ASSESSMENT OF THINKING SKILLS IN A NON-TRADITIONAL UNDERGRADUATE CHEMISTRY LABORATORY CLASS

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INTRODUCTION

In a traditional laboratory class, where the procedure of an experiment is given, verbatim, step-by-step, a student may perform the experiment without thinking about the processes that occur within the apparatus. Using laboratory classes in developing scientific thinking is as important as developing specific subject related skills, if not more[1]. As such, the practical classes of the chemistry course, CMU 2220, Concepts in Chemistry, in the BSc (Natural Science) programme of the Open University of Sri Lanka (OUSL), were developed in a novel format where the students have to uncover the procedure of each experiment through group discussion using a set of guiding questions[2]. The questions posses the *cognitive challenge* and the group discussion creates the *collaborative environment*, two key factors necessary for developing thinking skills[3]. The perceptions of both staff and students indicate that the students improved their thinking skills by participating in the laboratory classes of CMU 2220[2]. However, more objective measurement is necessary in optimising the strategy for inculcation of thinking skills during the laboratory classes. We report here the results of an attempt made in using multiple choice quizzes in achieving this objective.

Thinking skills may be broadly defined as *"the particular ways in which people apply their minds in solving problems"*[3]. A systematic categorization of various modes of thinking is often achieved using Bloom's taxonomy[4] where thinking processes are classified into a hierarchy. In increasing order of complexity they are recalling, understanding, applying, analyzing, evaluating and creating. Activation of a particular thinking process in Bloom's taxonomy requires the activation of all the processes below it in the hierarchy. For example, the highest order process of creation requires the activation of all the other thinking processes. The importance of developing higher order thinking skills in science graduates is well accepted[5].

The objectives of this investigation are to study the level of thinking assessed by the MCQs using Bloom's taxonomy and to compare the distribution of marks of MCQs with the distributions of marks of more traditional continuous assessments, viz. theory continuous assessment marks and the laboratory report marks.

METHODOLOGY

The laboratory class in CMU 2220 was conducted on 5 consecutive days during which each student conducted 8 experiments. Half a day was spent on completing each experiment. The results presented here are based on the performance of the 106 students who participated in the laboratory class at Colombo regional centre of OUSL.

At the beginning of each half day, each student was given a handout of an experiment containing a series of questions. The students were required to spend about 15 minutes studying them individually. Then they were required to engage in group discussion (typically, 6 – 8 members) in finding the answers to the questions and uncovering the procedure which took about 30 – 45 minutes. Thereafter, they explained the procedure to a demonstrator. They were allowed to perform experiments in small groups of 2 – 5, depending on the availability of apparatus, only after the demonstrator was satisfied that they have uncovered a viable

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procedure. Essential theory of the experiments was given to the students as a course material book at registration and they were expected to study it before attending the laboratory class. After performing an experiment the students were required to submit a report as is done in a traditional laboratory class which was marked by staff. This mark may not be considered as a reliable assessment of the thinking skills of the students since the students were encouraged to collaborate in developing the report although they were required to write it individually in their own words.

A 15 – 20 minute MCQ paper was administered at the end of each experiment in assessing the thinking skills. It contained 5 problem type multiple choice items on the experiment. They were designed to invoke thinking processes in students. For example, the stem of an MCQ could be based on two alternative procedures suggested in overcoming a difficulty experienced by a (hypothetical) student, such as the non-availability of the ideal piece of equipment in the laboratory. The choices could be based on a comparison of the precision or accuracy of the procedures. If one or both the procedures mentioned above were not given in the course material and not discussed in the laboratory class then the students had to think systematically in finding the correct answer at the time of answering the quiz paper. As such marks obtained by a student in a MCQ paper is a measure of the thinking skills of that student.

MCQ quiz papers were administered for seven out of the eight experiments. Two of the authors separately analysed the seven MCQ papers in determining the highest order thinking processes invoked in answering each question based on Bloom's taxonomy. Then the results were compared and an agreement was negotiated in the few cases where there was a discrepancy[6]. Particular attention was paid for what is presented in the course material and handouts in making a reliable identification of highest order thinking processes invoked in answering each MCQ. For example, a question invoking a seemingly higher order thinking process was classified as recalling if it appeared in that form in the course material since a student who has studied the course material well only has to recall it in answering the question.

