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Effectiveness of Formative Assessment As Learning Tool in Quantitative Analytical Chemistry Remote Learning

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ABSTRACT

The effectiveness of learning tools in remote learning mode during the COVID-19 pandemic was investigated in The *Quantitative Analytical Chemistry Course* in University of the Philippines-Diliman. The effectiveness of formative assessments with feedback was determined by comparing students' performance in the pretest and posttest assessments. Dependent sample t-test analysis of over-all performance of student showed that as a cohort, there was a statistically significant improvement in the posttest (M = 8.44, SD = 1.63) performance compared to pretest (M = 5.46, SD = 2.19), $t(49) = 9.926$, $p < 0.001$). The dependent t-test analysis indicate that there was a statistically significant improvement in nine topics while there was no statistically significant improvement in two topics. Results of the study indicate that in three of the topics with *Problem Solving/Analyze/Evaluate* type of questions, less than 55% of the students were able to fully answer the problem in the posttest. The findings indicate that for multistep *problem solving and evaluate* type of questions, additional learning strategies are needed for majority of students to be fully competent on the topics. This study also aimed to assess effectiveness of commercially available online learning platforms as learning tool. The data indicate that only 50% (28 out of 54 students) of the students accessed at least once the online learning platform during the duration of the course.

Keywords: *Formative Assessment; Online Learning Tool; Remote Learning*

INTRODUCTION

To prepare students in the 4th Industrial Revolution, higher education students should be able to acquire skills to thrive in an environment that is highly dynamic and where there is fast emergence of new technologies. One such skill is the ability to do self-directed learning (Reaves, 2019), which entails not only the understanding of new trends but also getting deep insights in order to apply and innovate the new technologies. The COVID-19 pandemic has provided opportunity to investigate learning strategies for self-directed learning for a broader population set of students. As universities are compelled to do remote learning using online platforms for all students regardless of connectivity, it is imperative to understand how effective different learning tools are.

Two asynchronous learning tools were specifically investigated in this study. One is commercially available video materials used to introduce the concepts to the students. For this strategy, we aim not only to assess content effectiveness of the video, but also to check the ability and preference of students to access the videos. Study.com was chosen because the teacher can track usage of specific lesson by each student. Students have the flexibility to access the lesson by watching videos or reading text with visuals. The first author bought a Study.com subscription as "teacher" from March 2021-January 2022. Up to 1,000 students can be signed up for free in classes created by the teacher.

The other learning tool investigated herein is the formative assessments with feedback. There are literatures that indicate that formative assessments can be used to enhance the learning of students (Black, 2003; Voinea, 2018). In this study, the formative assessments to be used are the combination of multiple-choice questions and problem-solving type of questions where students show their calculations and rationale for their solutions and answers. By requiring students to explain their solution, they demonstrated that they could articulate in writing how they were applying the concepts. Customized feedback were given in the formative problem-solving questions. The multiple-choice questions were at the analyze and evaluate cognitive levels (Krathwohl, 2010) that assessed critical thinking of students. For quantitative analysis, the formative assessment was used to collect pretest data. Same questions were given to students as part of summative assessment and were used as posttest data.

METHODS

Learning Materials and Tools. *University Virtual Learning Environment (UVLê).* In 2000, UVLê, a learning management system, was developed by three students of the University of the Philippines (UP)-Diliman with the guidance of then Director Roel Ocampo of the UP Computer Center. UVLê 1.0 was released in 2008 using the Moodle platform, which had a new user interface. Currently, the UVLê 2.0 is being used as the UP Diliman online learning platform (Interactive Learning Center Diliman, 2023). An UVLê classroom was created for the course. Two classes (27 students for each class) of Chem 26 (Quantitative Analytical Chemistry) during the First Semester Academic Year 2021-2022 (September 2021-January 2022) participated in the study. The UVLê classroom contained annotated lecture materials in PDF form, formative and summative assessments, and open forums. The timed assessments were created using the "Quiz" function.

