Using Spaced Repetition and Gamification to Enhance K-12 Student Science Literacy With On-Demand Mobile Short Reads

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***Abstract*—We present a work-in-progress project that implements spaced repetition and gamification through mobile application for STEM education as a learning system for K-12 students. Spaced repetition in the classroom has been studied and shown to be effective for foreign language and vocabulary acquisition as well as other types of training, while gamification has similarly been used to improve learners' engagement and motivation. This project combines the advantages of both instructional strategies and delivers it through a mobile learning system by using its ubiquitous nature. We believe by combining spacing and gamification with mobile learning technology, the learning system will yield fruitful results in STEM education. We discuss how existing literature affects our design and our plan of implementing such a system.**

Keywords—STEM education, mobile learning, ubiquitous learning, spaced repetition, gamification

I. Introduction

Science, technology, engineering, and mathematics (STEM) topics are atop of many educator lists. Educators want students to be engaged, motivated, and successful in a combination of STEM topics. To become a citizen of the STEM field, one needs to be able to master concepts and languages in this field. Sometimes this means having to memorize factual knowledge and defining some technical terms when first encountering STEM topics.

Learning low-level factual knowledge and definition of terms can be a mundane activity. Like many of us, we memorize them and use them until they are seemingly encoded in our long-term memory. The encoding process takes a long time for some people. Some learners may even give up before they truly master the low-level knowledge and are left thinking that they are not proficient in the STEM field. The truth is the learners may not have access to the environment that helps them practice the basic facts and technical terminologies. If such an immersive learning environment is available, they will be more likely to succeed in the STEM field.

Motivated by our drive to make STEM more accessible, we set out to find and create technology tools that are easy to use, can be accessed almost anytime and anywhere, and can help learners overcome the initial obstacle of learning STEM topics. It is important for learners to feel engaged within the content (STEM facts and languages) and outside of the content (attractive design, personal awards, competing with others, etc.) such that they keep practicing until they are comfortable with subjects that are being taught.

In addition to the aforementioned scientific and pedagogical reasons, a recent movement on reducing printed instructional materials in middle schools in our region also prompted us to design and develop an alternative for middle school teachers to enhance STEM learning. According to a recent study [1], about 74% of American teens have mobile access to the Internet and about 95% of them have access to the Internet. We realize that giving middle school students access to the materials online is a feasible alternative. Furthermore, current web technologies are mature enough to possibly provide a viable solution toward our goal.

In the following sections, we will discuss the theories and strategies that guide us in our design, followed by what the finished system will look like, along with a use case. The paper will conclude with future work including both short-term and long-term goals.

II. Related Work

A. *Spacing*

We examine the spacing effect from two aspects: within a training session and between training sessions. For the scope of the paper, we will focus on factual knowledge that can be presented, not necessarily mastered, in a single training session, each of which presents one or several facts to learners.

Within a single training session, both unknown and known facts can be presented for *acquisition* (unknown facts) and *maintenance* (known facts). The benefit of mixing unknown facts with known ones has been well documented [2]–[4]. The ratio, however, has not been established. Factors such as individual information processing capacity, ability to encode unknown facts into long-term memory, and the type and complexity of the unknown facts all play a role in selecting an optimal ratio. In general, sufficient processing time and opportunity for review should be provided before the learner is overwhelmed by too many new unknown facts.

The spacing between training sessions is another contributing factor. Researchers have found that spacing has a positive impact on learning new material and reviewing learned material. For example, Ausubel and Youssef [5] found that one spaced review significantly increased meaningful learning and retention after 48 hours in learning the endocrinology of pubescence. In a study [6] of trained users who were selected to memorize a randomly assigned code of 12 characters long, the authors successfully used spaced repetition and gradually increased the length of the code until it reached 12 characters. The significance of the study was that the user memorized seemingly meaningless words that are longer than the capacity of information processing initially found by Miller [7], which shows humans are able to encode random (meaningless) information using spaced repetition.

