Education Tech Research Dev
DOI 10.1007/s11423-017-9542-1

DEVELOPMENT ARTICLE

Investigating the effect of an adaptive learning intervention on students' learning

Min Liu[1] · Emily McKelroy[1] · Stephanie B. Corliss[2] · Jamison Carrigan[3]

Abstract Educators agree on the benefits of adaptive learning, but evidence-based research remains limited as the field of adaptive learning is still evolving within higher education. In this study, we investigated the impact of an adaptive learning intervention to provide remedial instruction in biology, chemistry, math, and information literacy to first-year students (n = 128) entering a pharmacy professional degree program. Using a mixed methods design, we examined students' learning in each of the four content areas, their experience using the adaptive system, and student characteristics as related to their choice of participating in the intervention. The findings showed the adaptive learning intervention helped address the knowledge gap for chemistry, but the same effect was not observed for the other three content areas. Math anxiety was the only student characteristic that showed a significant relationship with students' participation. While the students reported an overall positive experience, the results also revealed time factor and several design flaws that could have contributed to the lack of more student success. The findings highlight the importance of design in adaptive learning.

✉ Min Liu
MLiu@austin.utexas.edu

Emily McKelroy
emckelroy@utexas.edu

Stephanie B. Corliss
stephanie.corliss@austin.utexas.edu

Jamison Carrigan
jecarrigan@austin.utexas.edu

1 Learning Technologies Program, Department of Curriculum & Instruction, The University of Texas at Austin, 1912 Speedway Stop D5700, Austin, TX 78712-1293, USA

2 Department of Medical Education in Dell Medical School, The University of Texas at Austin, Austin, TX 78712, USA

3 Department of Educational Psychology, The University of Texas at Austin, Austin, TX 78712, USA

Published online: 22 September 2017

Keywords Adaptive learning · Personalized learning · College teaching · Mixed-methods · Math anxiety · Design

Introduction

Personalizing learning to meet students' diverse needs holds much promise to improve learning, as educational research informs us that students learn more effectively when instruction is individualized to the learners' needs (Baghaei et al. 2007; Benedict 2010; Kerr 2016). Advances in technologies present new opportunities for adapting instruction to individual learning paths. According to the 2016 NMC Horizon Report–Higher Education Edition, "the increasing focus on customizing instruction to meet students' unique needs is driving the development of new technologies" and it predicts the adoption time for adaptive learning is one year and less (Johnson et al. 2016, p. 28). Colleges and professional degree programs are increasingly interested in exploring the use of adaptive learning systems as a tool to address students' individual learning needs and characteristics as they enter formal academic programs which often challenge instructors to modify their instruction (Foshee et al. 2016; Hsieh et al. 2013; Lin et al. 2016). As an example, colleges and schools of pharmacy, in particular, have seen an increased variance in student preparedness to begin the Pharm.D. (the Doctor of Pharmacy) program, a postgraduate professional degree. Usually, students accepted for a postgraduate professional degree such as the Pharm.D. program, especially at large research universities, are highly selective. However, prior to entering the program, some students have been in the workforce for several years with limited time to engage in academic studies while others are recent graduates or have recently completed academic work directly related to their upcoming coursework. This variance in student levels of prerequisite knowledge and skills, particularly in the areas of chemistry, biology, math, and information literacy that are crucial for success in the program, creates challenges for faculty to integrate basic concepts into their curriculum. This additional teaching often results in valuable class time focused on reviewing the necessary pre-requisite content instead of using that time to explore new, relevant materials at a deeper level. Given these challenges, as well as recommendations from the pharmacy accrediting body to develop innovative approaches to teaching and learning (ACPE 2015) and an increase in students' competence in technology fluency and preference for alternative learning platforms of learning (Al-Dahir et al. 2014), adaptive learning technologies present an opportunity to provide refresher instruction in pharmacy education.

While there is much agreement on the benefits of adaptive learning, little evidence-based research is available as the field of adaptive learning is still evolving within higher education and very much at its nascent stage. Therefore, in this study, we aim to understand the impact of an adaptive learning intervention designed to provide refresher instruction in biology, chemistry, math, and information literacy on first-year professional Pharm.D. students' learning. We examined students' learning in each of the four content areas, their experience using the adaptive system, and compared student characteristics of those who engaged and did not engage in the intervention. The findings of this study can provide much needed insights to educators interested in using adaptive technology in their instruction.

Relevant literature

Adaptive learning

The goal of adaptive learning is to customize the learning experience by dynamically making changes based on the interactions and input provided by the learner (Somyürek 2015). This approach provides immediate feedback that is targeted and tailored to the learning process and focuses on improving students' learning (Johnson et al. 2009; Kelly 2008; Kerr 2016; U.S. Department of Education 2013). Technology-based adaptive learning systems have the ability to provide students with immediate assistance, resources specific to their learning needs, and relevant feedback (Johnson et al. 2009; Kelly 2008; Koedinger and Aleven 2007; Sancho et al. 2009; Walkington 2013). These systems can add value to the learning experience by presenting information in understandable and engaging ways that are situated in relevant and meaningful contexts personalized to the student.

Adaptive learning is promoted as a tool that has the potential to transform higher education by improving the quality of the educational experience through personalization. It has been garnered as an alternative to the traditional model to provide instruction based on the student's current level of understanding and address gaps in knowledge (Johnson and Samora 2016), and its use to address remedial instruction has been on the rise in recent years (Foshee et al. 2016; Hsieh et al. 2013; Lin et al. 2016). Using adaptive technology shows promise; findings in the literature indicate that it has the potential to increase persistence and achievement in developmental education (Lin et al. 2016; Yarnall et al. 2016). In a study conducted by Foshee et al. (2016), the researchers examined the use of an adaptive learning environment on math remediation. The researchers found statistically significant improvement in students' learning and math efficacy indicating that the technology-enhanced environment can lead to successful remediation. The researchers also found that the students' completion level impacted their ability to overcome math deficiencies and suggested that when an adaptive learning environment is fully embraced, it has the ability to reduce deficiencies.

Furthermore, in a study conducted by Yang et al. (2014), researchers found that when an adaptive learning system's interface and learning content was tailored to a students' learning and cognitive preferences, it improved the students' learning achievements. These achievements led to an increase in the student's belief in their own abilities. The strength of an individual's conviction in his or her own effectiveness is likely to affect beliefs about ability to perform and can have a direct influence on behavior and eventual success (Bandura 1977, 1982). Early evaluations of adaptive learning systems have yielded positive results leading to students acquiring knowledge and problem-solving skills that are vital in a complex world driven by digital resources and communication tools (Baghaei et al. 2007; Benedict 2010; Kong et al. 2014). Given the recent technological advancements, higher education institutions are exploring the potentials of adaptive technologies.

