Active Learning Through Student Generated Questions in Physics Experimentation Classrooms

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Abstract—*In hopes of helping students become more active and intellectually engaged learners while conducting physics experiments, a multiple-choice question-generation learning strategy was introduced to supplement traditional lab reports on the premise that only a fairly minor modification of traditional laboratory exercises was required. In total 39 university freshmen participated in the study during the spring of 2004. To understand if and in what ways multiple-choice question-generation instructional strategy might influence students' in-class learning behavior and study patterns, a single group research design involving non-participant observation and survey research methods were employed in the study and a multiple-choice question-generation component was introduced to the class around the mid of the semester. Comparisons were made between the "before" and "after" on students' in-class question-asking behavior and instructional VCD viewing practices. Against researchers' expectation, quantitative data analysis did not show prominent changes in the number of times students raised questions toward TAs or the instructor, nor did it influence the number of times students accessed VCD. Nevertheless, it affected students' study behavior in several significant ways. By requiring students to generate multiple-choice questions, it helped to cultivate an active and reflective learning atmosphere.*

Index Terms—*Active learning, Multiple-choice questions; Physics labs; Student generated questions*

INTRODUCTION

To help students become more active and intellectually engaged learners while conducting physics experiments has been a focus of many physics educators. Over the past decade or so, a number of projects were developed that emphasized engaging activities to which students were exposed in physics labs sessions. For instance, Ron Thornton at Tufts University and David Sokoloff at Oregon State developed a series of modules named "Tools for Scientific Thinking." The modules are a series of guided discovery laboratories in the areas of mechanics and thermodynamics, and focus on concept-building. These labs rely on computer-data-acquisition equipment that can convert analog signal to digital signal so as to give students a more concrete and quantitative view of the phenomena being observed [1]-[2]. Similarly, "Workshop Physics" developed at Dickinson College by Priscilla Laws, and "Physics Studio" developed at Rensselaer Polytechnic Institute by Jack Wilson, with the support of Universal Lab Interface (ULI) data acquisition probes linked to apparatus, enable students to have a simple and direct view of how involving elements interact [3]-[4]. With recent rapid advancements in networking, multimedia and 3-D technologies, simulation learning systems that allow students to perform virtual experiments by controlling apparatus to observe results have attracted physics teachers for the advancement of the experiential knowledge of students nowadays [5]-[7].

While empirical evaluations of those projects yielded supportive evidence of their effectiveness and efficiency, these innovative projects tend to be more expensive in terms of instructional time, developmental time, specialized training for involving instructors, and/or space required than the traditional physics lab format. Moreover, they usually make strong use of computer equipment and peripherals, which usually demand major modifications of a traditional physics lab structure and additional financial inputs from affiliated groups, making immediate widespread implementation difficult [8]. In hopes of counteracting undergraduates' passive learning mode that tended to treat physics labs as a routine process of following the procedures for collecting numbers and results, a multiple-choice question-generation learning strategy was introduced to supplement traditional lab reports on the premise that only a fairly minor modification of traditional laboratory exercises is required.

Learning strategies per se, student-questioning has been suggested to have a crucial role in students' active processing of given materials [9]. Active processing theoretical perspective assumed that for students to be active comprehenders and independent thinkers, they must generate questions that help shape, focus, and guide their cognition during the learning process [10]. Furthermore, student generated question was considered as a promising technique to facilitate participants' cognitive elaboration and as a valuable alternative to achieving meaningful learning by reinforcing higher-order thinking skills [9] [11]-[14].

Despite that some evidence supported the beneficial effects ensured from student generated question [9] [11]-[14], a closer analysis of existing studies revealed that the focus and context of these studies exclusively evolved around how student generated question instructional strategy may influence students' processing of prose or oral instruction. The potentials of student generated question for physics experimentation, where hands-on learning activities are the mainstay, have yet to be examined. As more and more classrooms emphasize student-directed hands-on learning activities, the potential impacts of student generated question in these learning environments would warrant further investigation. Specifically, the present study set out to investigate how student generated multiple-choice question will affect students' in-class learning behavior and study patterns. Three research questions for this study were examined:

1. Would students' in-class question-posing behavior differ in terms of its fluency (the number of questions generated), flexibility (the number of different categories of questions generated), and complexity (demanding application of more concepts/principles for solving) once multiple-choice question-generation task is introduced in class?
2. Would students' instructional VCD viewing behavior change in terms of frequency once multiple-choice question-generation task is introduced?
3. If and in what ways multiple-choice question-generation strategy influenced students' in-class learning behavior and study patterns?