B. Mobile Learning

With each major paradigm shift in technology, learning technology shifts as well. It has evolved from computer-based learning (personal computers) to web-based learning (the Internet) to mobile learning (smart phones and tablets), each enhancing features and taking on new opportunities upon it predecessor. As Cooke and Reichard [8] pointed out, implementing the spacing features mentioned in the previous section was difficult. It is, however, worth revisiting the idea and implementing these pedagogical strategies by leveraging current web and mobile technologies. We believe it will be fruitful and beneficial for learners.

Mobile learning technologies can provide personalized, on-demand, and ubiquitous access all together to the learners. What separates mobile learning from web-based learning mainly is that web-based learning delivers learning materials through the Internet in a fixed location (home, classroom, etc.) where mobile learning extends the concept to any device, anytime, and anywhere [9]. Personal mobile devices have been available for decades, but it is until recently that the technologies and infrastructure are widely available that make it truly ubiquitous.

Thornton and Houser [9] studied how Short Message Service (SMS) could be used by Japanese students for learning English vocabulary. They found that students mastered more words in the SMS group than the non-SMS group. However, only 11% of the test subjects also reported that they studied the "pushed" words immediately. In another study by Wu [10], a smartphone app for English vocabulary was provided to the experimental group but no other intervention. The control group was given the same word list in paper. The researcher sent a short SMS to all subjects, both control and experimental groups, to remind them to study harder. In the post test after 55 days, she found that the experimental group mastered significantly more words than the control group.

C. Gamification

Gamification is a strategy widely used to promote student engagement and motivation during the learning process. Gamification has attracted considerable attention from both education and business fields in recent years [11], [12]. The term "gamification" refers to the use of game elements in non-gaming systems to improve user experience and engagement [13]. Common game elements that serve such a purpose are leader boards, badges, points, levels, progress bars, and animations [13].

The effectiveness of gamification or serious games has been extensively studied, and the results yielded by pertinent research suggest that it positively affects both students' motivation and performance. For example, Wang [14] found that elementary school students (N = 165) in a game-based web quiz group took assessments more actively and performed significantly better than students in standard web-based groups. Similarly, Papastergiou [15] noted that gamified learning systems (i.e., those incorporating goals, rules, and progressive levels) not only improved student learning outcomes but were also more effective in motivating learners compared to non-gaming learning systems. In a more recent study, Tanner and McNamara [16] reported that students in the game-based tutoring system experienced significantly higher levels of self-enjoyment and motivation compared to their peers using a non-gaming system. Similarly, Buckley and Doyle [17] found that, the leaderboard and ranking system in their gamified learning software motivated students by providing a form of stimulation similar to gambling which is uncertain and exciting.

While gamification has a generally positive effect on students' performance and motivation, individual differences influence students' reactions to gamification. Attali and Arieli-Attali [18] conducted two large-scale studies (in which 1,218 adults and 693 middle school students took part, respectively) on the effect of points on learners' performance in computer-based math assessments. Students were given points feedback on their accuracy and speed under the point condition. Their findings revealed that the point manipulation had no influence on the response accuracy of either participant group. However, middle school students preferred to test under the point condition than test without point feedback. Thus, the authors concluded that point manipulation could potentially encourage less motivated students who tend to exert less effort to work harder on attaining their goals.

TABLE I. DESIGN PRINCIPLES AND THEIR ORIGIONS FOR THE CURRENT DESIGN

Principle	From
Move cards from "acquisition" to "maintenance" based on a fixed ratio in real time	Spacing
Resume from where the learner left from the previous training session	Spacing
Notify learners for reviewing "maintenance" cards	Spacing
Allow users to set when the "maintenance" card notificaiton appears	Spacing
Reward learners with achievement badges	Gamification
Provide points	Gamification
Present a leaderboard ranking based on learner activity	Gamification
Show training progress to enable self-awareness	Gamification
Start from easier cards then progess to more difficult cards	Gamification

III. Design Principles and System Design

TABLE I. lists the design principles that we use to guide our implementation. These principles, listed in the first column of the table, are based on the related work (section II) and usability studies [19]. We also listed from which part of the literature they were originally from in the second column of the table.