Adaptive learning in pharmacy education

In pharmacy education, innovative technologies such as adaptive learning have increasingly been used to address instructional challenges. For example, virtual patient case simulations that use looping and branching technology and provide adaptive feedback have emerged in schools of pharmacy. These environments allow students to review and practice key concepts in a controlled environment that provide immediate, individualized feedback. Studies on this technology have shown positive results to enhance student learning and engagement in their coursework (Al-Dahir et al. 2014; Benedict 2010). In a study conducted by Smith et al. (2014), virtual patient cases were developed to allow students to interact with patient scenarios. The system used branching technology that directed students' actions based on their response and provided students a learning path that was individualized to their knowledge, skill, and decision-making level. The students also received immediate feedback based on their interactions. Their study found that students' scores significantly improved from pre- to post- test after interacting with the technology and that students enjoyed the teaching experience and found it helpful to their learning.

Learners' characteristics and student success

Research has shown learner characteristics play an important role in students' learning. In a recent literature review, Nakic et al. (2015) found that the characteristics that affect a student's learning in an adaptive environment include a combination of demographic and background variables (e.g., age, gender, background knowledge, experience), cognitive characteristics (e.g., processing speed, working memory, special ability, etc.) and non-cognitive characteristics (e.g., anxiety, emotional and affective states, motivation, etc.). According to Chamberlin (2010), while assessing learning should focus on the curriculum students have learned from, all factors, including both cognitive and non-cognitive ones, that relate to students' learning are critically important. Research shows non-cognitive characteristics can affect how students learn and make decisions (Seifert et al. 2006). Affect is an important non-cognitive characteristic that impacts the learning process (Binet and Simon 1916; Chamberlin 2010; Messick 1979; Mullis et al. 2004).

The learner characteristics of particular interest to this study are math anxiety and prior educational experience. This is because the pharmacy curriculum usually has a heavy quantitative focus and a student's math anxiety can play a critical role in educational decisions and influence the student's achievement of educational and career goals. Literature has shown math anxiety can lead to student's avoidance of math courses or poor performance in math (Akin and Kurbanoglu 2011; Betz 1978). Students who have higher levels of math anxiety tend to have lower math scores (Ho et al. 2000). A student's affective state instead of cognitive ability may debilitate math performance (Akin and Kurbanoglu 2011; Ho et al. 2000; Jameson and Fusco 2014). Since students' knowledge and skills in mathematics are critical to a students' success in the Pharm. D. degree, in this study we measured students' math anxiety and investigated relationships between math anxiety and their participation in the adaptive learning modules and performance.

Students' performance in higher education often is related to their prior knowledge and experiences. Variables such as prior GPA and standardized test scores on the college admission exam (SAT), graduate school admission exam (GRE), and Pharmacy College Admission Test (PCAT) are linked with student success and commonly used as part of the admission criteria to colleges and graduate/professional schools (Allen and Diaz Jr. 2013; Salvatori 2001). In this study, we examined how Pre-Pharmacy GPA and PCAT scores related to both participation in the intervention and student learning.

Student perceptions of adaptive learning

A few studies examining student's perceptions of adaptive learning tools have indicated that learners reported a positive experience with adaptive learning (Johnson and Samora

2016; Mampadi et al. 2011; van Seters et al. 2012) and would use the adaptive tools again if given the option (Howlin 2014; Simon-Campbell and Phelan 2016). In a study that examined the implementation of an adaptive learning tool in a general psychology and a nursing physiopathology course, researchers found that students had a high perception of the adaptive tool (Howlin 2014). The study reported that 83% of students felt they learned the course material better by using the adaptive tool; however, over half of the students also indicated that the tool required a larger time commitment compared to a traditional class. Other researchers reported that students found getting feedback on their strengths and weaknesses was beneficial to their learning (Simon-Campbell and Phelan 2016; van Seters et al. 2012). While it is promising that adaptive learning systems can improve student understanding and engagement with content, research on the use of these systems continues to be limited. Research on learners' perception of using adaptive systems is needed because for an innovative learning system to be effective and adopted for educational use, learners' perception is a critical factor. Therefore, in this study we intend to address the following three research questions:

1. What is the effect of the adaptive learning intervention on first-year professional Pharm.D. students' learning in four content areas: Biology, chemistry, math, and information literacy?
2. How do student characteristics compare across those who engaged in the adaptive learning system and those who did not?
3. What are students' perceptions of their adaptive learning experience?

Method

Participants

The participants of this study included first-year students (n = 128) entering into the Pharm.D. program of a large research university in the Southwestern part of U.S. in the Fall 2015 semester. Of these 128 students, 35% were white, 39% were Asian/Asian American, 20% were Hispanic, 5% were black, and the rest consisted of two or more race groups/unreported. They came from various disciplines and the majority, 62%, had a bachelor's degree, 39% had a high school diploma, .02% had a master's degree. The faculty in the College of Pharmacy were interested in exploring the potential of adaptive learning to address differing student proficiency levels and to ease instructional challenges due to the differences in students' readiness for the rigorous curriculum they were about to begin. A total of four modules were created in the subjects of biology, chemistry, math, and information literacy, the areas that faculty deemed necessary for this adaptive learning intervention. All incoming students were invited to participate though participation was voluntary. A total of 74 students participated in the biology module (male = 26, female = 48), 52 students participated in the chemistry module (male = 17, female = 35), 62 students participated in the math module (male = 26, female = 36), and 50 students participated in the information literacy module (male = 22, female = 28).

Adaptive learning intervention

The adaptive intervention modules were created using the Brightspace LeaP™ adaptive technology and embedded, via Learning Tools Interoperability integration, within the campus learning management system, Canvas. LeaP™ is an adaptive technology that allows the developer to link information from a broad range of sources and develop learning outcomes, assessment items, and content within the system. Learning outcomes are statements that communicate what the learners are expected to achieve and how they are expected to demonstrate attainment (Kennedy et al. 2007). The LeaP™ system dynamically generates personalized learning paths based on the student's performance on a diagnostic assessment presented upon their initial engagement with the system. Different scores from the diagnostic test will result in different learning paths called by LeaP™ (see Figs. 1, 2). A semantic analysis engine is used to align the learning outcomes, assessment items, and content automatically in that LeaP™ semantically analyzes the questions to determine the best matches to the chosen learning objectives. Given the diagnostic test result, a learner is presented with a study plan as he or she navigates through a learning path.

Four content modules were deployed within the LeaP™ adaptive system: biology, chemistry, math, and information literacy. Faculty from the College of Pharmacy, within the respective content areas, identified the topics that posed the most common challenges for students entering the Pharm.D. program. They worked with advanced pharmacy student assistants to gather relevant content, including links to readings, videos, or other information that related to the identified topics. The instructional content was created and reviewed by the respective faculty members and then loaded into the LeaP™ system.