The researchers posited that by requesting students to construct multiple-choice questions pertaining to interacting physical phenomena during the learning process, which presumably would induce students to be more attentive to their tasks at hand and be more reflective on their own thinking and learning, a more active learning atmosphere in physics labs would be cultivated.

METHODOLOGY

Participants & Learning Environment

In total 39 university freshmen, while taking a "Laboratory for Physics" course, from the department of civil engineering in one national university in Taiwan participated in the study during the spring of 2004. "Laboratory for Physics" was a required course for all civil engineering major and was scheduled to be taken in the freshman year.

In this course, a total of ten laboratories related to thermodynamics, electricity, magnetism, dynamics, optics, wave transmission, centripetal force, and atomic physics were set up. The experiments were designed to be carried out in 12 3-hour instructional sessions in groups of 4.

To enhance observational learning and further guide students through the process of carrying out their experiments, in addition to lab manuals that delineated experimental procedures and required equipments and apparatus, a computer-assisted tutorial on each of the 12 experiments covered in 12 instructional sessions was developed in the form of VCD and made available to students for repetitive and flexible viewing both in- and out-of-class.

Research Design and Teaching Procedures

A single group pretest-posttest research design was employed in the study. To shed some lights on whether and in what ways a multiple-choice question-generation instructional strategy would influence students' in-class learning behavior and study patterns, a non-participant observation coupled with survey research method were used as data collection methods. A multiple-choice question-generation component was intentionally incorporated and introduced to the class at the beginning of the 7^{th} experiment (the second half of this course). This way baseline information on students' in-class question-asking and VCD viewing patterns could be gathered and compared against those of after the intervention.

As most successful student generated question instructional studies appeared to involve either direct instruction or explicit written instruction on question generation [9], a training session was arranged before having students construct multiple-choice questions on their own. The main purpose of the training was to help students master the skills of generating higher-order thinking (HOT) multiple-choice questions around important experimental elements. Adopting King's definition [15], HOT questions are "those that cannot be answered by the factual materials in the texts or by teacher's lectures. They require students to think, rather than remember or look up." Training was given orally in large group settings and involved direct instruction, practice and feedback. Afterwards each student received a 3-page training booklet that summarized the following points conveyed during the training session: (a) the rationale of incorporating multiple-choice question-generation in the class; (b) most frequent encountered types of questions in the context of physical experimentation with each type illustrated by several question examples related to physic experiments; (c) general guidelines on multiple-choice question construction (i.e., DOs and DON'Ts). Students were advised to use the booklet as a reference guide for good question-generation practice throughout the rest of the lab sessions.

As a routine, each of the participants was required to construct and hand in three multiple-choice questions before the end of each lab session while group lab report for each of the 12 experiments was due at the beginning of next lab session. Bearing in mind that providing feedback to questions students constructed was important, yet, time-consuming, the instructor gave students frequent feedback as a whole group by purposively selecting students' questions and used them as examples to accentuate certain question-generation guidelines throughout the semester. Besides, TAs used a grading system of plus (very good), check (good), and minus (you can do better) as individual feedback to students on the overall quality of their constructed questions. These codes were later translated as 90, 80, or 70, summed, and accounted for 15% of their class grade.

At the last class session, students were asked to fill in one-question survey at the last class session to tap on if and in what aspects multiple-choice question-generation task influenced their studying behavior.

Instruments

All questions students posed toward TAs and the instructor during the lab sessions were recorded on a pre-designed question-posing form. A separate form was develop to record the number of times each student accessed instructional VCD in each instructional session. Two graduate students of civil engineering major were trained to record and respond to students' in-class questioning prior to the commencement of the study. Comparisons were then made between the "before" and "after" of students' in-class question-posing and instructional VCD viewing behavior.

