Action Research - Design problems for undergraduate students in the Bachelor of Electrical and Electronic Engineering

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Abstract: This paper describes an action research exercise undertaken to assess and subsequently enhance the students' abilities in problem solving for engineering design problems. An analysis of the students' abilities/understanding before and after the training is included, and recommendations for the next phase of this action research exercise are presented.

1. Introduction

Problem solving is now considered as an essential skill for the workplace. ABET specifies the following two requirements of engineering baccalaureate graduates (Shuman et al, 2005):-

- An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability (3.c)
- An ability to identify, formulate, and solve engineering problems (3.e)

Design is a problem solving process itself in engineering (Siddiqui, 2006). Design problems are characterised by the fact that they are often complex, ill-defined and with no singular process model. Students who are learning to solve design problems need to face ill-structured problems in order to develop independent and contextual thinking skills. The problem solving process in design also requires system, procedural and strategic knowledge (Jonassen, 2004).

This paper describes a component of action research undertaken to:-

- Assess the students current level of understanding of problem solving related to engineering design problems,
- Identify areas of weakness, design and subsequently deliver suitable training material, and
- Analyse the success (or otherwise) of this training.

2. Background and Student Analysis

During 2006 the first year of the Electrical Engineering (EE) Course at Victoria University (VU) was delivered in PBL mode. The course is scheduled for phased changeover from traditional to PBL mode in the period 2006 to 2009. In 2007 the second year of the course is currently being delivered in PBL mode. Most of the students undertaking the course have come through first year, and will have undergone the normal introduction to the new paradigm. A second group of students may have transferred from the traditional course, which is being phased out, or are new students who are entering with Recognition of Prior Learning (RPL). This second group will not have had the same grounding in PBL techniques as the majority of the students and had to be brought up to speed as quickly as possible.

The majority of the students entering the first year are, on average, about 18 to 20 years old. Most have come here straight from school. They will probably have a Tertiary Entrance Ranking (TER) in the 60s or 70s. Many will be the first in their family who have attended university. Many will be from families with a low socio/economic background. Many will have a Language Other Than English (LOTE) as their first language. For many students they have come through a well structured school experience where they have been expected to be passive receivers of information assessed on their

ability to repeat what they have "learned". Many may have come from a cultural background which reinforces this role for the student. They are now, however, part of the "Family of Engineering Students". The language of tuition is English, and some have had very little experience with the language. Many have come through education systems which have been largely behaviourist rather than constructivist in nature. Some have little clue as to how they have come to be in an engineering course in the first place. Many have "part time" jobs, or other outlets, to which they devote a great deal of time. Absenteeism is, unfortunately, commonplace.

This mix of students must now work in teams in a PBL setting to construct their own understanding of knowledge through the guidance of the problems posed for them in their PBL classes. The task described in this paper was to attempt to facilitate the students' learning in the discipline of Problem Solving for Engineering Design Problems so that they may be more able to participate fully and control their own learning.

3. Action Research Outline

The basic aim of this action research was to work with a group of second year students in the Electrical Engineering course. As the course is now run using the Problem Based Learning paradigm, all students will be involved in the solution of problems. This paper describes a component of action research undertaken during semester 1 of 2007 to:-

- Assess the students current level of understanding of problem solving related to engineering design problems,
- Identify areas of weakness, design and subsequently deliver suitable training material, and
- Analyse the success (or otherwise) of this training.

This involved: establishing a baseline, designing appropriate materials for teaching Problem Solving to this cohort of students in this very specific context and finally an analysis of the changes brought about in the students (in terms of their theoretical knowledge which would be put to the test in practice in semester 2) who attended the training classes. Establishing the baseline and the subsequent analysis after the training classes was done using a specifically designed Pre and Post Training Questionnaire.