The math module consisted of three learning paths, and the biology and chemistry modules consisted of four learning paths each. The Information Literacy module had six learning paths, and its content was created based upon the *Information Literacy Standards*

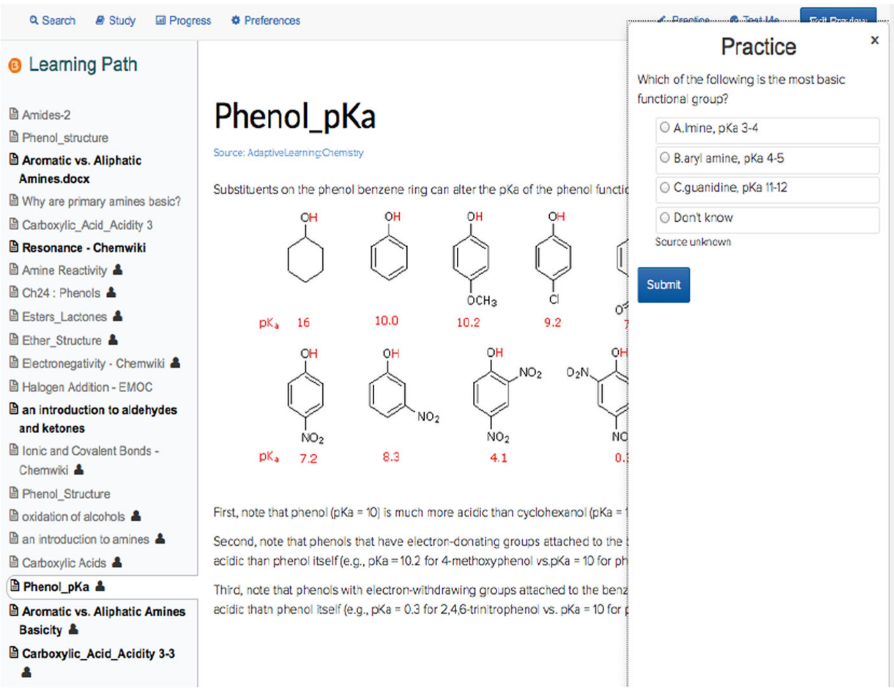

Fig. 1 A practice item from the chemistry module generated upon a student's request

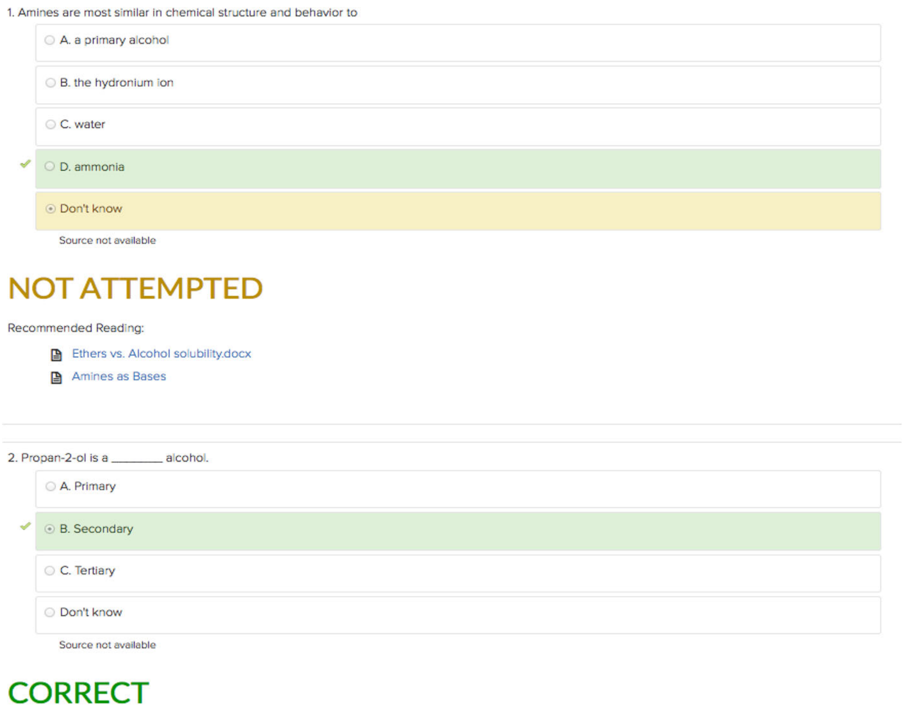

Fig. 2 Part of a diagnostic test

for Science and Engineering/Technology from the Association of College and Research Libraries, which serves as the reference for foundational information literacy skills for incoming pharmacy students.

Data sources

This study used a mixed-methods design (Creswell 2014) employing both quantitative and qualitative data sources to address the three research questions. It used the following five data sources.

Demographic variables

The following variables were obtained from university admissions data: Pre-Pharmacy GPA, gender, PCAT composite score, PCAT Verbal score, PCAT Quantitative score, PCAT Biology score, PCAT Chemistry score, PCAT Reading Comprehension score, and PCAT Writing score.

Performance

Students' performance in each of the four modules was evaluated by a pre-/post-test of their knowledge of the respective content. These tests were created by the pharmacy faculty who had previously taught the content. The biology test consisted of 24 questions, the chemistry test consisted of 28 questions, the math test consisted of 25 questions, and the information literacy test consisted of 26 questions. The same questions were provided in the pre- and post- tests for each module. Many test items were part of assessments used in the past to maintain consistency of the content. These tests were revised and refined by specialists with expertise in assessment and loaded into the LeaP^{TM} system. The raw scores were converted to percentage correct in the analyses.

Math anxiety

Students' math anxiety was measured by a revised math anxiety scale by Betz (1978) who used it to investigate factors related to the prevalence and intensity of math anxiety in college students. This revised scale is part of the Fennema-Sherman Mathematics Attitudes Scales, a well-established instrument that has been used widely and has high reported reliability and validity index ranging from .72 to .92 (Betz 1978; Chamberlin 2010; Cooper and Robinson 1991; Dew and Galassi 1983; Hackett and Betz 1989; Pajares and Kranzler 1995). This scale contains 10 Likert-type items describing situations related to mathematics with five possible responses ranging from strongly disagree to strongly agree. After reverse-coding five of the items, a higher composite score indicated a more positive attitude towards math (i.e., less math anxiety), which was then converted to a percentage out of 100.

Student experience post-survey

A survey, consisting of Likert scale, multiple-choice and open-ended questions, was given to the students after they used the system to explore and understand their experience in using the adaptive intervention. The survey questions focused on students' overall experience with the adaptive intervention (see Table 5 for survey questions), their experience in the specific content modules (see Table 6 for survey questions), and reasons why the students accessed or did not access the system (see Table 3 for survey questions). The survey was reviewed by specialists with expertise in assessment, instruction technology, and pharmacy for content and face validity.

Student focus group interviews

To further explore students' experiences, a total of three focus group interviews were conducted after the completion of the intervention. Participants for each group were carefully chosen to represent various perspectives: Group 1—*Engaged*- consisted of students that completed the pre-test and one to four of the content modules; Group 2—*Partially Engaged*- consisted of the students that completed the pre-test and at least one learning path but did not complete a full content module; and Group 3—*Not Engaged*- consisted of the students that completed the pre-test but did not engage in any of the learning paths. Invitations were sent to the students that met these criteria. Ten students participated in Group 1, eight students participated in Group 2, and 10 students participated in Group 3. Each focus group was conducted by an interviewer and assisted by one note taker, and lasted approximately 1 h. Interview questions were to examine students' satisfaction with their learning experience and their perceptions of which aspects were the most or least helpful to their learning. Sample questions include:

- Why did you decide to complete/not complete specific Learning Paths?
- Describe your overall learning experience using the adaptive learning system.

