Designing and Redesigning the Curriculum to Provide an Integrated and Challenging Program for Undergraduate Students in Earth Sciences

with comparisons between Nanjing University and The University of Sydney

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Introduction

While earth science is a typical discipline in science, earth science teaching more often resembles the procedures used for training engineers. One of the most important elements concerning the quality of science education is the design and implementation of the curriculum and training program. Unfortunately, despite many recent modifications the training program and courses taught at the Department of Earth Sciences at Nanjing University still require modification to bring them 'into line' with current western practice. This requirement arises from both the rapidly developing nature of earth science and historical factors. Undergraduate students in China also have the sometimes difficult task of mastering the English language. To achieve this they have to spend 6 hours or more in English classes every week. We therefore need to revise and update our training program with the two requirements that we place on our students in mind.

The comparison of teaching practice in China and the west given in this paper is mostly based on observations of the teaching practice and assessment system used by staff in the School of Geosciences at The University of Sydney (USyd). Comparisons between curricula are based on course descriptions placed on the websites of the University of Western Australia (UWA), the Australian National University (ANU), and the University of Tasmania (UTas). In general the Australian curricula are more integrative and it is apparent that they use a greater variety of teaching techniques than common in China. These Australian curricula have been used to design a new integrative program for the efficient training in earth science at Nanjing. To a large degree, the program proposed in this paper is just an initial blueprint, which will need to be modified, revised and improved over time according to its success.

The Status Quo

Current programs

The division of scientific disciplines is done quite differently in China in comparison to western countries and accordingly our curriculum is also designed differently. According to the subject catalogue promulgated by the Academic Degrees Committee of the State Council of China in 1997, earth sciences is a subject of second grade in science that has five sub-disciplines, these are: geochemistry; structural geology; Quaternary geology; paleontology and stratigraphy; and mineralogy, petrology and economic geology. In practice however, while the earth sciences curriculum has broadened at Nanjing and throughout China more generally, it is still relatively narrower in China than those in western countries.

Individual courses are designed by their teachers in isolation of the whole curriculum which often leads to the repetition of some content and concepts. Currently at Nanjing, geology students are required to complete 13 compulsory geological courses in four years (Table 1); there are another 34 courses available for their selection. In addition to all the geology courses and English they must take, our students must also complete 8 other compulsory courses including physics, mathematics, chemistry, computer science and biology. Consequently the burden on the students is very heavy, and to some extent the quality of their learning must be detrimentally affected by the amount of material they must take in order to complete their degrees.

The earth science curricula of several Australian universities are listed in Table 1. It is clear that they are quite different from one institution to another. The curricula at The University of Sydney and the University of Tasmania, which present fewer

Items	Nanjing University	The University of Sydney	University of Western Australia	University of Tasmania
First year	Introduction to earth sciences(*) Crystallography (*) Mineralogy(*)	Earth and its environment Earth processes and resources	Understanding planet earth Or '**our dynamic planet**' and '**inside planet Earth**'	Geology1 Or '**understanding Earth systems**' and '**earth resource, environment and evolution**'
Second year	Structure geology(*) Optical crystallography and Igneous petrology(*) Metamorphism petrology(*) Sedimentary petrology(*) Paleontology(*) History geology Introduction in hydrogeology (*) Geodatabase(*)	Plate tectonics and material Resource exploration Fossil and time Environmental geology and global climate change Environmental geology	Stratigraphic analysis (*) Mineralogy and igneous petrology (*) Sedimentary geology and geophysics(*) Structural geology and geomechanics(*) Overprinted rock and fluid geochemistry(*) Geofluid and geophysics(*) Sedimentary environments and processes Marine and environmental geology Remote sensing and applied image analysis Engineering geology	Geology2 (*) Fossil and environments through time (*) Introduction to geophysics and computer application Geology for mining engineers
Third year	Plate tectonics(*) Introduction to geophysics(*) Economic geology(*) Geochemistry(*) Environmental geology(*) Isotope geology Modern analytical instruments (*) Biogeochemistry Fluid geochemistry Organic geochemistry Geographic information system Gemology	Crustal growth and recycling Earth's evolution and energy Ore deposit geology and structural mapping Sedimentary processes Dynamics of ocean and margins Geophysical exploration	**Geological mapping (*) and 4 courses from below:** Petrology of igneous and overprinted rocks Physical hydrogeology Geochemistry Chemical hydrogeology Biogenic sediment analysis and applied micropaleontology Mineral and material microanalysis and imaging Introduction to ore deposits Structure geology and tectonics Marine and petroleum geophysics Ore genesis Mineral exploration geophysics Geophysics Geology Petroleum geology Mineral resource	**Geology 3 and 3 courses from below:** Computer in geoscience Ore deposit geology Sedimentary environment Exploration geophysics Ore deposit geochemistry Environmental geology Geology for geophysicists Geology for environmental science
Fourth year	Petroleum geology Geodynamics in China Remote sensing geology Environmental mineralogy Degree thesis(*)	Honours year		Advanced geology or Geology 4 One course selected from below: Geophysics 4 Geochemistry 4 Economic geology 4
Excursion	Geological observation survey(*) Geological mapping(*)		Geological fieldwork 72hr in second year	