In addition, one-question survey was disseminated to participants to be completed individually to collect data on if and in what ways multiple-choice question-generation task influenced their learning practice and studying behavior. The question was "Overall, generating multiple-choice questions in class changes which of the following behavior of yours? (Check all that apply)"

- Increase the number of times I viewed VCD
- Be more attentive while viewing VCD
- Increase the number of times I referred to physics manual or physics-related materials
- Be more focused while conducting physics experiments
- Think and reflect more on physics-related questions and phenomena
- Discuss more frequently and intensely with group members
- Ask more questions in class
- Note-taking practices
- Others (please specify)
- It did not affect my studying behavior in any ways

RESULTS

Data related to participants' learning behavioral changes, specifically, in-class question-asking behavior and VCD viewing practices in responsive to the introduction of multiple-choice question generation task during the course of the study are presented separately in the following sections.

Question-asking behavior

Against the researchers' expectation, in total only 18 questions were directed toward TAs and the instructor for the duration of the study. In fact, 61.11% of the questions (11 questions) were accounted for by the first two instructional sessions and with only 3 questions were raised after the intervention.

Further content analysis of the questions themselves indicated no distinct changes of nature of questions in terms of flexibility (the number of different categories of questions generated), or complexity (demanding application of more concepts/principles for solving). Predominately, questions students raised could be categorized as convergent type of questions and focused mainly on experimental procedures that would handle errors or yield proximal result or outcome for their respective experiment.

VCD-viewing behavior

A week-by-week depiction of the average number of times students accessed VCD for the duration of the study is shown in table 1. A single group t-test indicated a significant difference in viewing practice between the before (sessions #1-6) and after intervention (sessions 7-12) ($t = 2.40$, $p < .05$). Contradictory to the researchers' hypothesis, students asked significantly more questions before the intervention than after the intervention. Further examination of the data revealed that, alike the results in question-asking behavior, students at the beginning of the course (especially for the first two sessions) had the tendency to access VCD more so as to familiarize themselves with the logistics and environment of the associated new course. Taking this into account, a separate t-test was conducted to compare only the 3-6 experiments and the after intervention (7-12 experiments). This time no statistically difference was found in the number of times students accessed VCD ($t = 0.89$, $p > .05$) between the before and after intervention, indicating that the incorporation of student generated question instructional strategy made no significantly impact on students' VCD viewing behaviors.

TABLE 1
WEEK-BY-WEEK ACCOUNT OF THE NUMBER OF TIMES STUDENT ACCESS VCD

	Before								After						
W#	1	2	3	4	5	6	1-6	3-6	7	8	9	10	11	12	7-12
M	1.82	1.61	1.19	0.97	1.21	1.29	1.33	1.15	1.00	1.23	1.26	0.97	0.87	1.00	1.05
SD	0.97	1.06	0.87	0.76	0.77	0.80	0.61	0.59	0.57	0.71	0.94	0.59	0.58	0.40	0.41

In what ways did MC question-generation change students' learning habits

Tallying on students' response to the one question on the survey found that more than 50 % of the participants agreed that multiple-choice question generation made them "*think and reflect more on physics-related questions and phenomena* (82.05%)," "*be more attentive while viewing VCD* (69.23%)," "*discuss more frequently and intensely with group members* (64.10)," "*increase the number of times I referred to physics manual or physics-related materials* (53.85%)," "*more focused while conducting physics experiments* (51.28%)."

17 students indicated in the one-question survey that multiple-choice question generation "*increase the number of times I viewed VCD* (43.59%)." Further analysis of the raw data on the average number of times students accessed VCD, the researchers found that 14 students had a higher VCD access rate for the after period (7-12 sessions) than the before period (3-6 sessions). Though there is a slight difference between the data obtained from the survey (i.e., 17) and that obtained from non-participant observation (i.e., 14), there are considered consistent. Even though the t-test comparing the before (3-6 sessions) and after (7-12 sessions) of students' VCD viewing behavior did not reach a significant level ($t = .89$, $p > .05$), student generated question task somewhat induced almost half of the participating students to access instructional materials more frequently.

Only 1 student (2.56%) indicated that multiple-choice question generation affected them to "*ask more questions in class*" and one frankly expressed that the incorporation of multiple-choice question generation strategy "*did not affect my studying behavior in any ways*." The former result again was in alignment with that obtained from classroom observation—question generation did not induce students to ask more questions. Referring back to raw data again found that the one student who felt no changes or impacts from multiple-choice question generation task was in fact the one student that viewed VCD only once throughout the whole course. No wonder no change of any sorts was detected by the student.