- What was your favorite part of your learning experience? Why?
- How did your interaction with the Learning Paths impact your preparation for Pharmacy school?
- Was this adaptive learning approach an effective approach for you to review the content provided? Why or why not? Please explain.
- What suggestions do you have for making the adaptive learning reviews more effective to you? Why?
- What were your reasons for deciding not to engage with the Learning Paths after taking one or more of the pre-assessments?

Procedure

This intervention occurred from July 13 to August 21, 2015, for a total of 6 weeks before the start of fall semester. Students received an email from an associate dean of the College of Pharmacy that explained the purpose and timing of the adaptive learning intervention; encouraging all students to participate and complete all learning paths. The email also provided students with the link needed to begin.

When students clicked on the link provided, it directed them to a survey related to their demographic information and math anxiety. Once completed, they were given an access code for the adaptive modules. Upon entering each content module, students completed a pre-test that measured their content knowledge in that area. Once the pre-test was completed, they were free to interact with the adaptive content. The procedure was the same for each content module.

Students also completed a survey regarding their experience at the conclusion of this summer intervention. During the 1st week of the fall semester when students began their formal professional degree, students completed the post-test during normal class times and focus groups were conducted during the 5th week of the fall semester.

Analysis

To answer the first research question, we examined if there was a significant difference in change of performance from pre- to post-test for students who completed the adaptive learning paths and those who did not. We hypothesized that those who completed the learning paths of a content module would show a higher gain in their content knowledge than those who did not complete a learning path. Separate analyses were conducted for each of the four content modules. Students' participation was classified into two categories: (1) those who completed at least one learning path in a content module, which is an indication of more engagement in the intervention, and (2) those who accessed a module but did not complete any of the learning paths, which is an indication of less engagement. Completion of a learning path is defined by the student interacting in the learning path and completing an end of module quiz. Only participants who completed both pre- and post-tests were included in the analyses for this study. Student Pre-Pharmacy GPA, PCAT composite score, PCAT Verbal score, PCAT Quantitative score, PCAT Biology score, PCAT Chemistry score, PCAT Reading Comprehension score, PCAT Writing score, were used as control variables in this study. Only student characteristic variables with strong correlations to performance were included in the analyses.

An ANCOVA, using PCAT composite scores as covariates for biology, chemistry, and math and PCAT Verbal score as covariates for information literacy, was conducted to examine gains from pre- to post-test in each content area. Higher scores would suggest greater gains in the post-test. The between subject independent variable was those who completed at least one learning path versus those that did not. The dependent variable (DV) was the difference between the pre- and post- test scores. ANCOVA is used to control for the effects of PCAT scores that are not of primary interest in this analysis, but possibly co-vary with the DV, the knowledge gain score.

To answer the second research question, an Independent *T* Test was run for each of the four content modules between the group that completed a learning path and the group that did not, and students' characteristics variables (i.e., Pre-Pharmacy GPA, PCAT composite score, and math anxiety scores) were used as the DV in respective analyses.

To answer the third research question, Likert scale and multiple-choice questions from the survey were first analyzed descriptively. Then further analyses were conducted using a generalized linear mixed-model to test any differences of proportions of students' responses for reasons of engagement and their perceptions of experiences between the four different content modules while also taking into account interaction effects and random effects of students.

To supplement the quantitative data for this research question, the open-ended questions from the survey and the focus group interviews were analyzed using the qualitative data analysis framework by Miles et al. (2014) and the constant comparative method (Creswell 2014). First, the interviews were transcribed. One researcher coded each transcript and created a codebook, which listed each code and its description. The second researcher coded transcripts independently and then compared the coding, highlighting any inconsistencies. All disagreements were discussed among the team members until 100% inter-rater reliability was reached. The updated and refined codebook contained a total of 44 codes. During the coding process, seven definitions were expanded from the initial definitions. Three codes were added, and two codes were combined. The codes were then organized into themes (e.g., issues with content or design, personal motivation and other personal factors, and positive or negative reviews of the experience) to align with the research question. Quotes from the interviews are presented below unedited.

Results

In this study, we examined students' experiences with an adaptive learning system and the effects on students' learning. Our research questions focused on the effect of an adaptive learning intervention on students' performance in four content areas: Biology, chemistry, math, and information literacy, the characteristics of students who were more likely to use the adaptive learning system, and students' perceptions of their adaptive learning experience.

RQ #1: Effect of the adaptive learning intervention on students' learning

ANCOVA results showed a statistically significant difference between students that completed at least one learning path compared to those that did not complete a learning path for chemistry, using PCAT composite score as a covariate: $F(1,50) = 5.9$, $MSE = 138.89$, $p < 0.05$. Descriptively, the differences between the pre-test and post-test scores in biology, math, and information literacy were bigger for students that completed a learning path as compared to students that did not complete a learning path. However, these differences were not statistically significant. Table 1 presents means in each content area as well as the differences between pre- and post-test scores).

RQ #2: Comparing student characteristics of those who engaged versus those who did not?

Given that using this adaptive learning intervention was entirely the students' choice, we examined if certain students' characteristics were related to their decisions to participate. Of particular interest were indicators of students' prior knowledge and experience (e.g., Pre-Pharmacy GPA and PCAT composite score), and their level of math anxiety. The result of an Independent *T*-Test revealed that math anxiety was the only characteristic that showed a significant result. Those that did not complete a math learning path had less math anxiety ($M = 40.3$) compared to those who did complete a math learning path: $M = 36.59$, $t(57) = 1.98$, $p < .05$ (see Table 2).

To further investigate the relationship between students' math performance and students' math anxiety, a Pearson correlation was performed. Fifty percent of the students completed a math learning path while the other half did not. A Bivariate correlation between math anxiety, where a higher score indicates less math anxiety, and math post-test score showed a weak correlation ($r = .07$) for students who did not complete any math learning paths but showed a slightly stronger correlation ($r = .28$) for students who did complete at least one learning path. However, results of a linear regression showed no significant relationship between math post-test scores and math anxiety for students who

Table 1 Students' Pre- and Post-test scores for each content area after using the adaptive learning

	Completed at least one learning path			Did not complete any learning paths		
	n	*M*	*SD*	*n*	*M*	*SD*
Biology						
Pre-test	32	77.86	15.28	42	73.31	14.29
Post-test		85.55	13.59		79.86	12.14
Difference in pre- and post- test scores		7.68	15.16		6.55	12.21
Chemistry						
Pre-test	26	54.26	11.47	26	52.75	10.46
Post-test		64.42[a]	14.27		55.49	12.83
Difference in pre- and post-test scores		10.16	14.06		2.75	10.37
Math						
Pre-test	31	84.52	8.63	31	84.52	9.34
Post-test		87.48	7.28		86.58	7.7
Difference in pre- and post-test scores		2.97	10.53		2.06	7.44
Information literacy						
Pre-test	21	64.47	14.54	29	68.44	12.81
Post-test		67.40	19.67		66.18	10.70
Difference in pre- and post-test scores		2.93	19.94		−2.25	11.10

[a] $p < 0.05$

Table 2 Pre-pharmacy GPA, PCAT composite, and math anxiety scores for those who completed a math learning path versus those who did not

Variable	Completed a math learning path		Did not completed a math learning path	
	M	*SD*	*M*	*SD*
Pre-pharmacy GPA	3.49	0.36	3.51	0.70
PCAT composite	86.84	9.19	87.23	10.12
Math anxiety	36.59 [a]	7.83	40.30	6.57

[a] $p < 0.05$

did not complete any math learning paths nor for students who completed at least one learning path.