A variety of mechanisms to present the problems to the students was used to minimise the possibility of misinterpretation or confusion. Establishing the appropriate level of challenge for the students was not a problem, as the students were preparing themselves for second semester where they will be doing a community based project which they, themselves, have sought out. In the early part of the semester the students had undertaken a series of "Guided Laboratory Experiences" in microprocessor systems so that they might gain greater insight into problem solving by an experienced practitioner. Supporting the students in the presentation of their problems was also covered in the introductory workshop which included references to Causal modelling, Concept Mapping, Pareto diagrams etc. Reflection was, and will continue to be, an important activity as the students meet with the supervisor, and/or clients, during the period of the two problems. Students were expected to submit reflective articles during semester. They were expected to reflect not only on the design process (i.e. the product) but also on the problem solving process (i.e. the process). In second semester the initial problem statement given to, or developed as a contract in conjunction with, the students will have clearly stated competencies for them to aim at. The development of these competencies will be monitored during the formal and informal feedback sessions. The students will also undergo evaluation of their learning experiences independently of the supervisor. This will establish a second line of feedback for improvement processes.

4. Pre and Post Training Questionnaire

A Pre and Post training questionnaire was designed specifically for the implementation of this action research component. This questionnaire was initially used to establish the baseline for the design of the material for the training classes and then used subsequently to evaluate the efficacy of these classes.

Students were given the following information verbally and in the questionnaire itself, and asked to volunteer to do the questionnaire.

"We are trying to assess your understanding of how to solve "Engineering Design Problems. It would help us very much if you would please answer the following questions as carefully as you can. We will ask you again at the end of semester to see how much you have learned and improved your technique during semester. This is not an assessment of you and will in no way be held against you, so we need you to identify yourself so that we can compare your answers now and later."

1	How do you remember things?
2	What makes you learn, or helps you to learn?
3	How do you think you learn how to solve problems?
4	What different types of problems do you think exist? Try to identify 5 different types of problems.
5	Why do you think we pose problems for you in Problem Based learning?
6	Identify 5 features which you think typify "Engineering Design Problems".
7	Identify 5 elements about problems which could impact upon how you solve them.
8	Identify 5 elements of yourself and/or your learning/background which could impact upon how you solve problems.
9	Identify 5 ways in which teamwork could impact upon how you solve problems.
10	Try to identify 5 things which we, as supervisors, could do to help you solve problems.
11	If you have 10 desired products which have been requested for a project, but you are running short of time what would you do?

Table 1 Questions for Pre and Post Training Questionnaire

The questions are shown in Table 1, above. Questions 1, 2, 3, and to some extent 8 and 10 as well, look at the individual and their perceptions of learning and reflections on their own approach to learning. Questions 4 to 9 look at their current level of understanding of the nature of different types of problems, engineering design problems in particular, and their own interactions with problems. Questions 5, 9 and 10 look particularly at Problem Based Learning, and the students' understanding of this learning style and their own. Question 11 poses a simple "what if" scenario for the students to analyse and suggest possible solutions.

5. Analysis of the Pre and Post Training Questionnaire Results

The outcomes of the Pre and Post Training Questionnaires have been analysed. The number of "appropriate" answers to each question by each student has been recorded. Average scores per question and per student have been calculated as have total scores per student. All of these results are shown in tabular and graphical format. A Minimum score of 0 indicates that at least one person failed to enter any response to that question. A Maximum score of 5 indicates that at least one person recorded 5 or more appropriate responses to that question. The Min and Max values represent the spread of responses. This allows for a simple comparison of the Pre and Post Training scores, to gauge the efficacy of the problem solving training classes.

5.1 Summary for Pre Training Questionnaire.

The Pre Training Questionnaire was administered during a "compulsory" workshop for the whole class. Forty students participated. This represents only about 50% of the students who are actually enrolled in the subject. A participation rate of 50% is not all that bad (as was mentioned earlier, absenteeism is commonplace).

The marking scheme which is the basis of Table 2, below, is a very simple one designed to allow some sort of quantitative comparisons based on the students' own qualitative responses (Samsudin, 2007) (Fraenkel, 2006). Each response to a question was analysed as being appropriate or reasonable and allocated one mark. If a student gave four reasonable responses to a question he/she would receive a mark of 4 for that question. All questions were given a mark out of 5. The total maximum is, therefore, 55. All questions have a minimum of 0 which effectively equates to a "no response" to that question. The average is the total score for each question divided by the number of responses (40). This whole process was repeated for the POST Training Questionnaire. The turnout for this was 36.