Study.com Learning Platform. This is a commercially available learning platform. Specifically, "Learn Faster. Stay Motivated. Study Smarter" of Study.com was accessed on September 2, 2022. A classroom with curated videos for relevant topics in Quantitative Analytical Chemistry was created. Specific lessons relevant to the course's Learning Objective were selected from the Study.com library. Each topic contained both a video (approximately 5-10 minutes long) and written text with visuals. At the end of each lesson, the student had an option to take a multiple-choice quiz that was automatically graded. Usage of the site was not required. However, deadlines were given for each topic. Students were notified by Study.com if deadline for a certain topic was approaching. Moreover, answering of the multiple-choice quiz and access to study.com are optional, and hence not included in the calculation of the final grade of students.

Excel Spread Sheet. This spreadsheet was used to tabulate the data extracted from UVLê and to perform *t*-test analysis by creating a macro. An Excel *macro* is a set of instructions that Microsoft Excel executes to perform calculation of *t*-value as described in *T*-test analysis section.

Methods. *Pretest and Posttest Questions Selection.* Eleven formative assessment questions from five modules (Dynamic Equilibria, Acid-Base Equilibria, Solubility Equilibria, Coordination Chemistry, & Electrochemistry) of Part 1 of the Quantitative Analytical Chemistry Course were chosen to be tested in the study. Four multiple choice questions (MCQ) and three problem solving questions (PSQ) where students show and explain their step by step solution were used for both pretest and posttest data. Four PSQ questions in formative assessment (pretest) were converted to MCQ in summative assessment (posttest). Distractor-items used in the posttest were the common incorrect answers from the pretest. The questions used were categorized based on Bloom's Taxonomy cognitive levels as *apply*, *analyze*, and *evaluate*. All questions were derived from the Quantitative Analytical Chemistry Course Syllabus Learning Objectives.

Furthermore, the questions included were used in previous semesters either in formative or in summative assessment. These were questions where less than 70% of students did not get the answers correctly. The topics covering these questions are foundational competencies needed for Part 2 of the course. Formative assessments are timed quizzes within a module, where students can have more than one attempt. Attempts have to be done within a specified timeline. Summative assessment is the Cumulative Long Examination covering modules of Part 1 of the Quantitative Analytical Chemistry Course. The summative test is a timed Long Examination and can only be taken once.

Data Set Selection. Students who took both the formative and summative tests were included in the study. Students who only took the formative test in specific module/s but not the summative test, and vice versa, were excluded from the study. A *t*-test analysis per question was done. However, sample size vary per question as formative assessments are taken at different times.

For the over-all performance comparison, only students who took all formative assessments before summative assessments were included. The total number of students is 49 as five students missed one formative assessment.

Study.com Usage Data Extraction. Study.com learning platform dashboard for "Teachers" indicates: a) the students enrolled in the class; b) the students who accessed the assigned topics either by watching the videos or viewing the written texts; and c) the students who took the quiz, and d) the student's quiz score. The usage per student was tabulated in Excel sheet and summarized to determine the usage of the site.

Data Extraction of Pretest and Posttest Results. For each selected question in the study, the results of assessment per student were manually extracted and tabulated in Excel sheet. For MCQ, 0 (zero) was assigned for incorrect answer and 1 (one) was assigned for correct answer. For PSQ, 0 (zero) was assigned for partial and no points and 1 (one) was assigned for full points.

For the pretest, only first attempts were used for the pretest data set. For formative assessments, to maximize learning, students were allowed a second attempt after getting the feedback.

t-test Analysis. To determine whether there was improvement in over-all performance per student between the pretest and posttest, a dependent samples *t*-test was performed. The pretest and posttest scores were used to calculate the *t*-value using the equation below:

$$t = \frac{\Sigma D/N}{\sqrt{\frac{\Sigma D^2 - \left(\frac{(\Sigma D)^2}{N}\right)}{(N-1)\,(N)}}}$$

Where ***ΣD*** is the sum of the difference in the pre- and posttest scores, *N* is the sample size (number of students) and ***ΣD²*** is the squared sum of the difference between the pre- and posttest scores.