RQ #3: Students' perception of their experience using the adaptive learning system

Students' perceptions were gathered through survey responses and focus group interviews. Sixty-six students completed the post-survey voluntarily. Of those, 73% ($n = 48$) completed the biology module, 64% ($n = 42$) the math module, 62% ($n = 41$) the chemistry module and 49% ($n = 32$) the information literacy module. Eleven percent ($n = 7$) indicated they did not complete any of the content modules. Three focus groups were conducted based on level of engagement of the students: "Engaged" (i.e., students that completed the pre-test and one to four of the content modules, $n = 10$), "Partially Engaged" (i.e., students that completed the pre-test and at least one learning path but did not complete a full content module, $n = 8$), and "Not Engaged" (i.e., students that completed the pre-test but did not engage in any of the learning paths, $n = 10$).

Reasons for engagement

When asked why students decided to engage with specific content modules, survey responses revealed the top reason was curiosity about the content in the module, followed by intent to take advantage of the learning opportunity (see Table 3). However, a large percentage of the students also indicated they lacked confidence in their knowledge of chemistry (32.4%) and information literacy (41.9%). To further examine these differences, we ran a generalized linear mixed-model. Findings showed an overall significant result for the differences in reasons for engagement across content module ($p = 0.002$). Specifically, students reported the reason "lack of confidence in their content knowledge" more frequently for the chemistry module than the math module ($p < .05$) and the biology module ($p = .05$); and more frequently for the information literacy module than the biology module ($p < .01$) and the math module ($p < .001$). The descriptive differences in other reasons among the four modules were not statistically significant. Lack of time was the main reason students indicated they did not complete a specific content module or engage at all with the intervention.

The focus group interviews provided more detailed insights into the reasons why students chose to engage or not engage with the adaptive learning intervention (see Table 4). Some students who participated indicated they wanted to refresh their knowledge of the

Table 3 Reasons for accessing modules reported in student survey

Reasons*	Biology ($n = 45$)		Chemistry ($n = 37$)		Math ($n = 39$)		Information literacy ($n = 31$)	
	n	%	*n*	%	*n*	%	*n*	%
I was not confident about my [subject] content knowledge	7	15.6[a]	12	32.4[b]	5	12.8	13	41.9[c]
I was curious about the content in the review	32	71.1	21	56.8	29	74.4	18	58.1
It had been a long time since I took a [subject] course	9	20.0	13	35.1	13	33.3	6	19.4
I like to take advantage of every learning opportunity available to me	19	42.2	18	48.6	16	41.0	11	35.5
Other	1	2.2	1	2.7	1	2.6	0	0.0

* Students were asked to select all that apply

[a]Significantly different from chemistry at $p = .05$

[b]Significantly different from math at $p < .05$

[c]Significantly different from biology at $p < .01$ and math at $p < .001$

Table 4 Reasons for engagement or non-engagement in the adaptive learning intervention reported in focus groups

Reasons	Number of comments		
	Engaged group	Partially engaged group	Not engaged group
Reasons for engagement			
To refresh knowledge of content	5	6	n/a
Lapse of time since previous education	8	1	n/a
Curious about the content	6	0	n/a
Reasons for non-engagement			
Time constraint	n/a	n/a	8
Technical issue	n/a	n/a	5
Frustration with format, structure or design of modules	n/a	n/a	5
Too much content	n/a	n/a	3
Preference to wait until classes start	n/a	n/a	3
Participation was optional	n/a	n/a	2

content. One student commented, "I just wanted to know what I didn't know. Because I wasn't sure what my weaknesses were …, especially with math and biology, I made it an issue to know what it was I needed to brush up on…" Several students also indicated that there had been a lapse of time between their undergraduate education and the start of pharmacy school. A student commented, "[It has] been seven, 8 years since I took some of those courses, so—especially with chemistry, I wanted to make sure that, you know, I had a solid base going into pharmacy school." Six comments from the "Engaged" group revealed that curiosity about the content also motivated students to participate, as indicated in this comment, “I just wanted to see what was on there and get a quick basic understanding of the subjects and prepare myself.”

The most frequently stated reason for not engaging in the adaptive learning modules was time constraints due to personal schedules (e.g., work, summer courses, travel, etc.). Technical issues were also a factor preventing students from engaging in the intervention. For example, one student commented, “I put that password and username in, but it wouldn’t let me in.” Several students expressed frustration with the format, structure, or the design of the modules, as revealed in comments such as “I felt like I was just reading a textbook and I don’t learn that way.” Some students perceived there was too much content in the modules. One student stated, “I only got through like two tabs and I was in the library for 2 h…this is not going to cut it for me.” Three comments revealed that some students preferred to wait until pharmacy classes started to engage with the content; one student commented, “if I need to know it for class, I’ll refresh it then. I’m not going to learn all this stuff and then forget it again next week.” Two students commented that they chose not to participate because it was optional and they did not receive a grade for their participation.

When asked in the interviews why students chose to participate in specific content modules and not others, some students commented they selected the modules based on their interests or comfort level with the topic. Some opted out of completing modules in which they felt comfortable with the content. Other students revealed they chose to participate in the content modules linked with low pre-assessment scores and not participate in the content modules linked with high pre-assessment scores. For example, one student commented, “on two of them, biology and info literacy, I did really well on the pre-assessments, so I’m like, ‘I’m not going to waste my time.’ So I just really focused on the other two.” Furthermore, some students selected the shortest modules first moving on to the lengthier content reviews last. A few students indicated they chose the first one on the list and began working.

Student experience

Survey responses revealed that 53% of students (strongly) agreed that they learned a great deal from participating in the adaptive learning intervention, and 52% found the adaptive learning intervention easy and intuitive to navigate. While 65% reported the adaptive approach was an effective way to learn, about one-third of the responses were either neutral or not in agreement. Sixty-one percent indicated they would like to use the adaptive learning environment in their future studies, 24% indicated neutral, and 15% of students indicated they would not like using it in the future (see Table 5).

Students’ experience with each content module showed that they (strongly) agreed that the content in the modules helped them learn basic knowledge needed for pharmacy school and the content in the learning path was organized clearly to help them learn (see Table 6). However, there was a relatively higher percentage of students who (strongly) disagreed or were neutral when asked if the learning paths effectively directed them to only the content that they needed to review and if the questions and feedback in the learning path helped them learn the content. Generalized linear mixed-model analyses were performed to examine if any of these descriptive differences were statistically significant. The findings of the students’ experience with the content modules showed there was a significant difference between the math and information literacy modules regarding the organization of the content ($p < .01$). That is, more students felt positively about the organization of the

Table 5 Student's overall experience reported in survey

Survey questions	% of responses ($n = 55$)				
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I learned a great deal from participating in the adaptive learning environment	2	11	35	42	11
I found the adaptive learning environment easy and intuitive to navigate	4	11	31	38	16
I believe that the adaptive approach implemented via the learning paths is an effective way to learn	2	7	25	56	9
I would like to use the adaptive learning environment in future studies	0	15	24	45	16

Table 6 Student's experience with content modules reported in survey

Survey questions	% of responses				
	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree
I believe the [subject] content review helped me learn basic [subject] knowledge needed for pharmacy school					
Biology ($n = 45$)	2	4	33	51	9
Chemistry ($n = 37$)	3	3	27	46	22
Math ($n = 39$)	0	3	36	36	26
Information literacy ($n = 31$)	0	13	32	42	13
The content in the learning path was organized clearly to help me learn					
Biology	2	9	27	58	4
Chemistry	3	11	24	51	11
Math[a]	0	3	31	56	10
Information literacy	0	6	45	42	6
The learning paths effectively directed me to only the content that I needed to review					
Biology	0	9	49	38	4
Chemistry	5	11	35	35	14
Math[b]	0	5	41	41	13
Information literacy	0	13	48	32	6
The questions and feedback in the learning path helped me to learn the content					
Biology	2	4	40	47	7
Chemistry	3	0	41	46	11
Math	0	5	38	44	13
Information literacy	0	13	29	48	10

[a]Significantly different from information literacy at $p < .01$

[b]Significantly different from biology, chemistry, and information literacy at $p < .05$

math module than the information literacy module. There was also a significant difference between the math and the other three modules regarding whether the learning paths effectively directed students to only the content they needed to review ($p < .05$). More students felt positively about the math module than all three other content modules (see Table 6). The other descriptive differences relating to students' experience among the four modules were not statistically significant.

The results from the interviews aligned with the findings of the survey and provided more insight into students' positive experience as well as their concerns. Student comments indicated that the adaptive learning intervention was beneficial, and they would recommend it to other students (12 comments from the "Engaged" and 23 from the "Partially Engaged" groups). A few students reported that the video resources were helpful (two comments from the "Engaged," three from the "Partially Engaged," and two from the "Not Engaged" groups). One student said, "I like the videos, I was in summer mode and I didn't feel like reading a whole article. The videos really helped, especially with the things I needed to review on."

Although many students commented on the positive impact the adaptive learning intervention had on them; the focus group interviews revealed a number of concerns (see Table 7). A relatively large number of students' comments stated there was too much content, the modules were overwhelming, or the links to resources within the modules were not helpful. One student commented, "For biology, they kind of linked you to stuff and it was too much information," another commented, "I thought the articles [that we linked to] were too long, most of them. Because you only needed to know half of what was in there and you'd get, like, pages and pages and pages of articles." Many students also indicated they were discouraged from participating due to the structure and design of the adaptive learning intervention. One student commented, "It wasn't completely intuitive…. I don't feel like it led me through a pathway," and another commented, "hitting the next box should take you to the next section of the—that'll keep me going instead of having to go back to the main screen … you know, make it a continual flow and if you want to go back to the main page, you can, but not being forced to do that every time."

Some students felt there was not enough feedback provided in the quizzes or practice problems, or that the feedback provided was not helpful. For example, one student commented, "if you missed [a question] then [the] links [provided] didn't always match up with the question. Say it was over lipid bilayer, the links it would give you would be…off topic things that didn't really help you understand." Additionally, some students found that some of the quiz content was incorrect and reflected an incorrect answer thus impacting their confidence in what they were reviewing. One student stated, "Not all the questions

Table 7 Reasons for disengagement and frustration

Reasons	Number of comments	
	Engaged group	Partially engaged group
Too much content	35	30
Poor structure/design	27	22
Unhelpful links	10	12
Lack of relevance to course work	10	12
Insufficient feedback	5	10

had the right answers. That was frustrating, as well, so you couldn't know what to trust at that point. So it's like, well, which other ones is it counting wrong or right that isn't correct. That kind of made me hesitant to do some of the other sections." Finally, several comments revealed that students felt the content in the reviews was not helpful or related to what they were learning in their coursework.

Discussion

Research has shown that students learn best when their individual needs are targeted (Baghaei et al. 2007; Benedict 2010; Kerr 2016). With today's technological advancement, adaptive learning has emerged as a way to better meet individual student needs (U.S. Department of Education 2013; Johnson et al. 2009; Kelly 2008; Kerr 2016; Somyürek 2015), especially for remedial content (Foshee et al. 2016; Lin et al. 2016). The findings of this study showed that the adaptive learning intervention significantly increased students' knowledge of remedial chemistry content, the most complex of all four modules. The students in this study indicated an overall positive learning experience, which aligns with previous findings in the literature (Howlin 2014; Mampadi et al. 2011; van Seters et al. 2012). Over half of the students stated that the adaptive learning intervention helped them learn the needed knowledge to prepare for their professional school and considered the adaptive approach an effective way to learn. Such findings are encouraging and support other research that indicates a positive learning impact of using adaptive learning (Baghaei et al. 2007; Benedict 2010; Foshee et al. 2016; Kelly 2008; Kong et al. 2014; Simon-Campbell and Phelan 2016; Yang et al. 2014).

However, there was no significant increase in the students' knowledge of biology, math, or information literacy following the intervention. Several possible reasons could have contributed to this lack of student success. The intervention was voluntary and students self-selected the extent they wanted to engage. This study found that lack of time was a major reason cited by students for not participating in the intervention. This finding is consistent with the findings from the literature where the use of an adaptive learning system requires a larger time commitment from students than the traditional model of education (Howlin 2014). While students indicated their desire to take advantage of this adaptive learning opportunity, the timing of the intervention interfered with some students' previously scheduled summer plans, and therefore many chose not to participate fully.

The results also showed significantly more students indicated a lack of confidence in their knowledge of chemistry and information literacy, and this lack of confidence was a reason for their participation in the adaptive intervention. This finding shows a promising effect of using adaptive learning to not only improve students' knowledge, as we found with the chemistry module, but also to alleviate students' feelings of anxiousness about a lack of confidence in their knowledge. It also suggests that given rapid changes in technology, more remedial or a refresher of content may be needed for professional students as they enter into a formal degree program to keep their information literacy knowledge current, and adaptive learning, such as the intervention used in this study, can benefit these students.

More importantly, results revealed that certain design aspects of the modules contributed to students' confusion and frustration. Several students expressed reservations about the ability of the learning paths to effectively direct them to only the content they needed to review. These issues can be partly explained by the lack of alignment between the assessments and the content students were directed to as a result of their performance on the diagnostic assessments. Students expressed frustration with not knowing which items they missed and which content they should focus on when linked to long readings or videos that covered several topic areas. Perhaps the intervention was not adaptive enough to meet these students' needs because of the lack of alignment. Learner satisfaction and success decrease when learning experiences are not organized around clear learning goals and with direct alignment to instructional materials and assessments (Blumberg 2009; Kauffman 2015; Wiggins and McTighe 2011). The content modules were created by content experts (i.e., faculty who have taught the courses and their advanced pharmacy student assistants), but there were no personnel with instructional design expertise on the development teams. Additionally, the modules were created within a very short timeframe to meet the launch date deadline, and there was no time for formal usability testing which could have caught many of the navigation and design issues that students experienced.

Literature shows affect factors such as math anxiety are important in assessing learning (Chamberlin 2010; Messick 1979; Mullis et al. 2004). The results of this study showed that math anxiety was the only student characteristic that showed a significant relationship with students' participation; those that completed a math learning path had higher math anxiety. This finding is different from the literature indicating that students with higher math anxiety tend to avoid math courses (Akin and Kurbanoglu 2011; Betz 1978). It is possible students with higher math anxiety, due to their lack of confidence in the subject matter, wanted to use this learning opportunity to refresh their knowledge of the content in the summer before the start of pharmacy school. Since this was a low-stakes environment with no impact on their future course grades, anxiety about performance was lessened. In addition, the relationship between math anxiety and learning performance in this study is less clear as in other research (Ho et al. 2000). The results did not show a significant relationship between students' math anxiety and their learning performance. Such findings warrant further research.

The promise of adaptive learning is that it can customize the learning experience by making changes dynamically and provide targeted feedback (Somyürek 2015) so the instruction is individualized to learners' needs (Baghaei et al. 2007; Benedict 2010; Kerr 2016). While the intervention may have met the needs of some students and provided refresher instruction, we learned that the adaptive aspect of this intervention needed improvement.

Study limitations

This study is limited in that it was conducted to address a real-world instructional challenge in an educational setting, and therefore having a control group for experimental purposes was not an option. In addition, students' participation was entire voluntarily. Although over 85% of all those invited completed the pre-test, many of them did not ultimately access the intervention and, therefore, reduced the total number of actual participants. Students also had the freedom to interact with the content modules as they saw fit. Many entered a module but exited without completing the end of module quiz, which further reduced the number of "Engaged" participants. Readers are cautioned to keep these limitations in mind.

Conclusion

This study provides insights into the overall understanding of both the benefits and challenges of adaptive learning. The findings provide some empirical evidence that an adaptive learning intervention can have a positive impact on student learning. However, the success of an adaptive learning intervention depends on its design. In addition to having access to an adaptive system, content experts, and support from the institution, importance of the instructional design cannot be overlooked, and user testing of a system cannot be neglected. Designers should ensure a system effectively directs learners to only the content needed and that feedback is meaningful and directly aligned with the content. The type and quality of the resources provided should also be taken into consideration to ensure that they are meaningful to students' learning. Using resources that are not targeted to the specific learning outcome is ineffective. It is also important to consider timing and incentive structures to motivate all students to fully engage and participate thoroughly to receive the benefits of adaptive learning.

Acknowledgement We would like to thank Daniel Robinson, Ph.D. and Adam Sales, Ph.D. for their helpful advice on the quantitative analyses of this study; and Phillip Long, Ph.D. for his support to this project.

References

ACPE. (2015). *Accreditation standards and key elements for the professional program in pharmacy leading to the doctor of pharmacy degree*. Chicago, IL: Accreditation Council for Pharmacy Education.

Akin, A., & Kurbanoglu, I. N. (2011). The relationships between math anxiety, math attitudes, and self-efficacy: A structural equation model. *Studia Psychologica, 53*(3), 263.

Al-Dahir, S., Bryant, K., Kennedy, K. B., & Robinson, D. S. (2014). Online virtual-patient cases versus traditional problem-based learning in advanced pharmacy practice experiences. *American Journal of Pharmaceutical Education*. doi:10.5688/ajpe78476.

Allen, R. E., & Diaz, C., Jr. (2013). Use of preadmission criteria and performance in the Doctor of Pharmacy program to predict success on the North American pharmacists licensure examination. *American Journal of Pharmaceutical Education, 77*(9), 193.

Baghaei, N., Mitrovic, A., & Irwin, W. (2007). Supporting collaborative learning and problem-solving in a constraint-based CSCL environment for UML class diagrams. *International Journal of Computer-Supported Collaborative Learning, 2*(2), 159–190.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84*(2), 191–215. doi:10.1037/0033-295X.84.2.191.

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist, 37*(2), 122–147. doi:10.1037/0003-066X.37.2.122.

Benedict, N. (2010). Virtual patients and problem-based learning in advanced therapeutics. *American Journal of Pharmaceutical Education, 74*(8), 143.

Betz, N. E. (1978). Prevalence, distribution, and correlates of math anxiety in college students. *Journal of Counseling Psychology, 25*(5), 441–448. doi:10.1037/0022-0167.25.5.441.

Binet. A., & Simon, T. (1916). *The development of intelligence in childre*n. Baltimore, Williams & Wilkins. (Reprinted 1973, New York: Arno Press; 1983, Salem, NH: Ayer Company).

Blumberg, P. (2009). Maximizing learning through course alignment and experience with different types of knowledge. *Innovative Higher Education, 34*(2), 93–103.

Chamberlin, S. A. (2010). A review of instruments created to assess affect in mathematics. *Journal of Mathematics Education, 3*(1), 167–182.

Cooper, S. E., & Robinson, D. A. (1991). The relationship of mathematics self-efficacy beliefs to mathematics anxiety and performance. *Measurement and Evaluation in Counseling and Development*, *24*(1), 4–11.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). Thousand Oaks, CA: Sage Publications.

Dew, K. H., & Galassi, J. P. (1983). Mathematics anxiety: Some basic issues. *Journal of Counseling Psychology*, *30*(3), 443. doi:10.1037/0022-0167.30.3.443.

Foshee, C. M., Elliott, S. N., & Atkinson, R. K. (2016). Technology-enhanced learning in college mathematics remediation. *British Journal of Educational Technology, 47*(5), 893–905. doi:10.1111/bjet.12285.

Hackett, G., & Betz, N. E. (1989). An exploration of the mathematics self-efficacy/mathematics performance correspondence. *Journal for Research in Mathematics Education*, *20*(3), 261–273. doi:10.2307/749515

Ho, H.-Z., Senturk, D., Lam, A. G., Zimmer, J. M., Hong, S., Okamoto, Y.,… Wang, C.-P. (2000). The affective and cognitive dimensions of math anxiety: A cross-national study. *Journal for Research in Mathematics Education*, *31*, 362–379.

Howlin, C. (2014). *Realizeit at the University of Central Florida: Results from initial trials of Realizeit at the University of Central Florida*: Dublin, Ireland

Hsieh, T.-C., Lee, M.-C. L., & Su, C.-Y. (2013). Designing and implementing a personalized remedial learning system for enhancing the programming learning. *Journal of Educational Technology & Society, 16*(4), 32–46.

Jameson, M. M., & Fusco, B. R. (2014). Math anxiety, math self-concept, and math self-efficacy in adult learners compared to traditional undergraduate students. *Adult Education Quarterly, 64*(4), 306–322. doi:10.1177/0741713614541461.

Johnson, L., Adams Becker, S., Cummins, M., Estrada, V., Freeman, A., & Hall, C. (2016). *NMC Horizon Report: 2016 Higher* (Education ed.). Austin, TX: The New Media Consortium.

Johnson, B. G., Phillips, F., & Chase, L. G. (2009). An intelligent tutoring system for the accounting cycle: Enhancing textbook homework with artificial intelligence. *Journal of Accounting Education, 27*(1), 30–39.

Johnson, D., & Samora, D. (2016). The potential transformation of higher education through computer-based adaptive learning systems. *Global Education Journal, 2016*(1), 1–17.

Kauffman, H. (2015). A review of predictive factors of student success in and satisfaction with online learning. *Research in Learning Technology, 23*(1), 26507.

Kelly, D. (2008). Adaptive versus learner control in a multiple intelligence learning environment. *Journal of Educational Multimedia & Hypermedia, 17*(3), 307–336.

Kennedy, D., Hyland, A., & Ryan, N. (2007). Writing and using learning outcomes: A practical guide. Retrieved from https://www.researchgate.net/publication/238495834_Writing_and_Using_Learning_Outcomes_A_Practical_Guide.

Kerr, P. (2016). Adaptive learning. *ELT Journal, 70*(1), 88–93. doi:10.1093/elt/ccv055.

Koedinger, K. R., & Aleven, V. (2007). Exploring the assistance dilemma in experiments with cognitive tutors. *Educational Psychology Review, 19*(3), 239–264. doi:10.1007/s10648-007-9049-0.

Kong, S. C., Chan, T.-W., Griffin, P., Ulrich, H., Huang, R., Kinshuk,… Yu, S. (2014). E-learning in school education in the coming 10 years for developing 21st century skills: Critical research issues and policy implications. *Journal of Educational Technology & Society, 17*(1), 70–78

Lin, C. C., Guot, K. H., & Lin, Y. C. (2016). A simple and effective remedial learning system with a fuzzy expert system. *Journal of Computer Assisted Learning, 32*(6), 647–662. doi:10.1111/jcal.12160.

Mampadi, F., Chen, S. Y., Ghinea, G., & Chen, M. P. (2011). Design of adaptive hypermedia learning systems: A cognitive style approach. *Computers & Education, 56*(4), 1003–1011. doi:10.1016/j.compedu.2010.11.018.

Messick, S. (1979). Potential uses of non-cognitive measurement in education. *Journal of Educational Psychology, 71,* 281–292.

Miles, M. B., Huberman, A. M., & Saldana, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Mullis, I. V. S., Martin, M. O., Gonzalez, E. J., & Chrostowski, S. J. (2004). *TIMSS 2003 International Mathematics: Report findings from IEA's Trends in International Mathematics and Science Study at the Fourth and Eighth Grades*. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

Nakic, J., Granic, A., & Glavinic, V. (2015). Anatomy of student models in adaptive learning systems: A systematic literature review of individual differences from 2001 to 2013. *Journal of Educational Computing Research, 51*(4), 459–489. doi:10.2190/EC.51.4.e.

Pajares, F., & Kranzler, J. (1995). Self-efficacy beliefs and general mental ability in mathematical problem-solving. *Contemporary Educational Psychology*, *20*(4), 426–443. doi:10.1006/ceps.1995.1029.

Salvatori, P. (2001). Reliability and validity of admissions tools used to select students for the health professions. *Advances in Health Sciences Education, 6*(2), 159–175.

Sancho, P., Moreno-Ger, P., Fuentes-Fernández, R., & Fernández-Manjón, B. (2009). Adaptive role playing games: An immersive approach for problem based learning. *Part of A Special Issue: New Directions in Advanced Learning Technologies, 12*(4), 110–124.

Seifert, T. A., Pascarella, E. T., Wolniak, G. C., & Cruce, T. M. (2006). Impacts of good practices on cognitive development, learning orientations, and graduate degree plans during the first year of college. *Journal of College Student Development, 47*(4), 365–383. doi:10.1353/csd.2006.0042.

Simon-Campbell, E. L., & Phelan, J. (2016). Effectiveness of an adaptive quizzing system as an institutional-wide strategy to improve student learning and retention. *Nurse Educator, 41*(5), 246–251. doi:10.1097/NNE.0000000000000258.

Smith, M. A., Mohammad, R. A., & Benedict, N. (2014). Use of virtual patients in an advanced therapeutics pharmacy course to promote active, patient-centered learning. *American Journal of Pharmaceutical Education, 78*(6), 125. doi:10.5688/ajpe786125.

Somyürek, S. (2015). The new trends in adaptive educational hypermedia systems. *International Review of Research in Open and Distributed Learning, 16*(1), 221–241.

U.S. Department of Education. (2013). *Expanding evidence approaches for learning in a digital world*. Washington, D.C: U.S. Department of Education.

van Seters, J. R., Wellink, J., Tramper, J., Goedhart, M. J., & Ossevoort, M. A. (2012). A web-based adaptive tutor to teach PCR primer design. *Biochemistry and Molecular Biology Education, 40*(1), 8–13. doi:10.1002/bmb.20563.

Walkington, C. A. (2013). Using adaptive learning technologies to personalize instruction to student interests: The impact of relevant contexts on performance and learning outcomes. *Journal of Educational Psychology*. doi:10.1037/a0031882.

Wiggins, G. P., & McTighe, J. (2011). *The understanding by design guide to creating high-quality units*. Alexandria: ASCD.

Yang, Y.-T. C., Gamble, J. H., Hung, Y.-W., & Lin, T.-Y. (2014). An online adaptive learning environment for critical-thinking-infused English literacy instruction. *British Journal of Educational Technology, 45*(4), 723–747. doi:10.1111/bjet.12080.

Yarnall, L., Means, B., & Wetzel, T. (2016). *Lessons learned from early implementations of adaptive courseware*. Retrieved from SRI International website: https://www.sri.com/sites/default/files/brochures/almap_final_report.pdf

Min Liu, Ed.D is Professor of Learning Technologies at the University of Texas at Austin. She is the Program Coordinator & Graduate Advisor. Her teaching and research interests center on educational uses of new media and other emerging technologies and their impact on teaching and learning for learners at all age levels.

Emily McKelroy, MAEd is a Ph.D. Candidate in the Learning Technologies program at the University of Texas at Austin. Her research interests include the design and use of emerging technologies to increase student success and persistence.

Stephanie B. Corliss, Ph.D is the Education Evaluation and Research Specialist at the University of Texas at Austin Dell Medical School. Her teaching and research focuses on the use of instructional practices to enhance the teaching and learning experience.

Jamison Carrigan is a doctoral student in the Department of Educational Psychology at the University of Texas at Austin. His research interests include the nature and measurement of intelligence and the use of large, extant datasets to answer school-based questions.