												Total
No of responses	40	40	40	40	40	40	40	40	40	40	40	36
Min	0	0	0	0	0	0	0	0	0	0	0	5
Max	3	3	3	5	4	3	3	4	4	4	3	31
Average	1.38	1.68	1.28	1.45	1.2	0.7	1.1	1.08	1.68	1	0.98	16.42
Question No	1	2	3	4	5	6	7	8	9	10	11	

Table 2 Summary of Pre Training Results

Figure 1, below, shows the range of responses for each of the 11 questions in the PRE questionnaire. It is clear that the majority of students scored in the range 0 to 2 for most questions.
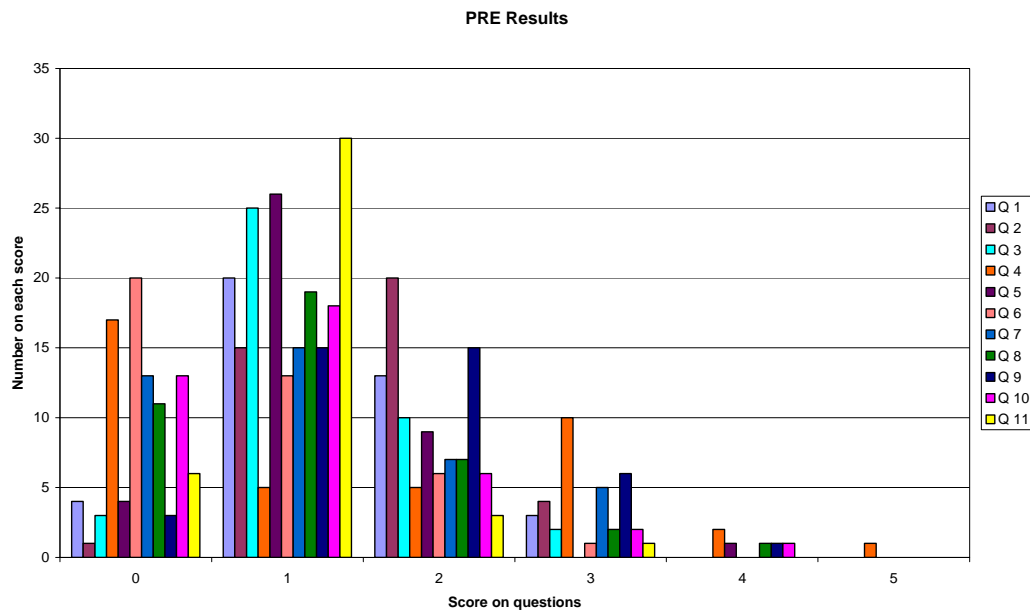

Figure 1 Range of responses for each question in the PRE questionnaire

Overall, the numbers shown in Figure 1 and Table 2 indicate that the students were weak across the board. This guided my choice of material for the Problem Solving training sessions which I would conduct with my group of second year students. Because the students appeared to need guidance across a broad range of topics related to Problem Solving, I divided my training presentations into three topic areas, as shown in Table 3, below.

1	Basic appreciation of the concepts of learning and learning styles
2	An introduction to the fundamentals, techniques and generic skills of problem solving
3	An introduction to problem types and design problems in particular.

Table 3 Topic Outlines for Problem Solving Training Session Material

To try to determine the efficacy of the training, the material was presented to only one group of students, the group of students to which I was allocated as their supervisor (my group). The remaining students in the "whole" group would then be the control group for this particular teaching experiment.

5.2 Summary for Post Training Questionnaire.

Three training sessions were conducted for "my group". My group nominally contained 15 students, but absenteeism meant that only 11 actually attended the training sessions, of which only 7 actually completed the POST questionnaire. Two other students who should have attended the training

sessions, but did not, actually completed the POST questionnaire, but their scores are not included in "my group" as they had not had the benefit of the problem solving training classes.

												Total
No of responses	36	36	36	36	36	36	36	36	36	36	36	36
Min	1	1	0	0	0	0	0	0	0	0	0	5
Max	4	4	3	4	3	5	5	5	5	3	3	31
Average	1.56	1.67	1.36	1.44	1.25	1.47	2.03	1.58	2.03	1	1.03	16.42
Question No	1	2	3	4	5	6	7	8	9	10	11	

