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Experiences Teaching a Graduate Level Research Methodology Course

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Abstract: A description of the Research Methodology course is given together with a list of the course contents and their objectives. The course does not aim to teach students how to do research in their special fields; instead it gives them practice in the mathematical, English language, and investigative skills needed for research at a professional level. The students come from a wide variety of backgrounds and have a wide range of abilities. Some of the difficulties they have are mentioned, and it is said that time-consuming individual adviser-to-student coaching is needed to bring the students up to international standards.

1. Introduction

In 1998 the Srindhorn International Institute of Technology (SIIT), Thammasart University, and the Joint Graduate School of Energy and Environment (JGSEE), King Mongkut's University of Technology Thonburi, invited me to teach a new course entitled *Research Methodology*. I was given the freedom to include in the course whatever topics I considered would best serve the needs of our graduate students.

Then, in 2003, Professor Prida Wibulswas, who had been instrumental in creating the Joint Graduate School of Energy and Environment and was at that time Director of the Sirindhorn International Institute of Technology, observed that no suitable textbook for this course was readily available in Thailand, and he asked me to write such a book. This book [1] is still used as a text for the course, and supplementary information for students is available on the website of the JGSEE [2].

The course is taught in a three-hour session once a week, and one homework exercise is given each week. There are two three-hour open book examinations: a mid-term exam and a final exam.

2. The Course and its Aims

The topics included in the course are based on my own experience in research. They are things that I had to do throughout my research career. Because the range of problems studied by our students in their research is wide the course does not teach any of the special subjects required. This is the responsibility of the thesis advisers and the instructors of the various specialized courses offered in our Graduate School. Instead, the aim is to practise the general skills required for technical research at a profession level [3].

The topics discussed in the classroom week by week are listed below. The practical skills the students are expected to develop include numerical and mathematical skills, skill in understanding and writing technical materials in English, the ability to do and write up simple experiments, and practice in making oral presentations. The academic content of the topics selected for these practice sessions is intentionally taken from an early stage in the education of the students, such as their high school or first year undergraduate general science studies. This is so that students can concentrate on the required skills without having to struggle to understand the scientific content.

Homework based on the topics discussed in the classroom is set each week. The homework is handed in one week later, and the work of the students is reviewed in the classroom in the third week. The students are encouraged to discuss the homework together because researchers always discuss their work together and learn from each other. However, the students are told to do the work themselves after the discussion. If they copy another student's work they are cheating themselves by failing to the practise the skills required. In spite of this warning students are apt to plagiarize so their homework is not graded, but a 1% credit is given for each satisfactory homework done up to a maximum of 10% of the total course grade to ensure that the students actually do the work.

3. Course Contents and their Objectives

3.1 Numerical measurements: Significant digits, SI units, dimensions

The number of decimal digits shown on an electric calculator is large, usually ten digits. Students sometimes give all these digits as the answer to a quantity they have calculated without thinking how many of them are significant. The objective of the exercises here is to make students aware of the significance of these digits, and investigate how changes in the digits in the input data produce changes in the digits in a calculated result.

The importance of attaching unit symbols to the numerical values of physical quantities is emphasized. It is a strange fact that in every exercise and every exam some students omit these symbols. I did not understand this until one day I asked a student, "Why do you not include the unit symbols?" "Because," the student answered, "Our school teachers never told us to."

Another objective in these exercises is to show how base SI units can be used to indicate the dimensions of a physical quantity and verify that theoretical calculations are dimensionally consistent.

3.2 Literature review: Summarize two articles on earthshine

In this exercise the students define what earthshine is (sunlight reflected from the Earth onto the dark side of the moon), reorder the facts in the two articles into their proper historical sequence, show how measurements of earthshine determine the Earth's albedo, calculate recent changes in the Earth's albedo from the data in the articles, and state that these changes are important for monitoring global climate change.