It is important to maintain good usability for both K-12 teachers and students. Therefore, a small number of teachers and students will be invited to use the system and provide feedback through focus group discussion. We will continue this learner centered design approach throughout the process. As a result, the design principles will be modified and enhanced later.

Because the project is still being implemented at the moment, we will discuss what we are using and plan to use to fulfill our design principles. We also focus on what the end users (students) will see and how they will use the system.

In terms of hardware, users are allowed to use devices with smaller screen size such as smart phones or with larger screen size such as desktop computers. This will provide users access with seamless transition among different sized devices.

In terms of software, we chose to implement the system using web technology instead of native apps because it makes it possible for different types of smart phones (iOS, Android, Windows, etc.) to use the system. We use Bootstrap and AngularJS (both are popular JavaScript frameworks, but for different purposes) to make the system interactive, responsive, and adaptive to different screen sizes. Data (user information, cards, progresses, etc.) are stored in a SQLite database with PHP being the interface between the database and the user interface.

0 shows a use case from the learner's perspective. After the user logs into the system, the learner can perform learning actions as well as reviewing and changing personal information. *View cards* action consists of viewing both acquisition cards and maintenance cards. The selection of cards is based on the internal algorithm of spacing and a variety of filters (subjects, categories, subcategories, tags, views since last time, etc.) We use subjects, categories, and subcategories to describe the hierarchy of cards. For example, Earth Science is a category under the subject of Science. Earth Science can contain subcategories such as atmosphere, anthrosphere, etc. Tags are used for metadata that does not fall into this strict definition. For example, a single tag can be "week 4" or "grade 7" so that teachers can organize cards easily without being limited to the *subject-category-subcategory* model.

Managing user profile action is similar to a typical website that collects and stores personal information. We collect this for customizing the program. *Badge and leaderboard* action shows the learner her personal achievement and also current leaderboards of different types.

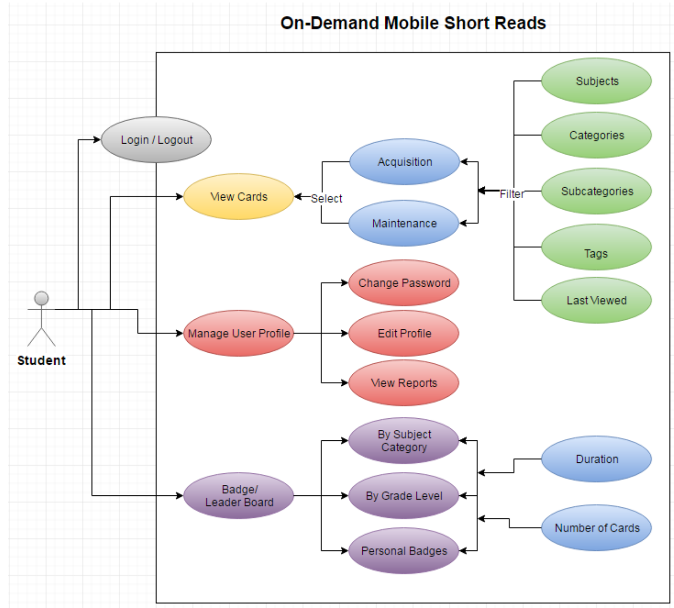

Fig. 1. Use Case from the learner's perspective

In addition to what the learner uses, there are three other actors in the system. Teachers can set up different tags such that learners can filter cards by tags. Contributors are subject-matter experts who create and put cards into the system. Reviewers are also subject-matter experts who can create cards and also review cards created by contributors. Once the cards are "published", the card selection will do its work and provide cards in a training session.