Finally, two students marked "others" to the survey question. One wrote that multiple-choice question generation helped increase his/her interests toward the subject matter while the other pointed out that the instructional approach helped him to be punctual for the class.

The responses to the survey as a whole supported the beneficial effects associated with incorporating student generated questions in physical labs.

TABLE 2
FREQUENCIES AND PERCENTAGES OF STUDENTS' RESPONSE TO THE SURVEY QUESTION

In what ways did MC question-generation change your learning habits	N	%
Increase the number of times I viewed VCD	17	43.59
Be more attentive while viewing VCD	27	69.23
Increase the number of times I referred to physics manual or physics-related materials	21	53.85
More focused while conducting physics experiments	20	51.28
Think and reflect more on physics-related questions and phenomena	32	82.05
Discuss more with group members	25	64.10
Ask more questions in class	1	2.56
Note-taking	13	33.33
Others	2	5.13
Did not affect my studying behavior in any ways	1	2.56

DISCUSSION & CONCLUSIONS

A number of suggestions have been made in the literature about how the questions that students ask can be of value. As to their teachers, they can give insights into students' reasoning, cognitive developmental ability and what they want to know and when they want to know it [16]-[17]. For the students' own sake, asking questions help them focus their attention, reflect on observations, and are catalytic to further meaningful exploration, learning and motivation, which in the end not only improve prose processing and lecture comprehension, but also elicit inferences, explanations and other high-level thinking [15] [18]-[19]. Despite student generated questions hold promises for the development of students' domain knowledge and higher order thinking skills, a preliminary investigation by West & Pearson (1994) examining student questioning behavior in college classrooms across the university found that only an average of 3.6 student questions asked per hour of instruction. Besides, undergraduates tended to hold passive learning mode and treated physics labs as a routine process of following the procedures for collecting numbers and results. Thus, what instructional strategy can teachers adopt to elicit and foster more active and inquisitive learning atmosphere in the classroom would be an important question to be answered. In light of literature and past research on student generated questions, the researchers contemplated that by incorporating a multiple choice question-generation learning activity it might have a positive effect on students' in-class learning behavior and studying patterns in the classroom, specifically in the area of in-class question-asking behavior and instructional material viewing practice.

When faced with the tasks of constructing multiple-choice questions while carrying out physics experiments, students need to generate a question-stem, provide the correct answer to the posted question, and come up with three plausible distractors. To accomplish these tasks, presumably, students must reflect back on which parts of the encountering experiences are important and worth testing. They also need to tactically phrase the question. Additionally, they are required to give the correct answer to the posted question if not evident in the texts. Subsequently, they need to ponder three distractors that can effectively discriminate those who have learned the scientific concepts and/or principles from those who have not. Under these learning situations students would be more likely to be intellectually active in order to meet those tasks demands.

By quantitatively and qualitative analyzing students' in-class VCD-viewing and question-asking data collected via non-participant observation and survey research methods, questions related to whether and in what aspects student multiple-choice question generation instructional strategy would create more active processing of incoming information on the students' parts could be answered. Contrast to the researchers' expectation, t-tests between the before and after intervention did not show prominent changes in the number of times students raised questions, nor did it influence the number of times students accessed VCD. Nevertheless, quantitative data from the survey combined with qualitative data from interviews with purposively selected participants revealed that the incorporation of multiple-choice question generation affected students' study behavior in some significant ways.

Particularly, for those who chose to view a specific VCD more than once, most interviewees indicated that they purposively located only portions of the VCD for further viewing and clarifications. The main reasons for their repetitive viewing were to either locate parts they identified as important or those that still puzzled them. Many interviewees added that completing multiple-choice question generation task undeniably accentuated the necessity for them to focus on important concepts in each experiment and for them to make sure that they understand the main concepts and procedures. By identifying important parts of the materials and/or focusing on parts that were hard to comprehend, students were essentially engaging in cognitive strategies skills, such as rehearsing, organizing, continuously monitoring their state of cognition, and embarking debugging strategies when encountering comprehension difficulties. These behavior are indicative of active, self-regulative learners.