The Relative Frequency of invoking the thinking process, α, as the highest order process in the MCQ paper of the j[th] experiment, denoted by $RF(\alpha,j)$, was determined using the relationship $RF(\alpha,j) = 100\times\left[n(\alpha,j)/N(j)\right]\%$ where $n(\alpha,j)$ is the number of times the thinking process α is invoked as the highest order process in answering a MCQ in the quiz paper and $N(j)$ is the total number of times such thinking processes are invoked in the paper; i.e. $N(j) = \sum_{\alpha} n(\alpha,j)$. An Average Relative Frequency, $ARF(\alpha)$, of invoking the thinking process α, as the highest order process, over the quiz papers was calculated using the relationship $ARF(\alpha) = \left[\sum_{j=1}^{7} RF(\alpha,j)\right] \Big/ 7$. $ARF(\alpha)$ is a measure of the percentage of the thinking process α is invoked as the highest order process in a MCQ paper.

RESULTS AND DISCUSSION

Figure 1 indicates the average relative frequency of invoking thinking processes in a MCQ paper as the highest order process.

Highest order thinking process assessed by the MCQ paper is evaluation since creation cannot be assessed using MCQs. On average 18% of MCQs invoked evaluation as the highest order process. The MCQs that invoked evaluation process, invoke all the other lower order processes in Bloom's hierarchy, viz. recalling, understanding, applying and analyzing. Hence the actual percentages of invoking the said lower order processes are higher than what is shown in Figure 1. For example, 1% of the MCQs invoke analyzing as the highest order process. Since it is just below evaluation (which is the highest order process invoked) 19% of the MCQs have evoked analysis. As such, 100% of MCQs has evoked recalling. 70% and 25% of MCQs have evoked understanding and applying, respectively. However, to obtain a mark for a MCQ a student has to invoke the highest order process necessary in finding the answer to that MCQ since marks are given only for the correct answer.

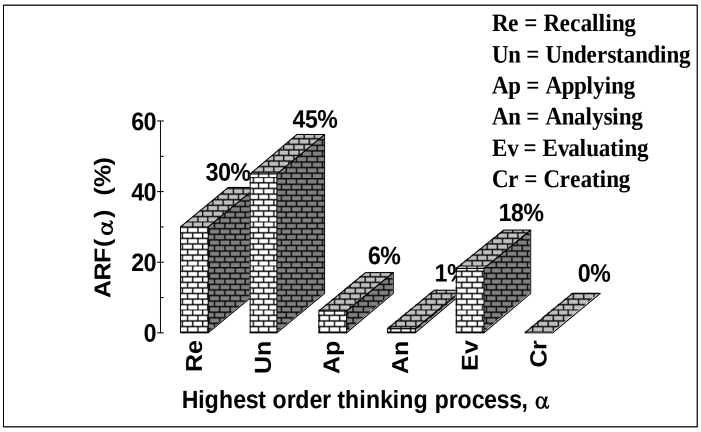

Figure 1: Average relative frequency of invoking thinking processes in a MCQ paper

CMU 2220 has 3 Continuous Assessment Tests (CAT) in its theory component. The mark obtained by a student averaged over these 3 tests (denoted by ACAT) is a measure of his/her academic achievement in the theory domain of the course. Similarly the marks obtained by a student in a MCQ quiz, averaged over all 7 such quizzes (denoted by AMCQ) is a measure of his/her ability in invoking thinking processes in the context of the 7 experiments.

Figure 2 shows the relative frequency distributions of ACAT, AMCQ and the laboratory report marks (together with their mean values).

As expected, the distribution of the laboratory report marks is skewed towards higher values with a mean of 75%. AMCQ has a nearly bell shaped distribution with a much lower average of 49%. However, one has to be careful in interpreting the distribution of AMCQ since the students can score by randomly marking responses in MCQs. Each MCQ has 5 possible choices. Hence on average a student can score 20% by randomly selecting responses to MCQs without invoking any thinking process. Hence, a lower bound to the distribution of AMCQ may be obtained by shifting the AMCQ by 20% towards lower marks which is shown in figure 2 as (AMCQ – 20). One may safely assume that the distribution of student marks which assesses the thinking skills of the students to lie between the two distributions mentioned above. An estimate of this “adjusted distribution” may be obtained by taking the average of AMCQ and (AMCQ – 20) which is indicated in the dashed dotted line in figure 2. This adjusted distribution is an estimate of the distribution of student thinking skills as assessed by the MCQs. As seen in figure 2, adjusted distribution is qualitatively similar to the