The objective of this exercise is thus to take students beyond the poorly written literature reviews in many theses, which contain nothing more than simple references to what a few other workers have done in the field without any discussion and without any use of the work in the rest of the thesis.

3.3 Fitting formulas to data: Exact fit and 'best fit'

One of the curses in the modern technological world is the existence of software that fits straight regression lines, and calculates correlation coefficients, for whatever input data are used. Having used this software, students think they have then analyzed their data. This, of course, is nonsense. Moreover, the software often plots graphs that fail to show the correct shape of the function required.

In this part of the course the students are given simple methods of analyzing data for a variety of purposes such as polynomial interpolation, exponential extrapolation, deriving the parameters in a theoretical function from graphs of measured data, and estimating the best values of quantities by a 'least squares' fit when the measurements are linked in a network. The students are thus expected to think about the proper way to analyze their data when they do their research.

3.4 Description and use of equipment: How to make and use a table-top furnace

Most scientific work involves the use of special equipment, which must be described accurately in a thesis, especially if it has been designed or made by the student. Accordingly, the students are given practice in this skill with a story from the *Scientific American* (April 2000) about an amateur scientist who made a table-top furnace and used it to measure the moisture content of garden soil. The students are required to rewrite the technical content of this story in their own words as it should be written in a professional report or a thesis.

3.5 Home experiment: Determination of the Circle Constant

The students know that the circumference of a circle divided by the radius is 2π, where $\pi = 3.14159265...$, and this can be calculated theoretically to any number of decimal digits. But they do not see that testing this value in the real world is a valid experiment. A real circle drawn on a sphere has its circumference divided by its radius less than 2π because the radius is longer than that of a flat circle. And the rim of a cowboy's hat has this ratio greater than 2π because the rim, waving up and down, is longer than the rim of a flat circle.

The students are asked to determine the circle constant of circular objects, some big and some small, using simple equipment such as a ruler and string or a tape measure. The objective of this exercise is to let the students see how difficult it is to measure the circle constant in this way with an accuracy better than three significant digits.

A second most important objective is to have the students estimate the uncertainty in their result from the accuracy of their measurements, which will be about one millimeter if they are done carefully with the simple equipment mentioned above. This will give them a band of possible values of the circle constant found from their measurements. The students are then expected to see whether or not the theoretical value lies within the band of values they have found.

It is difficult for some students to understand this analysis. To them there is only one question: "Does my result agree with the theoretical value or not? If it does not, then the error in my result is simply the difference between my result and the 'true' value." I tell them that in experimental work we have to estimate the uncertainty in a result such as this from the uncertainties in our measurements so that we can say with confidence what band of values must contain the true value.

3.6 Short presentation: Your favourite creative hobby

Reseachers must be able to explain their work to an audience. The students develop confidence in their ability to do this by making short presentations of a topic with which they are familiar. This is often difficult for students whose native language is not English, but since they are speaking only to their friends, they are not nervous in the classroom. Each presentation is limited to three minutes and is illustrated by six slides, so the students have 30 seconds in which to state the point of each slide.

The main difficulty in this exercise is to get students to prepare good slides. The usual problems are small letters that cannot be seen by people sitting far away from the screen, and insufficient contrast between the colour of the letters and the colour of their background. Other problems are the inclusion of too much detail in the slides, and the student confusing the audience by saying in the presentation words that are different from the words on the slide. It is sad that these faults are often seen in professional conferences because modern technology makes the preparation of excessively complicated slides so easy.

3.7 Mid-term examination

The time allowed is three hours. In the exam the students may use the textbook, their lecture notes, dictionaries, and electric calculators. This use of an open book exam is based on the idea that when doing research we always have books and references at hand anyway. The exam tests how well the students can use the information available. However, the candidates are not allowed to use mobile phones or access to the internet.

Part I: Some quantitative data are given and the students are required to analyze the data mathematically by the methods treated in the classroom and the homework exercises.