Figure 2 shows some of the interface for learners. One of several ways to select an area of interest is to go from subjects, to categories, and to subcategories. After a subcategory is selected, the system will automatically select a card based on our model (spaced or sequential). Learners can also view their own progress as shown below.

IV. Evaluation of Learning

We will work with middle school science teachers in our region to recruit their students evaluate the learning outcome of different factors (spaced or sequential, game or no-game). We will first test the following two hypotheses.

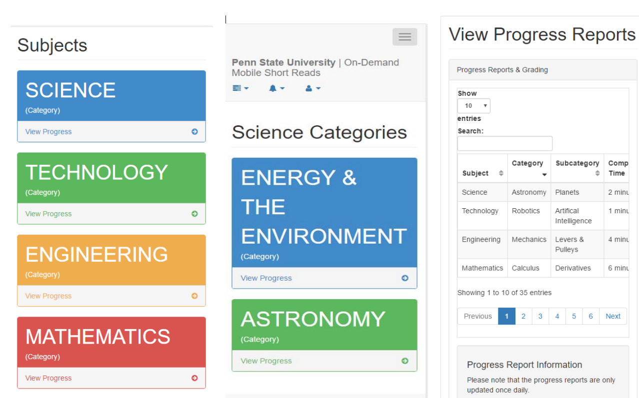

Fig. 2. Screenshots of user interface for learners to select subjects, select categories, and view personal progress (from left to right).

h_1: Students who are in the group of spaced repetition will perform better after treatment than those who are in the acquisition-first-maintenance-later (sequential) group.

h_2: Students who are in the group of gamification will spend more after-school time than students who are in the group without gamification.

Participating teachers will determine one category for the study. Students will be randomly assigned into four different groups (listed below) and an after treatment test will be administered.

Group *spaced, game*: Short STEM reads will be presented in the 2 acquisition and 1 maintenance ratio. Students will also earn scores by the number of cards learned and reviewed. A leaderboard will be available for students to compare with their peers.

Group *spaced, no-game*: Short STEM reads will be presented in the 2 acquisition and 1 maintenance ratio. No leader board is provided.

Group *sequential, game*: Short STEM reads will be presented in order. Cards are presented in round-robin order. Students will also earn scores by the number of cards learned and reviewed. A leader board will be available for students to compare with their peers.

Group *sequential, no-game*: Short STEM reads will be presented in order. Cards are presented in round-robin order. No leader board is provided.

We will make sure that each student has access to a mobile device (either the one that they own or provided by us) and an account to our mobile learning system on the first day of the study. The students will be given an introduction and use the app in class for 10 minutes in the beginning of the study. After the introduction, students are left with the device and use the app at will for one semester. At the end of the semester, the after treatment test on the selected category will be administered to all participating students.

The results, both after treatment test and the number of cards viewed, will be analyzed by using ANOVA to test the effect of learning schedule and leader board in our mobile learning system.

V. SUMMARY AND FUTURE WORK

Learning facts is an important task for learners in the STEM field like vocabulary in learning foreign languages. Spaced repetition has been an effective strategy for learning foreign vocabulary. Changing the repetition schedule is easier in a lab environment than in a realistic learning environment. We use current mobile technologies, powerful enough to change the repetition variables on the fly, to make this strategy possible in a real learning situation.

Our target learning group middle school students, are familiar with mobile technologies, particularly smartphones and tablets. When implementing the spaced repetition strategy in a mobile learning system, combined with lessons we learn from gamification literature, the system can be very engaging and effective.

In terms of system design and implementation, we need to create an assessment component that can be used to determine when cards can be moved from acquisition to maintenance. The current design is based on number of exposures, which is a less accurate form of assessment. Ultimately, we will have an automatic component to create questions from the existing cards. This will improve the accuracy of judging the learner's progress and also user experience.

We will also conduct user studies (as early as fall 2016) to evaluate whether using the system improves students' performance and motivation.

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