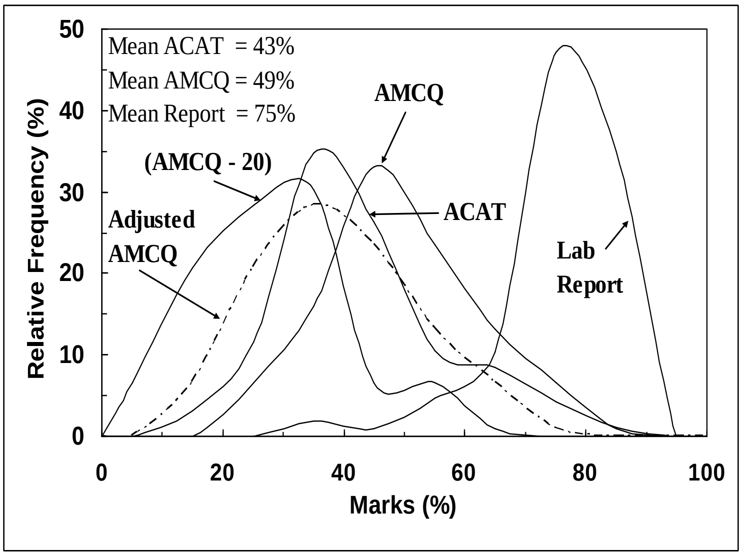

Figure 2: Relative frequency distributions of ACAT, AMCQ and laboratory report marks

distribution of ACAT marks. This may be interpreted as an indication that the student population who attended the laboratory class at CRC has achieved a level of competence in thinking skills which is similar to their academic achievement as reflected in CAT marks.

CONCLUSIONS/RECOMMENDATIONS

In the 7 MCQ papers used in assessing the thinking skills, 81% of the MCQs invoked the lower order thinking processes, recalling, understanding and applying. 19% were devoted for assessing higher order thinking skills, analyzing and evaluating. As such, on average, MCQ papers are biased in assessing lower order thinking skills. By including MCQs capable of assessing higher order thinking skills, one could improve the quizzes in assessing more higher order thinking skills.

The distribution of thinking skills of students as assessed by the said quizzes is qualitatively similar to the distribution of CAT marks, averaged over the three CATs, in CMU 2220 in academic year 2011/2012. As such one may conclude that the student population which attended the laboratory classes at CRC has achieved a level of competence in thinking skills (as assessed by the MCQs) which is similar to their academic achievement as reflected in CAT marks.

An examination of marks obtained by students for individual MCQs could be used in measuring the extent of the development of lower order and higher order thinking skills, separately, in the laboratory class. A similar analysis of the CAT papers and marks obtained by students for individual questions could reveal the extent of development of thinking skills in the theory component. Comparison of these results would reveal the impact of the laboratory class in the development of thinking skills of students. The authors have commenced such a study.

REFERENCES

Bennet, S. W. and O'Neale, K. (1998). Skills development and practical work in chemistry. University Chemistry Education, 2: 58 – 62.

Bandarage, G., de Zoysa, M. N. K., Dikkumbura, A. S. and Makandu, A. (2011). A novel approach in transforming a recipe driven laboratory class in chemistry to a thinking oriented laboratory class. Proceedings of the Annual Academic Sessions of The Open University of Sri Lanka, 14 – 15 September 2011, 307–310.

Fisher, R., (2010). Thinking skills. pp 374-387. *In:* Arthur, J and Cremin, T., (Eds). Learning to teach in primary school, Routledge, UK.

Andersin, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., Raths, J. and Wittrock, M. C. (2001). A taxonomy for learning, teaching, and assessing: a revision of Bloom's taxonomy of educational objectives. Addison Wesley Longman, Inc., UK.

Fensham, Peter J. and Bellocchi, Alberto (2013). Higher order thinking in chemistry curriculum and its assessment. http://eprints.qut.edu.au/60747/ (Accessed on 25 July 2013)

Tantrigoda, R. U., Bandarage, G., Nawaratne, C., Nilakarawasam, N., Rajendra, J. C. N., Wickramasinghe, B. L. K. and de Zoysa, M. N. K. (2012) Evaluating the success of assessment of a level 3 chemistry course in the BSc degree programme of the Open University of Sri Lanka (OUSL) as a tool of measuring the cognitive skills of students: A preliminary study. Abstracts of the International Conference on Chemical Sciences, Role of chemistry research in national development, 20 – 22 June 2012, Colombo, Sri Lanka, p 77.