Part II: A text is given containing tangible information. The students give short answers to four questions testing their ability to highlight important facts in the text and discuss the contents.

Part III: The students write an essay of about 250 words on a topic connected with research. The topic is related to the classroom sessions and homework exercises done before the exam.

3.8 Writing a proposal: Qualitative experiments on photosynthesis

The students write a proposal for a set of simple qualitative experiments verifying what conditions are required for photosynthesis to occur in plants, and what gases are absorbed and emitted by plants during photosynthesis and respiration. Photosynthesis is assumed to have occurred if starch is found in the leaves of the plant. The conditions examined are: the need for sunlight, the need for carbon dioxide in the air, and the need for chlorophyll in the leaves. It is expected that most students have already seen these experiments in their science lessons at school.

The objective here is to ensure that the students are strictly logical in their proposals. If, for example, they say that the presence of starch in the leaves of a plant at the end of an experiment shows that photosynthesis occurred during the experiment, this will not be proved if they fail to say that the leaves must be destarched by keeping the plant in the dark and then tested before the experiment; the starch could have been in the leaves all the time and might not have been produced under the conditions of the experiment.

3.9 Descriptive statistics: Mean, variance, correlation, simple analysis of variance

There are two main objectives in these exercises. The first is to show how statistics are simple ways of summarizing a large number of measurements. The second is to introduce the analysis of variance as a way of evaluating the causes of variation in measured data. The formulas given are for the statistics of a population of measurements, not the probability theory of samples. The distinction between these two concepts is not always clear in the textbooks when the complicated formulas for estimates from samples are given instead of the simpler formulas for the statistics of populations.

3.10 Discussion of a controversial topic: Nuclear power from thorium instead of uranium

The students are given information comparing the economic, environmental, and safety issues associated with uranium and thorium nuclear reactors for generating electrical power. The data suggest that thorium is better than uranium, so should thorium be used instead of uranium in the future? The students are asked to write a report on this question and say what they believe the answer should be. The objective of this exercise is to get students to present a properly reasoned argument and arrive at an informed conclusion from the facts rather than from a biased opinion.

3.11 Dynamic systems models: Deterministic systems, chaos

Much modern research, including some of the research done in our graduate school, is done by the computer modelling of dynamical systems. The models use finite difference approximations to differential equations. The objective of these exercises is to let the students see how these models perform by doing simple model calculations themselves. The examples given are: (a) the flow of water into and out of linked storage tanks, which is a prototype for hydrology models of rainfall and water supply, (b) the advection of air, which is a prototype for numerical weather prediction, and (c) the Verhulst population model for the seasonal reproduction of biological populations under a limited food supply. The students are asked to investigate how a bad choice of the time step in the advection model can produce falsely damped results or a system crash due to digital overflow, and how different parameters in the Verhulst model can represent a stable population, or chaos and the extinction of the population. The students are also shown how the movements in a completely deterministic system, such as three bodies moving under gravity, can be chaotic and unpredictable.

3.12 Home experiment: Determination of the acceleration of gravity

The method used is timing the swings of a pendulum. Some students think that the acceleration of gravity is exactly 9.81 m/s^2, as quoted in the textbooks, and they do not know that this is an approximate average at sea level over the surface of the Earth. The acceleration of gravity in Bangkok is 9.783 m/s^2, and this is the value they should find if they do the experiment carefully. As in their first home experiment, the students estimate the uncertainties in their measurements and compare their result with the value in Bangkok.

3.13 Short presentation: Good and bad practice in research

This is similar to the first three-minute presentation with six slides given by the students before the mid-term exam. But now, having studied research ethics and how research should be done, the students are asked to tell the class about one of their own experiences where a good result was obtained, or where something went wrong and how the problem was solved.