Table 4 Summary of Post Training Results For the Whole Group

Figure 2, below, shows the range of responses for each of the 11 questions in the POST questionnaire. The range of scores has broadened somewhat from that shown in Figure 1, but is still largely in the range 0 to 2 for most questions.
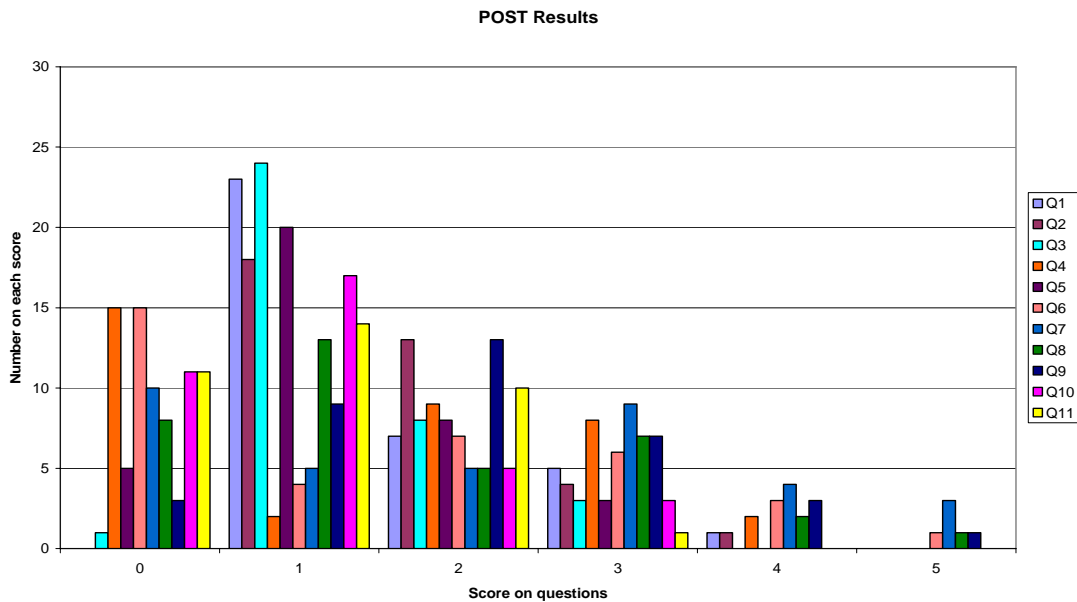

Figure 2 Range of responses for each question in the POST questionnaire

Table2 and 4 show a slight increase in the average total from 13.5 to 16.4. This could be accounted for because the students are just a little more practiced. This group of 36 actually includes my group (who did somewhat better – please see below). If I leave out my group the increase in the control group is only to 14.17. Table 5 shows the Post training responses from my own group, who actually went through the training. As can be seen from Table 5, the increase in the average total score is then from 13.5 to 25.71.

												Total
No of responses	7	7	7	7	7	7	7	7	7	7	7	7
Average	2.14	2.14	1.71	2.71	1.71	2	3.57	2.86	3.14	1.86	1.86	25.71
Question No	1	2	3	4	5	6	7	8	9	10	11	