The parameters needed are as follows:

1. Confidence level (0.05 or 95%)
2. *T*-value from *t*-tables (2.0106)
3. Degrees of freedom (for *N* = 49 students, degrees of freedom = 48)
4. Calculated and absolute *t*-values

Through this method, the null and alternative hypotheses were formulated. The null hypothesis (H_o) was "There is no significant improvement in the performance between the pretest and posttest scores per question." On the other hand, the alternative hypothesis (H_a) was "There is a significant improvement in the performance between the pretest and posttest scores per question."

The Excel *t*-test function was used to confirm the results of the macro created.

A dependent samples *t*-test was also conducted to determine if there was a statistically significant improvement for each student per question. Formula and method were derived from the one samples t-test. The *t*-test was conducted using the following equation:

$$t = \frac{\bar{x} - \mu}{s/\sqrt{n}}$$

where $\bar{x}$ is the mean of the difference between the pretest and posttest of each student, μ is the mean of the null hypothesis, *s* is the standard deviation, and *n* is the sample number of students.

The parameters needed for this *t*-test include:

1. Confidence level (0.05 or 95%)
2. *T*-value from *t*-tables (2.0066) (2.0096) (2.0057)
3. Degrees of freedom (for *N* = 53 students, degrees of freedom = 52; for *N* = 50 students, degrees of freedom = 49; for *N* = 54, degrees of freedom = 53)
4. Calculated and absolute *t*-values

Through this method, the null and alternative hypotheses were formulated. The null hypothesis (H_o) was "There is no significant improvement in the performance between the pretest and posttest scores per question." The alternative hypothesis (H_a) was "There is a significant improvement in the performance between the pretest and posttest scores per question."

RESULTS AND DISCUSSION

Quantitative Analytical Chemistry (Chem 26) course is a service course offered by the Institute of Chemistry of the University at the Philippines-Diliman to non-Chemistry majors. The course is divided into two parts: Part 1 covers Introduction to Chemical Kinetics and Chemical Equilibria, while Part 2 covers Quantitative Analytical Techniques.

This study covers only Part 1 Chemical Equilibria modules (Dynamic Equilibria, Acid-Base Equilibria, Solubility Equilibria, Coordination Chemistry, and Electrochemistry). The study was done during the First Semester of Academic Year 2021-2022, where classes were done online synchronously and asynchronously. Two sections composed of students of different majors participated in the study. UVLê, a UP Diliman Moodle-based LMS was used to provide learning materials (annotated lecture in pdf) and assessments.

Table 1 shows the distribution of the 54 students from the two sections. Ages of the student-participants were not obtained. Based on class information, students were freshmen to junior undergraduate students. This information is not collected in UVLê; hence, not included in the study. The students were informed that their section is part of the Academic Program Improvement Grant that aims to study diagnostic and formative tools. When students sign up for UVLê, they consent that their data may be used. For the Study.com part, student had to sign up on their own to be part of the cohort.

Table 1. Composition of Student Cohort.

Major	**Number of Students**
BS Materials Engineering	32
BS Geology	1
B Secondary Education	14
BS Community Nutrition	1
BS Biology	3
BA European Language	1
BS Molecular Biology and Biotechnology	1
BA Communication Research	1
Total	54

The effectiveness of formative assessment was determined by comparing the students' performance in specific questions from the formative assessment (designated as pretest) with student performance in summative assessment (designated as posttest) for Part 1 of the course. The dependent sample *t*-test analysis of over-all performance of student (n = 49, 95% confidence) showed that as a cohort, there is a statistically significant improvement ($t(49) = 9.9984$, $p < 0.001$) in posttest compared to pretest (Table 2). However, out of 49 students, six students obtained a lower score in posttest as compared to their pretest, and four students retained their score. This means that the online formative assessment with feedback is effective as a learning tool for 80% (39/49) of the cohort.