(* compulsory course)

Table 1. The geology curriculum of different universities

courses than NJU and the University of Western Australia, are relatively integrated – they cover material drawn from a range of earth science disciplines and subdisciplines. Courses in China remain bounded by the traditional disciplinary or sub-disciplinary borders and are mostly devoid of interdisciplinary content – this is even evident in their names. The case of the University of Western Australia seems to be somewhat special because it retains a large teaching and research staff. This institution has good industry and government support which helps it maintain its student numbers. This may be because many of their graduates will find work in mining or resource exploration in the state of Western Australia which form a substantial part of the economy there. Consequently, the more traditional earth science curriculum works well there and reform of it seems relatively slow in comparison to other Australian campuses. But in other universities the training programs have to be modified to meet the changed nature of earth sciences.

Reflections from interviews with students

Many students don't like taking earth sciences in NJU because of the lack of job opportunities and the course design. Students tend to be enrolled in the degree because it is the one they qualified for rather than because they want to be there. Many take and persist with a degree in earth sciences because it entitles them to post-school English language instruction. Some comments recorded in interviews with students are listed below.

- *'Geology is Boring. I have to remember many facts and definitions, classification schemes about mineral properties, rocks and ore deposits. The knowledge we must learn about earth sciences is so scattered although the real geological environment is so engaging. I was bored in my second year and became tired of all the required rote memory stuff. I can remember all this useless information which can be easily found in reference books.'*
- *'I am a third-year student. I don't think I will find a job in the future although earth sciences is an interesting subject. I can identify many rocks and minerals. I am good at field survey and geological mapping. But I don't have any idea at all about what my career will be because the job opportunities get less and less. And I don't see myself wanting to work and live in the countryside in any time soon. At the same time I find that I am not trained to do any other job. I can't see know what I have learned can be used for anything else...'*
- *'I don't like earth sciences at all. I am fond of information technology. But unfortunately my High School Exam score was too low to enter my favourite discipline. I was allowed entry into the Department of Earth Science. Otherwise I had no chance of getting into NJU. I will change my major after graduation.'*
- *'Excursions are very interesting and we can study in groups. But the classwork is so boring. The teachers just give us lectures and too much homework. I study earth sciences passively.'*

But student responses at The University of Sydney are quite different. Most of the students like geology and want to learn more from the courses:

- *'I think geology is an attractive subject. They teach us lots of interesting knowledge about evolution of life and the planet. I will keep doing geology because I like it.'*
- *'Excursions are exciting. I can find many beautiful samples, such as fossils, crystals as well as viewing our grand landscape. It is fantastic to experience a geological trip.'*

An Honours student said:

- *'I think geology is an interesting discipline. I decided to enroll in the school of geoscience when I entered USyd. I thought to myself "If I find it boring, I will change my major." I'm not too worried about my job prospects – something suitable will turn up.'*

The statements given by the students interviewed in Nanjing suggest that in many cases low initial motivation and the way the students are taught causes them to become averse to earth sciences. The fact that these students have not developed a scientific schema or overarching view of earth sciences after two or three years learning also causes them to be unhappy with their degree. This is probably because they perceive the earth sciences to be just a collection of many bits of boring knowledge, which is a typical misconception of earth sciences throughout China. So it is clear that there must be something wrong with the program of courses and course delivery. In addition, the students should acquire a variety of transferable skills during their three-year training, including an ability to learn, communicate, collaborate in a group, and solve problems. All of which would help them to be engaged in different jobs after they graduate.

Problems with the curriculum at Nanjing

The current program of courses and the delivery of courses as well as the assessment system in NJU should be modified and reformed. Based on a comparison with the curricula of some of the Australian Universities the following points should be considered and used to guide this process.