I tell the students examples from my own experience. As an undergraduate studying physics I treated all the experiments in the teaching laboratory as mini research projects. My careful measurements of a molecular band spectrum found that the expected results written in the instruction book of the laboratory were wrong and had to be corrected. Also I invented, with the help of my mathematics tutor, a new way of analyzing measurements of a system of contact potentials between different metals. Later, using a high vacuum apparatus in low temperature experiments for my doctor degree, I forgot to let air into the apparatus when closing it down for the night. The next morning the apparatus was full of oil which had been sucked up from the vacuum pump! Much time was wasted opening the apparatus for cleaning and putting it together again. My professor said,"Everybody forgets to let the air in once, but only a fool forgets twice."

3.14 Final examination

This exam is similar to the mid-term exam. It is based mainly on the exercises undertaken during the second part of the course, but it also requires the students to use skills practised in the first part of the course.

4. Grading of the Examinations

The written papers of the students in the two examinations are graded with numerical marks for each question based on the criteria shown below. These marks are averaged to obtain an overall grade for the paper.

A (4 marks)

Fully acceptable as a research quality answer.

B (3 marks)

Acceptable, but has omissions and/or defects.

C (2 marks)

Incomplete or weak, but shows potential for research.

D (1 mark)

Unacceptable; does not show potential for research.

F (0)

No answer, or a completely wrong answer.

The credit given for the mid-term exam is 30% of the total course grade. The credit given for the final exam is 60% of the total course grade; this is double the credit for the mid-term exam on the assumption that the students will have improved their skills by the end of the course. (As mentioned earlier, the remaining 10% of the course grade is for the homework exercises.)

The marked mid-term exam scripts are handed back to the students with comments telling them how they were graded and how they can improve their answers in the final exam. Students can challenge their mid-term grade, and it is possible for the mid-term grade to be changed if the challenge is justified, but this is exceptional. The final exam scripts are not handed back to the students.

5. The Students and their Difficulties

The students in the Joint Graduate School come from a wide variety of different backgrounds and fields (science, engineering, biology, environmental management, etc.). They are mostly from Thailand and Asia, but we sometimes have students from Africa, Europe, and North America. This means that there is a wide spectrum of abilities among the students, not only in mathematics and science but also in the English language.

Typically there are about twenty students in the class each semester. It is not therefore possible to give intensive individual coaching to students. However, I can discuss selected examples of the homework in the classroom, showing the class what pieces of work are good and what must be corrected.

A few of the students are practically native speakers and writers of English, but working in English is hard for students whose prior experience with the language is limited and whose native language has a structure different from that of English.

Another difficulty for most students is that they do not know the standard needed in internationally acceptable professional research. There is a quantum jump between this standard and what they have hitherto done in high school and undergraduate courses. Often their mindset is that of school children doing homework just 'to please Teacher' instead of developing a mature professional style based on a deep understanding of the task in hand. They do not see the need to be careful in their work. For example, instead of submitting a properly finished thesis for their Defence Examination some students submit a hastily written draft containing many easily avoidable mistakes.

The only way to overcome these difficulties is through coaching by the thesis adviser. There is no short cut to bypass the time that this requires. At the graduate research level the relation between student and adviser is most important so that the experience and insight of the adviser can be handed down to the next generation of researchers in a person-to-person manner [4].

When I was an advanced student doing research I was coached by my professor in writing a professional paper. My first drafts were immature and the paper had to be rewritten many times. This coaching lasted many hours over several weeks. At last the professor said, "Now it is an excellent paper and we can send it to the journal for publication." The journal accepted it without asking for any revisions.

6. Concluding Remarks

Throughout the life of the Joint Graduate School it has always been held that this Research Methodology course is important. Accordingly, it has always been compulsory for all students. Although some of the students are more experienced than others (because the class contains students for the master degree and the doctor degree together) this does not matter. All students, whatever their level, benefit from the practice they get by doing the set work to the best of their ability. One cannot say "This student can do research," or "This student cannot do research." Research is an art which, like all the arts, is improved by lifelong practice.

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References

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