What's more, students' responses to the survey further provided evidence that the inclusion of multiple-choice question generation element affected their learning practice. Rather than statistically quantitatively changed the number of times students accessed VCD, multiple-choice question generation seemed to qualitatively changed students' viewing and other studying behavior. Explicitly, it helped a predominate of students to "*be more attentive while viewing VCD* (69.23%)," "*increase the number of times I referred to physics manual or physics-related materials* (53.85%)," "*more focused while conducting physics experiments* (51.28%). And even thought multiple-choice question generation did not statistically induce students to direct more questions toward TAs or the instructors, it did have significant impacts on other areas. Manifestly, it made students "*think and reflect more on physics-related questions and phenomena* (82.05%)," and "*discuss more frequently and intensely with group members* (64.10)." By requiring students to generate multiple-choice questions during the journey of their learning, it seemed to transform the classroom into a more reflective and inquisitive learning atmosphere that are more active and interactive. In sum, this study found that multiple-choice question generation activity qualitatively change students' learning behavior, and helped students become more active learners.

REFERENCES

[1] Sokoloff, D. R. & Thornton, R. K., *Tools for Scientific Thinking*. Vernier Software, Portland, OR, 1993.

[2] Thornton, R. K., "Conceptual dynamics: changing student views of force and motion", In C. Tarsitani, C. Bernardini and M. Vincentini, (Eds.)

Thinking Physics for Teaching (Plenum), 1995.
[3] Laws, P., "Calculus-based physics without lectures", *Physics Today*, Vol. 44, No. 12, 1995, pp. 24-31.
[4] Wilson, J. M., "The CUPLE physics Studio", *The Physics Teacher*, Vol. 32, 1994, pp. 518-529.
[5] Liu, C., "Web-based simulations on chemistry and physics lab activities", Paper presented at *Society for Information Technology & Teacher Education*, 2002.
[6] Miller, K. A. & Glod, A., "3-D virtual classroom technology", Paper presented at *Society for Information Technology & Teacher Education* 13th International Conference. Nashville, March 18-23, 2002.
[7] Ireson, G., Hucknall, P., Kinchin, J., Parker, K., Reading, J., Wallington, R. & Williams, G., "Multimedia CD-ROMs: what do they offer to enhance physics teaching?" *Physics Education*, Vol. 36, March, 2001, pp. 155-167.
[8] Cox, A. J. and Junkin, W. F., "Enhancing student learning in the introductory physics laboratory", *Physics Education*, Vol. 37, No. 1, 2002, pp. 37-44.
[9] Wong, B. Y. L., "Self-questioning instructional research: A review", *Review of Educational Research*, Vol. 55, No. 2, 1985, pp. 227-268.
[10] Singer, H., "Active comprehension: From answering to asking questions", *Reading Teacher*, Vol. 31, 1978, pp. 901-908.
[11] English, L. D., "Children's problem posing within formal and in formal context", *Journal for Research in Mathematics Education*, Vol. 29, No. 1, 1998, pp. 83-106.
[12] King, A., "Inquiring minds really do want to know: Using questioning to teach critical thinking", *Teaching of Psychology*, Vol. 22, 1995, pp. 13-17.
[13] Leung, S. S. & Wu, R. X., "Problem posing with middle grades mathematics: Two real classroom examples", *Mathematics teaching in the middle school*. Reston, VA: National Council of Teachers of Mathematics, USA, 1999.
[14] Silver, E. A., "On mathematical problem posing", *For the Learning of Mathematics*, Vol. 14, No. 1, 1994, pp. 19-28.
[15] King, A., "Facilitating elaborative learning through guided student-generated questioning", *Educational Psychologist*, Vol. 27, No. 1, 1992, pp. 111-126.
[16] Donaldson, M., *Children's minds*. London: Fontana, 1978.
[17] Elstgeest, J., "The right question at the right time", In W. Harlen (Ed), *Primary science: Taking the plunge*. London: Heinemann, 1985.
[18] Biddulph, F. Symington, D. & Osborne, R., "The place of children's questions in primary science education", *Research in Science & Technology Education*, Vol. 4, No. 1, 1986, pp. 77-88.
[19] Keeley, S. M., Ali, R. & Geging, T., "Beyond the sponge model: Encouraging students' questioning skills in abnormal psychology", *Teaching of Psychology*, Vol. 25, No. 4, 1998, pp. 270-274.
[20] West, R. & Pearson, J. C., "Antecedent and Consequent Conditions of Student Questioning: An Analysis of Classroom Discourse Across the University", *Communication Education*, Vol. 43, 1994, pp. 299-311.