Current Deficiencies:

a) Too many required courses.
b) Too much overlap between different courses, which leads to repetition. For example, the genesis of granite is taught in igneous petrology, geochemistry, metamorphic petrology, plate tectonics, and isotope geology.
c) Too many lectures and too little practical work in the courses. Generally, there is much less than one hour of practical work for each hour of lectures. Nearly one-third of all our courses are just delivered by lectures without any practical work.
d) The arrangement of content tends to be very boring because there is too much description, classification, facts (and/or unrelated facts) packed into the lectures. Students can only deal with this material by rote learning and committing it to memory.
e) Classroom teaching styles are not diverse but need to become so. All our courses are taught in the same way – there is no variety. Lectures, lectures, lectures. The students have no alternative but to become passive learners. We do not challenge them.
f) The current assessment system is not challenging or all that effective. Traditionally, teachers at Nanjing emphasize end-of-semester examinations to simply assess and rank the students. There is no formative assessment that will help the students to learn the material given to them. The examinations tend to be unsophisticated and reward the simple recollection of facts or the reproduction of remembered knowledge. Examination papers are poorly designed with little intellectual difficulty. Students are only rarely expected to solve problems. Consequently, students often 'cram' for the examination (in less than a week), perform 'successfully' and them forget most of the knowledge as soon as they have completed the examination.

The improvement of the quality of education in earth sciences in NJU requires profound reform in every one of the above areas, as well as in: program arrangement, timetabling, and introduction of computers and IT into the classroom. Curriculum design seems to be at the root of the problem here. An integrated and challenging program should be formulated that is achievable in the teaching time available. This will provide the mechanism that will enable our teachers to develop their teaching strategies. By saving time in an appropriate way then we can require students to do the practical work that will enable them to acquire useful skills and abilities.

Designing an integrative and challenging curriculum

Guidelines

We must be guided by our decisions about what we need to know and learn about the earth in the rearrangement of curriculum. It is necessary to clarify what the earth sciences studies before the design of curriculum.

As the conception of the earth system and theory of plate tectonics were proposed and accepted worldwide in the 20th century, the earth science gets more integrated than any time in its history. As indicated from Figure 1, the content in earth science could be divided into three parts: earth materials and dynamics; earth history; and methods for studies on the earth.