Table 5 Summary of Post Training Results for those who attended the workshops

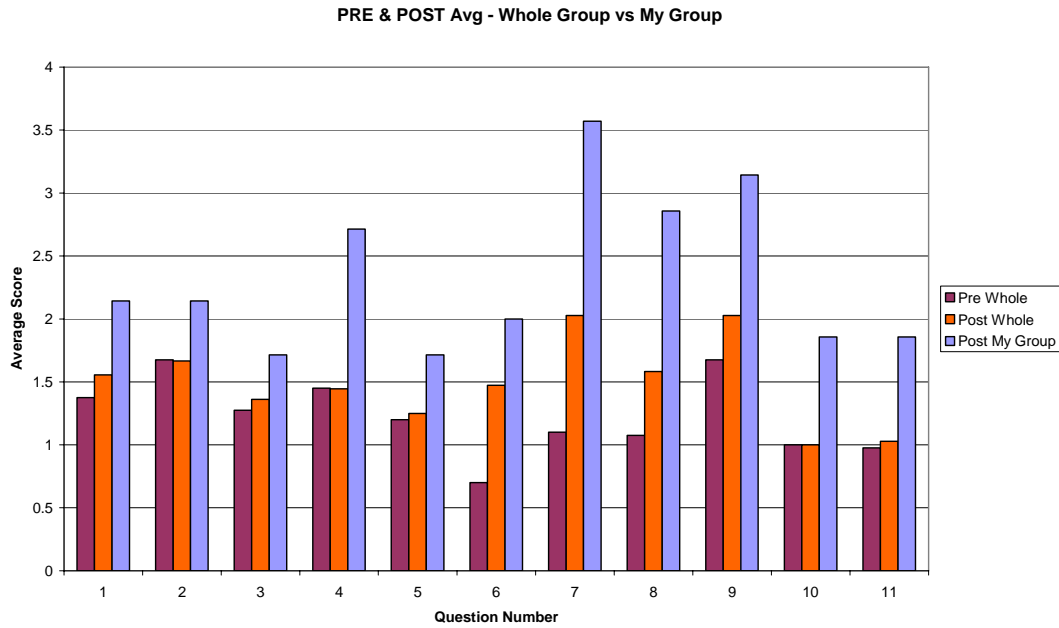PRE & POST Avg - Whole Group vs My Group

Figure 3 Range of Average scores for each question in the POST questionnaire
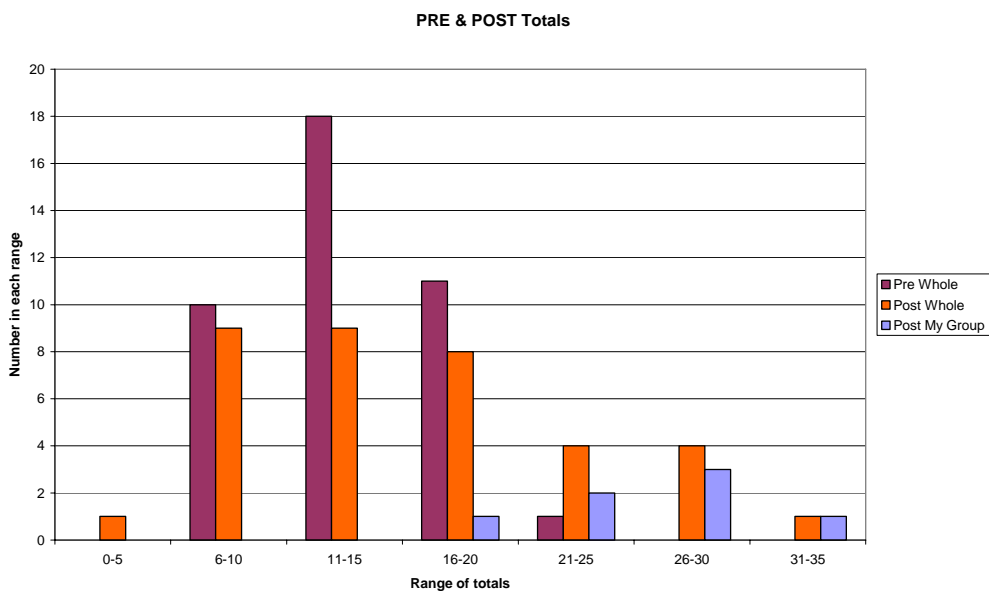
PRE & POST Totals

Figure 4 Range of Total scores for each question in the POST questionnaire

Figure 3 shows the average scores for each question for the whole group Pre training, the whole group POST training and for my group POST training. The differences now become quite apparent. The training in problem solving has resulted in a significant overall increase in average scores for those who participated. This has not occurred because one or two have increased dramatically, rather because all have improved significantly as shown by the fact that the totals for my group are all towards the top end of overall totals, as shown in Figure 4, which shows the range of Total scores whole group Pre training, the whole group POST training and for my group POST training.

5.3 Analysis and Comparison of the Responses to each Question in PRE and POST Training Questionnaire

The following are the responses to each question. I have included the most common responses, although they are not in any specific order. It can be seen from the analysis of the Post Training Questionnaire responses shown above that the average across all questions has increased. This has

been largely due to the fact that students gave *more* responses. The most gratifying feature is, however, that in addition to more responses being given, a few *new* responses directly and/or indirectly related to the training classes began to emerge. These are all shown in the analysis of the responses to each question as follows:-

Q1 The new responses show a greater awareness of the things that they do to remember things. They have moved beyond tacit knowledge and are now more able to articulate their thought and memorisation processes.