Table 2. Over-all Performance of Cohort.

	Pretest[1] (n = 49)	**Posttest[2] (n = 49)**
M	5.46	8.44
SD	2.19	1.63
$t(49)$	9.9296	
p	< 0.05	

[1, 2]Total possible scores range from 0 to 11.

The results are similar to those obtained by Cohen and Sasson (2016) when they investigated, among others, the impact of online formative test with multiple attempts in undergraduate physics course of Life Science students. In their study, students had five attempts to do the physics problem solving question. Their study found that there is statistically significant difference in the mean of first attempt and mean of last attempt. The percentage of students with higher grade in the last attempt, however, was not reported.

Table 3 shows the results of the dependent-samples *t*-test analysis for seven questions that were exactly the same for pretest and posttest. The results indicate that in six out of the seven questions in the test, there is a statistically significant improvement in the students' performance. Moreover, Table 4 presents the percentage of student that answered each of the questions correctly. The data set used for calculation is the same as the data set used in Table 3. These results indicate that formative assessment is effective in improving students' performance in most of the topics. For the multiple-choice question (Table 4, Question 2) that did not show a statistically significant improvement, it can still be concluded that majority of the students have competence in this topic as 91% of the student already answered the question correctly in the pretest, while 96% answered the question correctly in the posttest. In contrast, for one of the problem solving type of questions, (Table 4, Question 7) although there was a statistically significant improvement, less than 50% of the students obtained full points in the posttest. Further checking of the scores and answers of the students in this question indicates that the students did not get full points because of deduction for incorrect number of significant figures in their final answer in the posttest. In the pretest, the same students obtained no or partial points as students were only able to solve part of the multistep problem. This means that students were able to learn how to solve the problem, but they did not learn how to get the correct number of significant figures.

Table 3. *T*-test Analysis of Exactly Same Question in Pretest and Posttest.

Topic	***M* of $^1(\chi-\mu)$**	***SD* of $^2(\chi-\mu)$**	***N***	***t* value**	***p* value**
K and Extent of Reaction	0.3962	0.5664	53	5.0708	$p < 0.05$
K_a and Strength	0.0566	0.3048	53	1.3519	$p > 0.05$
Chelate Effect	0.4340	0.5004	53	5.6206	$p < 0.05$
Reactivity Given E^o_{cell}	0.5200	0.5436	50	6.7640	$p < 0.05$
Buffer Component Calculation	0.1852	0.5852	54	2.3255	$p < 0.05$
Fractional Precipitation	0.1887	0.5210	53	2.6366	$p < 0.05$
Nernst Equation	0.2400	0.5692	50	2.9815	$p < 0.05$

$^{1,2}\mu = 0$ means no change between pretest and posttest; χ = difference between posttest and pretest; χ can be 0 (same score), -1 (posttest incorrect, pretest correct), +1 (pretest incorrect, posttest correct)

The results may also indicate that the customized feedback helped the students how to solve the problem. Since no feedback was given for significant figures for incorrect problem-solving strategy, the students were not able to know their misconception on determining the correct number of significant figures for problems with *log* and *antilog* operations. To ensure that the students also learn this concept, feedback should still be given to the students on the significant figures in their final answers in the formative assessment regardless if the solution, strategy, or numerical answer is correct.

For this type of course, it is important that students practice doing problem-solving work. Aside from the fact that problem solving is what chemists do regardless of the branch of chemistry, students who were successful in chemistry courses are those who already have or have developed good problem-solving skills (Bodner and Herron, 2002). In answering the questions, the student also had to explain their assumptions and formula they were using. As the assessments were remote and asynchronous, some students may have mindlessly copied solution from books and other learning materials. By requiring students to explain their solution, they needed to carefully analyze the problem and clearly explain their problem-solving strategy. Consequently, students' explanations reveal their misconceptions. For example, some students used the ICE method incorrectly in buffer component calculation, and a number of students used [X] value in solubility equilibria as the insoluble fraction. If no explanation was given, students did not get full points.

