesson or exam at an appropriate level.

5.5   Discussion

Given the feedback from both studies involving student and teacher design partners, several lessons were learnt that will be used to guide future development of PAPER. These are summarized in this section:

1. **The importance of differentiation.** PAPER should take advantage of the digital medium and differentiate itself from print versions of exam questions. The personal coach, which recommends questions tailored to individual ability levels, is one such example. An area that requires improvement is the use of color, sound, animation and other multimedia elements to maintain the interest level of users. This is especially so for PAPER's target group of users who are exposed to a variety of Web sites, computer games and other software.
2. **The importance of content.** An attractively designed system will still fail if users do not find the content useful or of sufficient quality. This is especially so in PAPER where students depend on it for exam preparation. Thus, future development of PAPER should occur in two tracks, one focusing on features and usability, while the other on geography content. The latter will require the services of experts such as geography teachers.
3. **Ease of use.** Teachers and students have only a fixed number of hours at school and a variety of activities to perform. To facilitate adoption, a new system such as PAPER should be intuitive, reliable and easy to use. It should not waste valuable time or users will focus on other tasks such as learning how to use a competing and better designed software.
4. **Consultation with actual users.** An educational tool such as PAPER should not be treated as an end in itself. In other words, teachers will not rush to adopt a system simply because it is available. Instead, the system must demonstrate that it is able to help meet the learning objectives set by teachers, and be easily integrated into the existing curriculum. Consequently, system developers need to work with target users to determine how best to design and deploy GeogDL.

6 Conclusion

With the development of PAPER, GeogDL now offers a suite of digital library services ranging from traditional search and browse to dynamic ones that integrate and adapt content. Using existing services in GeogDL, students are able to interact with individual resources such as attempting an examination question and viewing the associated solution. The new mock exam feature in PAPER assembles questions to create a timed, simulated version of the geography examination. The personal coach adapts to students' ability levels and utilizes past mock exams to recommend further questions for practice that are tailored to individual needs.

The PD sessions revealed that our design partners generally concurred with the goals and features of PAPER. From the students' point of view, they felt that PAPER offers an environment that helps students prepare for the geography exam in ways beyond what books can provide. Further, since students can independently interact with PAPER, teachers have more time to spend catering to individual students' learning needs. However, more work needs to be done. We plan to further refine

PAPER by incorporating the suggestions elicited from our design partners and running trials of the system in schools. Nevertheless, we anticipate that this richer, personalized, interactive experience offered by PAPER will better fulfill our goal of developing a digital library that meets the educational needs of students.

References

1. Bridgeman, S., Goodrich, M.T., Kobourov, S.G., and Tamassia, R.: PILOT: an interactive tool for learning and grading. ACM SIGCSE Bulletin, Vol. 32, No. 1 (2000) 139–143.
2. Chua, L.H., Goh, D.H., Lim, E.P., Liu, Z., Ang, R.: A digital library for geography examination resources. Proceedings of the 2nd ACM/IEEE Joint Conference on Digital Libraries (2002) 115–116.
3. Coleman, A., Smith, T., Buchel, O., and Mayer, R.: Learning spaces in digital libraries. Proceedings of the Fifth European Conference on Research and Advanced Technology for Digital Libraries, Lecture Notes in Computer Science, Vol. 2163. Springer-Verlag, Berlin (2001) 251–262.
4. Digital Library for Earth System Education. http://www.dlese.org/
5. Druin, A., Bederson, B., Boltman, A., Miura, A., Knotts-Callahan, D., and Platt, M.: Children as our technology design partners. In Allison Druin (Ed.), The Design of Children's Technology (51–72). Morgan Kaufmann Publishers, San Francisco (1999).
6. Ellington, H., Percival, F. and Race, P.: Handbook of Educational Technology. 3rd Edition. Kogan Page, London (1995).
7. Geography: GCE Ordinary Level. http://www.moe.edu.sg/exams/syllabus/2232.pdf.
8. Gibbs, G.: Improving student learning through course design. Oxford Centre for Staff Development, Oxford (1997).
9. Muller, M.J.: PICTIVE – an exploration in participatory design. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'91) (1991) 225–231.
10. Nwana, H.S.: Intelligent tutoring systems: An overview. Artificial Intelligence Review, Vol. 4 (1990) 251–277.
11. Theng, Y.L., Goh, D.H., Lim, E.P., Liu, Z., Pang, N., Wong, P., Chua, L.H.: Intergenerational partnerships in the design of a digital library of geography examination resources. Proceedings of the 5th International Conference on Asian Digital Libraries, Lecture Notes in Computer Science, Vol. 2555. Springer-Verlag, Berlin (2002) 427–439.
12. Tinoco, L., Fox, E., and Barnette, D.: Online evaluation in WWW-based courseware. Proceedings of the 28th SIGCSE Technical Symposium (1997) 194–198.