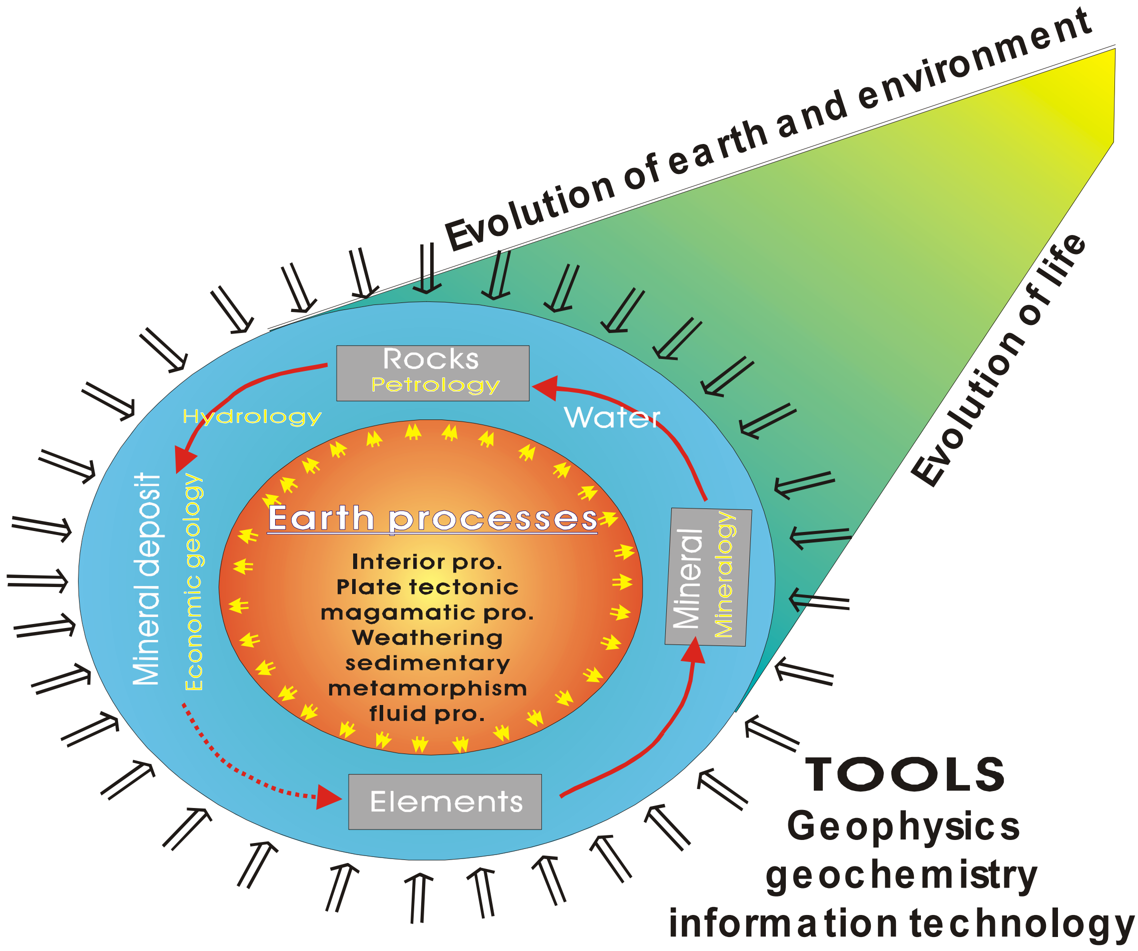

Figure 1. The main components studied in earth sciences

The earth originated from the nebulae of primary solar system and evolved into a gigantic planet composed of more than 100 elements, present as rocks and minerals, geofluids, atmosphere, and a large partition called mantle and core whose phases remain unclear. All the material is moving and recycling driven by the solar energy input from the space and the radioactivity energy produced in the inner earth. The shape and the environment of the earth changed inconceivably in the history of 4.6 billion years as the geological processes occurred. Life came into being, and the climate, distribution of land and ocean experienced a long history full of variation and geological events. The diversity of life is the product of the interaction between the organic system and the changing environment and many ore deposits and reservoirs of fossil fuel formed in the earth history. Aim at the exploration of natural resources and acclimatization of activities of human with the environment; earth sciences should employ many techniques to study the dynamics of the earth and the evolution of the earth materials.

A proposed integrated curriculum for Earth Sciences at Nanjing

The modern conception of earth system science as presented in many modern western textbooks has been used as a guide to design the integrated and challenging 4-year (8-semester) curriculum for undergraduate students given in Table 2. Courses are divided into three types: introduction courses, core courses and integrated courses. Not all of the core courses are compulsory courses, but it is envisioned that at least five of these core courses must be selected by students. Every course proposed should contain content taken from a wide scope of the earth sciences which should also cross the disciplinary borders. This will help the students build an integrated schema of the whole field.

Type of course	Courses	
Introduction course	Earth system	1st semester
Core course(1): earth occurrence	Earth material Structure and tectonics Earth processes Hydrology and water resource Evolution of earth and life	2nd semester 4th semester 3rd semester 5th semester 4th semester
Core course(2): methods	Geochemistry Geophysics Geoinformatics and geomodelling	5th semester 6th semester 6th semester
Integrative course	Evolution of Earth system and environmental response Bachelor thesis	7th semester 8th semester

Table 2. Integrated curriculum for undergraduate students in earth sciences

In addition to these courses students need to go on excursions because these activate students' interest in earth sciences, and advance their understanding of the material present in class as well as create opportunities for groupwork and problem solving. Both the interviews with the students from NJU and The University of Sydney reveal that students have the same, positive attitudes to fieldwork. These should take the form of one-day excursion integrated with practical classes and a three-week fieldwork trip in the semester breaks of second and third year. They are therefore designed into the curriculum: each of the long-term excursions will include the tasks of observing and describing geological phenomena along with extensive experience of geological mapping.

Redesigning the curriculum and its delivery

The role of university education is not only the transfer of knowledge from the older generation to the younger generation. The development of skills and abilities in students is much more important. So the reform of curriculum should help students to acquire a variety of skills and abilities rather than just the construction of a schema for the earth sciences. It is not possible to achieve this simply with curriculum reform, it will also be necessary to modify the way we deliver our courses and change our approach in assessing them.

Redesigning course content

Based on the interviews with students, the course content is unsatisfactory because it contains too much scattered information about the classification and description of minerals and rocks. Course content should be optimized and be integrated in a reasonable framework, which enhances the ability of students to build an open schema for the course. The framework should allow this knowledge to be updated easily because earth science develops continually. Each course should present the basic theories and laboratory methods in a way that helps students understand them.

Some possible actions that would allow this aim to be achieved are: reducing the amount of lecture-based or theoretical description and classification; increasing the time spent on practical classes; focusing on the explanation of some key concepts and theories rather than focusing on the detail; and providing appropriate case studies to help comprehension. Of course, a teaching committee should be organized to consult with the teachers about the arrangement of course content and assist them with the practicalities of these reforms.

Changing course delivery

Because people learn in different ways and the various parts of course content are more suited to different teaching strategies, a variety of appropriate strategies should be employed in course delivery. One important aim of higher education is to train students to be able to research and analyze. