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Computer Quiz Games in General Chemistry for Engineering Majors in an English as a Second Language Environment

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ABSTRACT: Computer quiz games are introduced to improve teaching and learning in a freshman engineering chemistry course in an English-as-a-second-language (ESL) environment. These quiz games are developed and implemented as supplemental and augmentative tools to enhance traditionally delivered lectures. The paper shows an increase in students' motivation and compares the performance among students who participated in computer quiz games, a paper-based quiz, or neither activity. An assessment of the effectiveness of quiz games in learning is conducted via a proposed novel chemistry achievement test, the Freshman Engineering Chemistry Aptitude Test, and an attitude questionnaire. The findings contribute to our understanding of the role of game-based learning in students' achievement in chemistry and their motivation and attitudes toward learning general chemistry at a university within an ESL environment, while the computer games developed are useful in all English-based chemistry classes.

KEYWORDS: *Introductory Chemistry, Games, English as a Second Language, Student-Centered Learning, Computer-Based Learning, Hands-On Learning*

INTRODUCTION AND MOTIVATION

Freshman engineering chemistry is considered difficult by a non-negligible fraction of students[1] and is sometimes reported as a course with lower than desired or expected achievement.[2] The factors leading to this include diminished interest in general science courses and subadequate instruction for large classes.[3,4] As switching from a traditional to a completely interactive, student-centered teaching methodology is not easy at most institutions,[5] we developed a novel approach, augmenting traditional course delivery through a relatively small portion of class time on a weekly basis. We also aimed to encourage deeper student involvement and provide tools enabling self-paced learning.[6,7] Beyond these globally relevant issues, many local students (UAE and the broader Arabian/Persian Gulf region) acquire a limited understanding of scientific concepts at all educational stages, partly due to traditional teaching methodology and partly due to over-reliance on rote learning,[1,8,9] making the goals and objectives of this work worthy of regional attention.[10,11]

Since the 1970s, interactive engagement methods have been introduced in science classes,[12] including the studio method;[13] exploratory laboratory method,[12] cooperative learning,[8] peer instruction,[14,15] student team-achievement division (STAD) method,[6] educational computer game-based learning,[16,17] e-learning,[18,19,20] and web-based learning,[21,22] among others. Notable among these approaches is educational gaming, which relies on the motivational power of games to make learning more enjoyable.[23] Common to all of these methods is introducing an in-class activity that keeps students engaged in the learning (and, sometimes, evaluation) process, in contrast to traditional approaches of students' passive presence while instructors deliver content.

With the current trend of increasing use of online learning tools likely to continue, our approach, computer quiz games (CQGs), is one potential pathway toward increasing the use of both modern computing and interactive engagement learning methods in science education. One critical issue in promoting learning is the activation of students' self-regulating systems that aid in the development of motivation,[24,25] thus affecting academic achievement by influencing behaviors such as attendance, participation, question asking, advice seeking, studying, and participation in study groups.[25,26]

GAME ASPECTS AND ROLE OF QUIZ GAMES IN COURSE DELIVERY AND SYLLABUS

Classroom-based games are considered effective educational tools.[27,28] Game quizzes can increase flexibility in the classroom, permit group or independent work, and introduce collaboration and competition. Numerous applications of game principles to enhance learning have been reported.[29−34] Some recent developments include Jeopardy-type games,[16,35] "Go Chemistry" and card games,[30] exercise games,[36] and the game-based review module.[31]

The CQGs are weakly incentivized[37,38,39] as follows. The introductory general chemistry for engineering majors (GCEM) course grade comprises contributions from the laboratory (25%), midsemester exams (20%), traditional quizzes (25%), and final exams (30%). The overall grade

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from traditional quizzes could be improved through CQGs by performing better than ~67% of the class on quiz games, with a maximum possible improvement of 2.5 points toward 100 points for the course grade (equivalent to 2.5% of the course grade).

CHEMISTRY LEARNING IN AN ESL ENVIRONMENT

Basic language proficiency plays an important role in course delivery and learning in science,[40−42] as poor language proficiency increases the chance of conceptual misunderstanding.[41] Despite nearly all university instruction in English, difficulties in English proficiency are considered to be a very common issue for college education in the UAE and MENA (Middle East and North Africa).[43] This is affected in unpredictable ways by a large international multigenerational migrant population, which creates an increasingly heterogeneous population in secondary and university education that does not map onto other well-studied populations (e.g., USA, Europe, Australia, or Asian Far East). The educational environment in the UAE differs from that encountered by ESL students studying in English-speaking countries in that education may be the only context in which English is the predominant day-to-day language. The population of students majoring in engineering disciplines at Khalifa University is unique in several ways: >98% are ESL speakers and are of diverse socio-economic backgrounds and students are either UAE nationals (~85%) or come from a diverse group of predominantly MENA-region expatriates (~15%). Within the overall set of ESL issues encountered elsewhere, reading comprehension is the skill lagging most. Simultaneously, there exist substantial gaps in several areas of elementary mathematics. These skill deficits hamper learning from both the students' and instructors' perspectives, which motivates the development of teaching and learning strategies that enhance or augment language skills alongside chemistry.[41]

RESEARCH QUESTIONS

The following research questions are explored in this report:

1. What is the relationship among ESL performance, learning gains, and chemistry course performance?
2. Does the implementation of CQGs improve learning gains compared with two control groups: students with paper-based quizzes and students who have neither CQGs nor paper quizzes?
3. Does the implementation of CQGs affect students' attitudes toward and motivation for learning chemistry?

METHODOLOGY

Students registered in the GCEM course in the fall 2014 (Sem I) and spring 2015 (Sem II) semesters were randomly assigned to groups X (answering questions via CQGs) and Y (answering questions from the same question set on paper) of approximately equal population size. Student-specific weekly performance was anonymized. Both CQGs and paper quizzes (PQs) were administered simultaneously in class for ~10 min per week for 10 weeks during a 15-week semester. Group Z comprised students registered in the same course in fall 2015 (Sem III), for whom neither CQGs nor PQs were administered. At the beginning of each semester, all groups were addressed with a demographic survey and a chemistry achievement pretest in the form of the Freshman Engineering Chemistry Aptitude Test[44] (FECAT, see Supporting Information). We also used math entrance exam (taken by all students before enrollment) data. At the end of each semester, all groups took the FECAT again and an attitude survey.

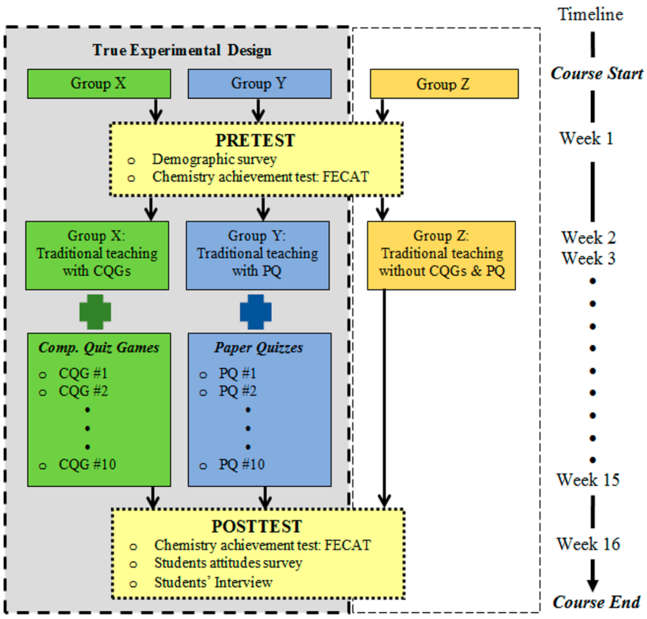

Figure 1. Experimental design for game-based learning in the first-year chemistry course.

In addition, selected students representing all of the demographic categories and performance levels were interviewed after the end of the semester. In addition to our own motivation to use control groups, a need for varied control groups is felt in some previous studies.[45−47]

Chemistry Quiz Game (CQG)

Upon starting the CQG, the student is presented with a dialogue frame and asked to confirm his or her identity (for record keeping), after which the game rules are displayed. The student starts the quiz by clicking the button labeled "*Start when ready*!" on the frame displaying the rules. The student sees a matrix of nine questions. Simultaneously, a countdown timer begins and is displayed in a frame titled "*Referee*" alongside the updated score. Each element in the matrix is a clickable button, allowing students to select a question.

Each button deactivates after one click to prevent the same question from being selected twice. Clicking a question button prompts the opening of a question frame, which is organized as follows: at the top is the question, containing text and/or graphics; underneath are four possible answers (also text and/or graphics-based), each of which is a clickable button. In the current implementation, there is only one correct answer.

Answers are randomly organized in the frame on each run to avoid bias or recognizable patterns and to reduce the likelihood of cheating in the classroom environment. At the bottom of the question frame are three additional buttons, "*hint*", "*pass*", and "*help*". "*Hint*" provides a clue, "*pass*" leaves the question without incurring a point penalty, and "*help*" removes two wrong answers. Clicking the "*help*" or "*hint*" buttons incurs a point penalty, as specified in the rules. If the correct answer is selected, points are added to the total score. If the "*pass*" button or a wrong answer is clicked, then the correct answer is displayed before the quiz continues. The game ends when either the timer reaches zero or the student has

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J. Chem. Educ. XXXX, XXX, XXX−XXX

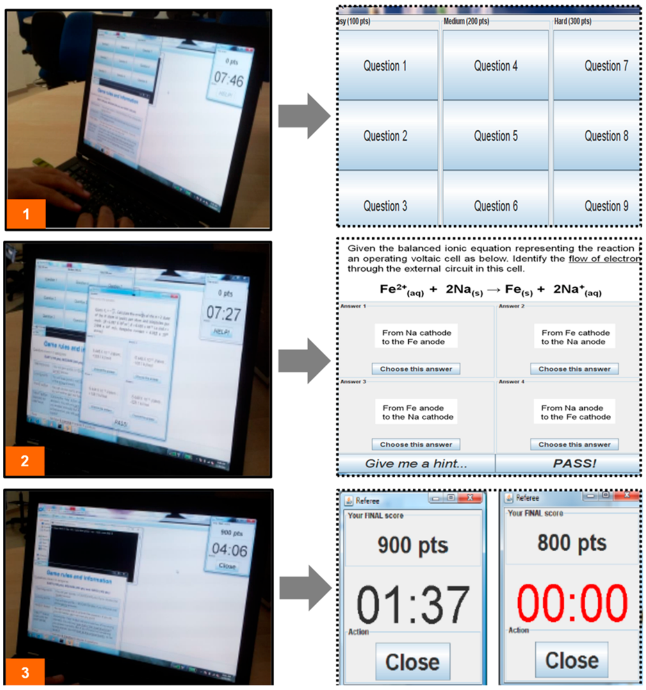

Figure 2. Details of the implementation on students' laptops. Images on the left show the snapshots in time of students' progression through the phases of the game. Images on the right are a more detailed look. Labels "1", "2", and "3" indicate various aspects of the user interface, with details shown on the right.

attempted to answer the maximum allowed number of questions (currently five of nine). At this point, all interactive features are disabled, the final score is computed and displayed, and the result is written into a file (linked to the student's username). The Supporting Information contain a modified online version of two such quiz games.

Within standard game classifications,[37,38] our CQGs are quantitative games; the score is prominently displayed and responds to student entries throughout the game.

They are also finite games (a limit of five choices out of nine possible questions). Also, winning is the goal; students learn the anonymized top-class score and the distribution of scores between finishing one game and playing the next. One difference from traditional computer games is that students in this study could not choose when to play the game. Future faculty users could allow students to play at individually chosen times and to choose whether to strictly follow the syllabus. The students are free to define their own strategy of which "easy", "medium", and "hard" questions to answer. The CQGs are 10 min long or less for two reasons: (a) to minimize disruption of the traditional classroom and (b) to allow variation of instructional activities on a 10−12 min time scale, as recommended elsewhere.[33,34,34]

Freshman Engineering Chemistry Aptitude Test (FECAT)

The FECAT has been developed in parallel with the CQG, primarily as a tool to measure learning gain via post-test vs pretest assessment. The test follows a typical US-style first-year engineering majors chemistry syllabus, similar to the corresponding KU course (KU has had ABET accreditation since AY 2014/15). There is no overlap among the FECAT, CQG questions, and course assessment instruments. FECAT could also be used (a) as an independent course assessment instrument, (b) to assess student readiness to take a freshman engineering chemistry course, and (c) to help instructors tailor lectures if used as a diagnostic test in the first week. The test contains 36 multiple-choice questions (see Supporting Information), the content and wording of which are based on Bloom's taxonomy.[48] Questions are classified into five categories: (1) basic properties of matter and fundamental laws of nature, (2) chemical properties of elements and compounds, (3) chemical reactions, (4) heat and other energy concepts in chemistry, and (5) atomic structure and chemical bonds. A thorough analysis of the FECAT performance, including an analysis of individual categories, is provided in a separate report.[49] For the student population participating in this study, FECAT has a typical Cronbach α coefficient of between 0.72 and 0.81, depending on the semester, indicating that reliability is good.[50,51] We expect that further applications and some improvements of the test will lead both coefficients to increase toward more desirable values of 0.85 and 0.9, respectively, which would make the reliability "very good" or "excellent". Normality tests for each question showed that the skewness and kurtosis of 30 questions are within the recommended range, given $\alpha = 0.01$, so the critical z value is ± 2.58.[52] Questions 7, 15, 21, 23, 26, and 30 do not satisfy these criteria but are close. Within the five categories, each category had only one question not satisfying the above criteria. The values of Hake's gain and other results in this report have included these questions since their impact on the increase or decrease of the gain is much smaller than the uncertainty. Table 1 shows the steps undertaken to make FECAT a validated instrument.[53]

Students' Attitudes Survey

The attitudes survey is based on selected sets of questions about "enjoyment of chemistry lessons", adapted from the Test of Science-Related Attitudes questionnaire (TOSRA) by Fraser,[54] and "motivation" questions, based on the Science Motivation Questionnaire (SMQ) by Glynn and Koballa[54] and Kebritchi, Hirumi, and Bai.[45] A five-point Likert-type scale with *Strongly Agree* (SA), *Agree* (A), *Not Sure* (N), *Disagree* (D), and *Strongly Disagree* (SD) was used as the response format of the survey.

Interview Protocol

Interviews were conducted after the end of the semester. Interviewees (n = 29) were selected from a range of backgrounds (i.e., gender, nationality, and course performance). Interviews were composed of two parts: questions answered on a Likert scale and open-ended questions with follow-up. Interviews were recorded, transcribed, viewed, and checked with interviewees for clarification.

■ RESULTS AND DISCUSSION

Demographics

Demographic details, including the number of students per semester and per group, gender, and nationality, are shown in Table 2. Note that groups X (CQG) and Y (PQ) were initially equal in size, but incomplete data sets for some students were removed from the analysis (e.g., if a student completed less than 7 of the 10 CQGs or PQs or was absent for the post-test and/or attitude survey). Due to a lack of available information before the study began regarding English literacy and math skills, students were randomized to groups X and Y based on the IELTS pretest, resulting in an uneven distribution of student abilities across these three categories. See Table 1 for the additional information eventually gathered. Variations in

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J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 1. Summary of the FEACT Validation Steps

Validation Aspect	Elaboration
Test content—what does an instrument measure	Steps that the content is appropriate: (a) IRB review has not flagged any of the questions or the instrument design and length; (b) four instructors who were not the members of the research team but who taught the course in the relevant period all reviewed and approved the instrument.
Phased introduction	After developing the initial version of the instrument: (a) Phase 1—tested 4 faculty members and 8 2nd- and 3rd-year students who had already passed GenCHEM course; (b) their feedback led to minor modifications, which fed into the version that was filed for IRB; (c) pilot version was then reviewed by nonparticipating chemistry faculty (see previous item), (d) data collected with the version presented in the Supporting Information.
Internal structure of the instrument	Each of the five question categories has multiple questions dedicated to it, and at no point in the implementation of FECAT did we identify a significant deviation in the rate of correct answers (e.g., a factor of 50% more correct answers for one of the questions in the category than for any other in the same category)
Response process	We have chosen multiple choice as a response mode and odd number (5) options for each question. For each question, there is only one correct answer; one answer acts as a "strong distractor", and one or two more act as "plausible guesses". At least one, sometimes two, choices are, for most students, reasonably clearly wrong options (depending on students' precollege background).
Relationship to other variables	Among external metrics are (a) English language proficiency IELTS scores (total, reading) and (b) Gen CHEM final exam scores. Hake gain measured with this instrument against these independent variables shows a good correlation.
Consequences of testing	Identifiable demographics subgroups (gender, performance bins) have fairly small differences, indicating no significant bias is introduced by this instrument.
Dissemination	FECAT was shared with three institutions in the Middle East, one university in Europe, one university in Southeast Asia, and four universities in the US. We hope additional use will lead to more publications based on this instrument.
Literature validation	Initial results of this work (both on FECAT and one CQG) were presented at three conferences, one of which led to refereed proceedings.

Table 2. Number of Students per Semester, per Group, Gender, and Nationality[a]

Semester	Semester I		Semester II		Semester III (Group Z) neither CQG nor PQ	
Group X (CQGs)	male	12	male	36	male	43
	female	22	female	27	female	51
	UAE national	25	UAE national	58	UAE national	83
	foreign	9	foreign	5	foreign	11
Group X →	IELTS=5.61±0.53		IELTS=5.47±0.69		Group Z IELTS = 5.56 ±-0.55	
Entry scores	Math = 55 ± 22		Math = 54 ± 22		**entry scores** → Math = 52 ± 23	
Group Y (PQs)	male	10	male	37		
	female	26	female	21		
	UAE national	24	UAE national	51		
	foreign	12	foreign	7		
Group Y →	IELTS=5.78±0.50		IELTS=5.62±0.58			
Entry scores	Math = 55 ± 19		Math = 58 ± 17			

[a]Three consecutive Sem(esters) (group X = CQG − computer quiz game; group Y = PQ − paper quiz; group Z = neither); maximum IELTS score = 9.0, IELTS = The International English Language Testing System; maximum math score = 100.

the male−female ratio between individual semesters were beyond the experimenters' control.

Hake's Gain on FECAT

All three groups (X, Y, and Z) showed learning gains in the FECAT post-test vs pretest methodology, as shown in Figure 3. In Sem I, the Hake gain for group X (with CQGs) was slightly larger compared to group Y (with PQs), whereas groups X and Y both had similar positive Hake gains in Sem II. Although the differences were small, it must be noted that as a result of imperfect randomization, students in group Y had higher overall GPA, math skills, and IELTS scores (English skills) compared with students in group X. In comparison,

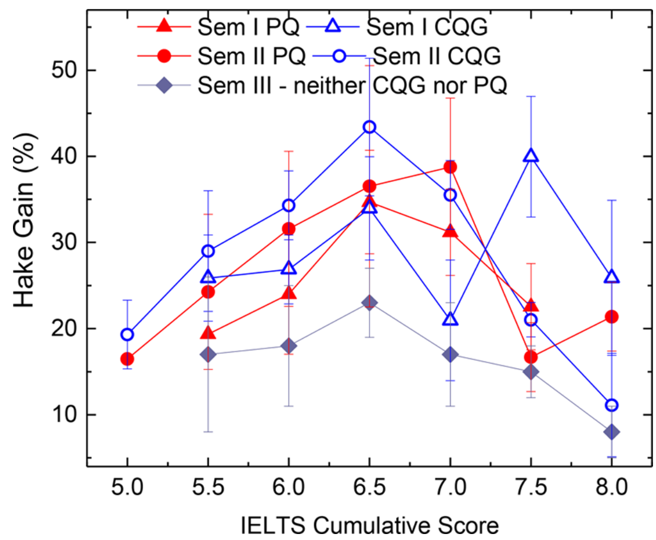

Figure 3. Hake gain vs the cumulative IELTS scores in three semesters for X (CQG − computer quiz games), Y (paper quizzes), and Z (neither CQG nor PQ) groups. Care is needed in interpretation due to relatively small group sizes.

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J. Chem. Educ. XXXX, XXX, XXX−XXX

group Z, from Sem III (with neither CQGs nor PQs) showed a lower Hake gain compared with groups X and Y, while having nearly identical math and IELTS scores and overall GPA. Next, we discuss the FECAT Hake gain as a function of two independent variables: cumulative IELTS (comprising contributions from reading, writing, listening, and speaking) and final exam scores. There is an increase in the gain as the cumulative IELTS score increases to the IELTS value of 6.5. This is understandable in that a higher IELTS score is frequently (but not always and not very highly) correlated with increased performance and GPA.[55,56] Also, students with IELTS = 7.0 and higher often had such high pretest scores that they were unable to have a significant Hake gain.

The results in Figures 3 and 4 also show that both CQGs and PQs could be effective tools in boosting student performance, especially for the IELTS bands, where a majority of students fit (IELTS 5.5−7.5). The change in the final exam score shows a more steadily rising function of the IELTS score, as one would expect for the assessment that students were actively preparing for through biweekly and midterm assessments throughout the semester (unlike FECAT). We make the following observations:

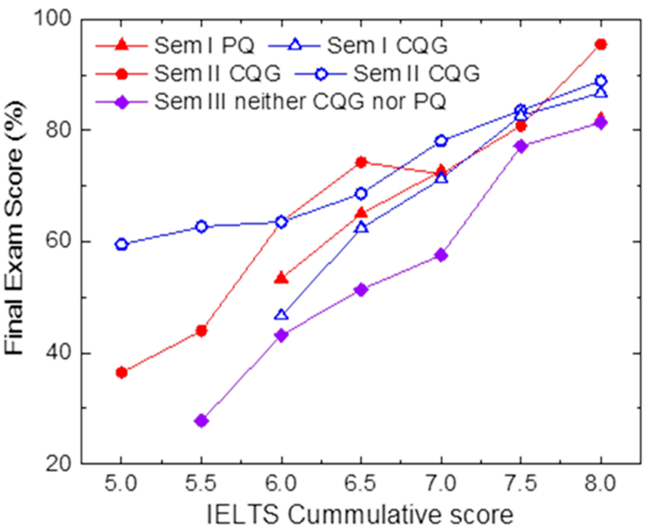

Figure 4. Comparison of final exam scores across IELTS values in this study. (CQG − computer quiz games), Y (paper quizzes), and Z (neither CQG nor PQ) groups. Care is needed in interpretation due to relatively small group sizes.

Group Z students, who did not use either CQG or PQ at any point in the semester, show lower Hake gains, demonstrating that the activity itself (whether it is CQG or PQ) helps students achieve higher gain regardless of the type of activity.

The relatively small difference in Hake gain for individual IELTS performance levels, between CQG (group X) and PQ (group Y), is ascribed to at least two factors: (a) the presence of nearly identical motivating factors and (b) accidental, hard to control, skills imbalance in the makeup of X and Y groups, in favor of the Y group.

Another method of comparing students' progress is to examine how many students increase (move up) in their performance percentile group over the course of the semester. Figure 5 displays such data for the second semester of the study (similar data exist for the first semester). The shift of the number of students from a performance average in lower to higher percentiles is visible in both panels with some quantitative differences between CQG and PQ student groups. Within each activity, CQG and PQ, we see the shift of mean value toward a higher percentile, specifically from 43rd to 64th and from 40th to 58th, respectively. It is worth pointing out that there are at least five different curricula (US, UK, Canadian, IB, and local state schools) currently implemented in UAE high schools; thus, the context for the FECAT design and future use is not just as a research instrument but also as a freshmen college readiness assessment instrument.

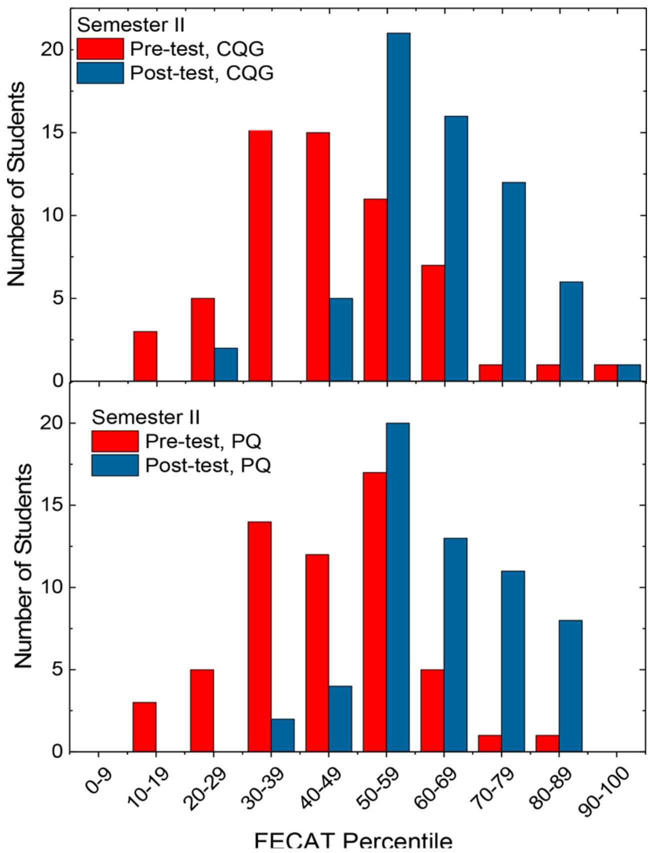

Figure 5. Comparison between pretest and posttest; the number of students as a function of the performance percentile on the FECAT. CQG − computer quiz game and PQ − paper quiz.

Students' Attitudes Survey

Responses for one of the motivation questions/statements, "*I find learning chemistry interesting*", are summarized in Figure 6 (by group and semester). We selected this particular question because its distribution of responses is very similar to the distributions of responses for the two enjoyment questions, namely, "*Chemistry lessons are fun*", and "*I enjoy the activities we do in chemistry class*". Data for some other questions are available in the Supporting Information. Most students agreed or strongly agreed with this statement in both CQG-run semesters.

These data are very encouraging regarding the relatively positive effect of the CQGs on student motivation and enjoyment.

Analysis of Interviews

Finally, we will complete the triangulation of data collection (FECAT results, attitude surveys, and interviews) with a discussion of the students' interviews. The questions and statements asked are listed below.

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J. Chem. Educ. XXXX, XXX, XXX−XXX

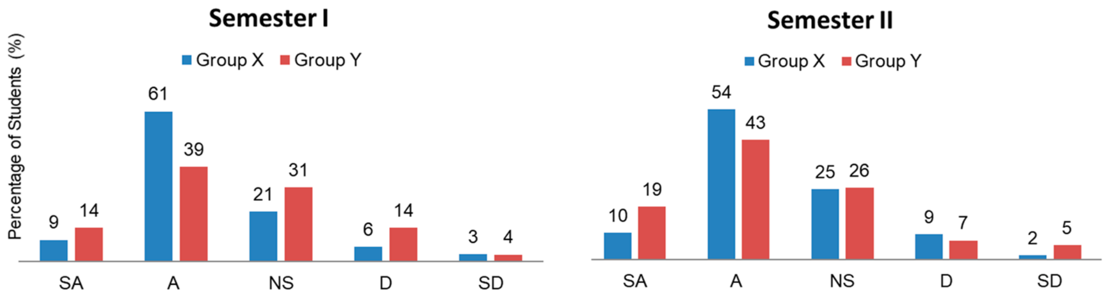

Figure 6. Comparing students' response to "*I find chemistry interesting*" for (a) semester I and (b) semester II, ND computer quiz games (CQG − group X) and paper quizzes (PQ − group Y). (SA) − strongly agree...(DS) − strongly disagree.

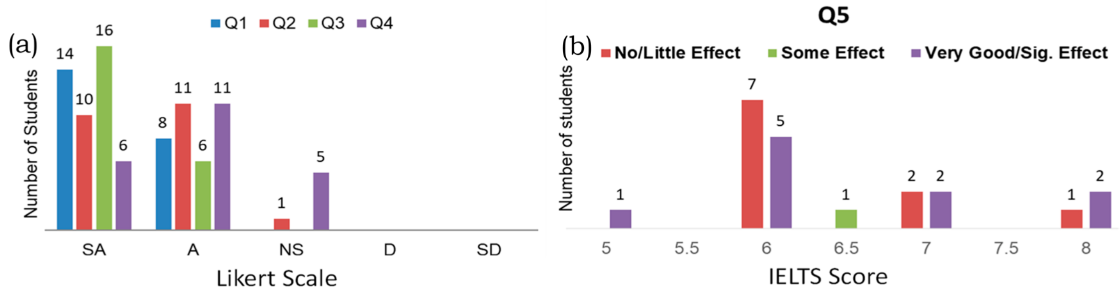

Figure 7. (a) Refers to interview questions 1 through 4. (b) Refers to interview question 5.

1. I enjoyed chemistry lectures more if they had CQGs.
2. I think that playing CQGs helped me in learning some new chemistry concepts.
3. I think that playing CQGs increased my motivation to learn chemistry.
4. I think that playing CQGs increased my interest in learning chemistry.
5. How did your level of English skills affect your desire to play CQGs?

For interview question 1 (Figure 7a), all interviewees report either "A" or "SA" for the statement that playing CQGs increased their enjoyment. Similarly, in interview question 2 (also Figure 7a), students report that their grasp of concepts in chemistry was helped by the CQGs. We wish to note here, however, that it is hard for students to objectively distinguish between the increase in conceptual knowledge due to the regular traditional coursework and the increase due to CQGs.

Moving to interview questions 3 and 4, a majority of students (∼73%) report that they feel strongly motivated to study chemistry because of, at least in part, CQGs. Answers to the fourth question indicate that while no students reported decreases in interest to study chemistry due to the CQGs, fewer students reported strong positive effects compared with the motivation.

In a pair of interview questions where students need to rely on their self-reported skills, students with lower English skills (typically below or at cumulative IELTS score of 6.0) agree that their desire (interest) to look forward to playing the CQGs was in part driven by the lower English skills. Figure 7(b) indicates that slightly over 50% of students agree or strongly agree that their lower level of English led to their desire to play CQGs as a compensatory learning mechanism. This last finding points toward the anticipated channel of introducing computer games into the learning process in ESL science classrooms and in many countries of the Global South, where a portion of higher education teaching and learning processes is conducted in English.

SIGNIFICANCE AND CONTRIBUTION TO THE PRACTICE OF CHEMISTRY EDUCATION

To the best of our knowledge, this is the first multisemester, two different control groups study on the effectiveness of CQGs in an ESL environment for engineering majors, possibly overall and particularly in the MENA context. The study has several specific contributions, which may be considered independently or as mutually supportive of each other. Among these contributions are 10 CQGs, tailored to the US-style freshmen engineering chemistry curriculum and the FECAT assessment instrument. The FECAT and a pair of modified CQGs are available in the Supporting Information.

While more work remains to be done on the gaming aspects of CQGs (modification of the current quiz games for the multiplayer option, enabling online access), the combination of computer- and game-based learning as an interactive engagement supplement to traditional teaching in chemistry is clearly worth pursuing. An additional claim to significance stems from the geographical and cultural context; successfully introducing an ESL MENA audience to game-based learning provides some of the strongest evidence yet of the method's widespread applicability. Our results provide a source of information regarding issues in contemporary science education and may help academic and government education authorities gain insight into quality improvement.

This study contributes to developing a more adequate research-based explanation of the effectiveness of game-based learning, particularly in the chemistry education context but also in a wider variety of disciplines, and opens space for both instructors and students to augment traditional teaching and learning.

The "part-time" (a fraction of one class time) interactive engagement method in this report provides an alternative route to improving pedagogical practices in science, while positive

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J. Chem. Educ. XXXX, XXX, XXX−XXX

results of this research could encourage instructors to incorporate games into their classrooms as a viable alternative or to supplement existing teaching methods. Even if the role of CQGs proves to be limited, their use may aid in tracking student learning and help instructors offer individualized advice. The systematic weekly implementation of CQGs enhances student performance in a GCEM course, despite the otherwise traditional administration and time-limited game playing (~5% of the weekly class time).

LIMITATIONS AND FUTURE PERSPECTIVES

Based on commonalities in issues facing students at various universities in the broader Arabian/Persian Gulf region, a parallel study at several universities would offer additional insights by increasing the study population size and offering the potential for new quantifiable observations. While desirable, this is remarkably difficult to administer under local higher education regulations. A longer period of exposure to the CQG activity (more than 10 min per week) could have provided more insights into various facets of the effectiveness of the CQGs.

The CQGs presented here are single-player games. We intend to implement multiplayer versions with options including collaborative games and online multiplayer games. As stated above, this project is motivated by the continuous need to improve and develop learning and testing tools for use in all learning environments and in support of engagement. There are several common issues across different ESL environments,[40−43,56] and further implementation may help address some of the ESL issues.

We see a potential for blending computer game-based learning (CGBL) in general, and CQGs in particular, with other RBIS[57] (research-based instructional strategies) such as just-in-time teaching (JiTT), concept tests, and collaborative and cooperative learning (e.g., peer instruction and think−pair−share). For example, CQGs could be used as a working tool in collaborative learning or as an initial discussion point in the studio method. We see this work as related to a number of recent papers, such as web-based competitive quiz games,[58] gamification of introductory organic coursework,[59] and offering learning alternatives in socially deprived situations.[60] We are examining an option of CQGs that we developed being implemented in the Kahoot web platform[61,62] for accessibility and broader use. Among goals achievable with CQGs are (a) fostering prolonged motivation[63] and (b) engagement.[64]

CONCLUSIONS

The answers to our research questions are as follows:

(1) For the large fraction of the study population, learning gain increased as a function of the IELTS score. Considering that this IELTS score range covers a broad range of TOEFL values (60−101), it is understandable that the dependence of the Hake gain on IELTS is not smooth. For a small subset of the population above IELTS = 7.0, the pretest scores are high enough that large gains are not likely.

(2) CQGs and PQs both helped improve students' learning gains compared with students who had neither activity (semester III, fall '15). There is an indication of a statistically significant difference between chemistry achievement for students in group X (with CQGs) and group Y (with PQ) only for subsets of the overall population (either in separate semesters or for one gender). There is an indication of a statistically significant difference between group X (CQG) and group Z (without CQG or PQ). The four stages of the self-directed learning model (dependence, interest, involvement, and self-direction) proposed by Grow[65] might explain how students were motivated and transformed from low to high self-directed learning.

(3) There is an increase in positive attitudes among the CQG group compared with the PQ group. Interview data also indicated that students playing CQGs had positive attitudes toward and motivation and interest to learn chemistry. This is supported by discussions in the literature,[66−68] which highlight that the greatest educational benefit of computer-assisted instruction could be increased student motivation and improved attitudes, together with[69] where it was reported that games can be used to increase both intrinsic motivation and cognitive growth.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.3c00479.

FECAT test (PDF)
Instructions on playing the quiz game (PDF)
Two of 10 computer quiz games (other games available upon request) (ZIP)
Additional data (PDF)
Interview protocol (PDF)
Attitude questionnaire (PDF)

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J. Chem. Educ. XXXX, XXX, XXX−XXX