Q2 The new responses show an appreciation of alternative motivators. Teamwork and having fun are now part of their learning tools. They have made the connection between doing problems and learning. This is good, because they are in a PBL course.

Q3 The new responses show a more methodical approach. Teamwork, planning and a set of rules are very much a part of their everyday learning, but they had previously not made the connections.

Q4 The new responses included answers such as "moral" and "ethical". This shows a realisation that their role as professional engineers involves much more than technical concepts.

Q5 The new responses show that the students are moving away from the concentration on the Product and a better focus on the Process. They are making the link between learning and their future job opportunities i.e. real life as a professional engineer.

Q6 The new responses show that the students have incorporated ideas directly from the training class material. The "full design model" included by one student was, in fact, a five point model similar to the waterfall model.

Q7 The new responses again show the incorporation of teaching material into their standard vocabulary for explaining their understanding of problem solving. The use of the word "Stress" is interesting, in that is a form of self reflection. The students are now realising that teamwork is, and will continue to be, a significant factor in the rest of their learning and working lives.

Q8 The new responses show a marginal realisation that they as individuals must plan their learning and/or problem solving. The most significant factor in this whole question is, however, the inclusion of the poor team skills as a major Negative factor impacting upon their learning. Since this questionnaire was completed by only about 50% of those that might have been expected to complete it, it is highly possible that the students were making comments about those of their colleagues who were absent. This indicates that in future, perhaps, we should include more strategies that the students may be able to use to encourage fuller participation by all team members.

Q9 The new responses show a reliance on the team structure. An acknowledgement of personal responsibility has emerged, but the negative impact of poor teamwork is recognised. The comment "Getting along so well that nothing gets done", could initially be seen as negative, but this strong bond may well provide the support and encouragement necessary when the going gets tough.

Q10 The new responses show a clear move away from dependence. The earlier requests for answers and for the supervisor to "fix team problems", is a clear indication of a surface approach. The word "Facilitator" emerges for the first time. There are no requests for the answers to be provided, rather they are asking for direction so that they may do things for themselves. The comment "Be honest" is very interesting, presumably the student in question has suffered some form of educational dishonesty in the recent past. This merits investigation.

Q11 The new responses show an increased awareness that they could be working with a real client. In the Pre training responses, the concept of doing the important things first was raised, but it was never identified that the client is the arbiter of "Importance". In the Post training responses the concept of re-negotiating time and/or priorities was clearly stated for the first time. Overall, these new responses show a broadening of the students' awareness of themselves and their role as a professional in society.

6. Conclusions

This paper has described the processes which were undertaken in this action research exercise to:-

1. Identify the students' initial levels of knowledge on problem solving,
2. Create appropriate training classes to help to fill any gaps identified, and
3. Analyse the outcomes by re-testing the students' knowledge after the training classes.

The initial baseline was established using a PRE questionnaire. The results of this questionnaire were then used to decide what material to include in the training classes. The efficacy of the training classes was determined by using a POST questionnaire.

The questions were designed to take the students through a series of thought processes and themes. Firstly they were invited to reflect on their own thinking and learning processes. Then they were invited to consider aspects of problems and their relationship to PBL, whilst simultaneously being directed towards thinking about "Engineering Design Problems" as a special type of problem. Following this, they were invited to make connections between the skills they might have which can be directed towards solving these problems and how teamwork and supervision fit into this overall equation. Finally, since the theory is of no use if there is no opportunity to put it into practice, a simple scenario was presented to the students and they were invited to apply some of the ideas they had developed in the previous questions towards the possible solutions to this problem. This question also investigated how they incorporated their broader social and client based skills into the possible solutions to the scenario given.

The student responses indicated that though many students had a tendency towards using deep learning approaches most use surface approach to learning. Student responses also seemed to support the constructivist theory of learning as their responses indicated that they learn best if the learning is contextual, which could help them to relate what they are learning with their existing sense of reality. They also seemed to support social setups for learning and being able to learn something within a variety of contexts. Responses also indicate that concrete and tangible knowledge is important for the engineering students.

Overall the results have been very encouraging. It appears that students definitely benefit from classes specifically designed to teach problem solving for Engineering Design Problems. The numbers of students in the trial group were small, but the results indicate that a similar action research exercise should be carried out next year with a larger number (probably the whole class) of students participating.

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