Table 4. Percentage of Students Answering Questions Correctly.

Module	Topic	Bloom's Cognitive Level Category	Question Type	*N*	Pretest Percent Correct (%)	Posttest Percent Correct (%)
Dynamic Equilibrium	K and Extent of Reaction	Analyze	MCQ[1]	54	45	85
Acid-Base Equilibrium	K_a and Strength	Analyze	MCQ	54	91	96
Coordination Chemistry	Chelate Effect	Analyze	MCQ	54	53	96
Electrochemistry	Reactivity Given E_{ocell}	Analyze	MCQ	50	36	86
Acid-Base Equilibria	Buffer Calculation	Apply, 3 steps	PSQ[2]	54	65	85
Solubility Equilibria	Fractional Precipitation	Apply, 3 steps	PSQ	53	70	89
Electrochemistry	Nernst Equation	Apply, 3 steps	PSQ	53	22	46

[1]MCQ = Multiple Choice Question
[2]PSQ = Problem Solving Question

Specific problems were chosen so as not to overburden the teacher in grading and to ensure that feedback was given in a timely manner. The teacher was able to give individualized feedback on students' work, especially in multistep *apply, analyze,* and *evaluate* types of question. Providing individualized feedback was especially important for students who may have been struggling. In a few cases, the students have used the first attempt to clarify their understanding of the problem. The teacher then provided clues or guided the student on how to approach the problem. These observations on customized feedback are similar to findings and recommendations by Ogange et al. (2018) wherein they remarked that "for meaningful learning to occur, online instructors need to provide feedback packaged in a manner that makes sense and allows students to correct their misconceptions" (p. 35).

Table 5 shows the *t*-test analysis (95% confidence level) for four questions where the type of question was changed from Problem Solving Question to Multiple Choice Question. As changing the question from problem solving to multiple choice question presumably made the question easier, the amount of time to answer the question was reduced in the posttest.

Table 5. *T*-test Analysis of Questions Changed from Problem Solving to Multiple Choice.

Topic	*M* of [1](χ-μ)	*SD* of [2](χ-μ)	*N*	*t* value	*p* value
Q_p & K_{eq}	0.1890	0.5567	53	2.4654	$p < 0.05$
K_c Calculation	0.1509	0.6323	53	1.7372	$p > 0.05$
Salt and pH and K_a	0.3019	0.5746	53	3.8155	$p < 0.05$
Solubility and pH	0.4151	0.4975	53	5.4018	$p < 0.05$

[1, 2]$\mu = 0$ (means no change between pretest and posttest); χ = difference between posttest and pretest; χ can be 0 (same score), -1 (posttest incorrect, pretest correct), +1 (pretest incorrect, posttest correct.

The results indicate that for one question (K_c calculation, Table 5, Question 2) that involve calculation and numerical answer, no statistically significant improvement in students' performance was seen. Looking further into the raw data indicate that of the 17 students who did not answer this question (K_c calculation) correctly in the pretest, 15 students were able to answer the question correctly in the posttest. However, this improvement is negated by seven students who answered questions correctly in the pretest, but answered question incorrectly in the posttest. Interestingly, for the other question (Q_p and K_{eq}) that also involved calculation, the raw data shows that all (*n* = 14) students who answered the question incorrectly in the pretest answered the questions correctly in the posttest. However, four students who answered questions correctly in the pretest did not answer the question correctly in the posttest. These observations would indicate that for certain students, understanding of the problem-solving concepts is short-lived or superficial.

Table 6 shows the percentage of students who answered correctly for the four questions. For two questions (Table 6, Questions 3 and 4) that can be answered without doing calculations, statistically significant improvement was indicated. However, the percentage of student answering these two questions correctly in posttest is low (45% and 54%).

Table 6. Percentage of Students Answering Questions Correctly.

Module	**Topic**	**Bloom's Cognitive Level Category**	**Question Type**	***N***	**Pretest Percent Correct (%)**	**Posttest Percent Correct (%)**
Dynamic Equilibrium	K_p and K_{eq}	Apply, 2 steps	PSQ[2]→MCQ[1]	54	74	93
Dynamic Equilibrium	K_c calculation	Apply, 2 steps	PSQ →MCQ	54	65	80
Acid-Base Equilibria	Salt, pH and K_a	Evaluate, 3 steps	PSQ →MCQ	54	24	54
Solubility Equilibria	Solubility and pH	Evaluate	Essay → MCQ	53	4	45

[1]MCQ = Multiple Choice Question
[2]PSQ = Problem Solving Question

These results are consistent with the findings of Surif et al. (2014) that students of chemistry courses found it more difficult to answer conceptual and open-ended problems compared to direct application problems. In that "paper and pencil" study, 54% and 15% of the students scored above 40% of the test in conceptual and open-ended problems, respectively, while 96% of the students answered more than 40% of direct application problems. The two *apply* type of questions in Table 6 would be equivalent to direct application problems, while the questions on "Salt, pH and K_a" and "Solubility and pH" are equivalent to open-ended and conceptual questions, respectively.

Since the reason for the low percentage of students answering the questions correctly in posttest was not clear, the same questions were used in formative assessment (PSQ) and summative assessment (MCQ) in the following semester. One week after the summative examination, the students who still did not get the two questions correctly were "interviewed" via email on the possible reason. Four students answered the survey. Two students gave time constraints as the reason, one student indicated the choices made her more confused on the answer, and one student indicated that he did not recognize that the question was the same question from the formative test. As these topics are important in Part 2, these concepts need to be reinforced in the application of the concepts in relevant Part 2 Modules.

Effectiveness of Commercially Available Online Learning Platform. Tracking of usage of Study.com indicated that only 50% (28/54) of the students accessed the Study.com site at one time during the whole duration of the course. On the average, per lesson topic, only 9 out of 54 students accessed the assigned Study.com lesson. In the previous semester, survey of students where Study.com class was also made available show that 15 out of 37 students rated Study. com site as helpful in their learning.

The effectiveness of Study.com may be dependent on a student's learning preference. Two *Application* videos (Rechargeable Batteries and Buffers and Kidney) were voluntarily and specifically cited by students as a good learning tool when students were asked what one specific topic they have learned the most in Part 1 of the course. Similar observation was obtained in previous semester. In that semester, Study.com lessons were assigned for Part 1 modules only. When the survey was conducted, two students commented that the Study.com site was their primary source of learning and asked to have Study.com videos assigned for Part 2. This "deprivation test" (McCune, 2019) reaction show that these students are highly satisfied with Study.com as a learning tool, that they look for it when they are deprived of it.

Given the low number of students that accessed the site for each topic, no quantitative analysis was done to assess the effectiveness of Study.com content. Furthermore, as this study did not specifically ask reasons for not accessing Study.com videos, authors did not include this in the paper. Nonetheless, communication with students did indicate that lack of incentive can be the main reason, as students asked if they were required to do Study.com activities. Students prioritized to doing the required UVLê activities. "Commonly, students do not see feedback as useful and frequently ignore it completely, unless it is seen as a means to acquire more points or a higher grade" (Rogers, 2022, p. 45).

CONCLUSIONS

Based on the findings for this student cohort, formative assessment with feedback can be an effective tool to provide a statistically significant performance improvement in certain *apply, analyze,* and *evaluate* topics in Quantitative Analytical Chemistry. However, additional learning strategy is needed for analyze and evaluate, as well as for multi-step problem solving topics to ensure that more than 55% of students can be fully competent in the lesson.

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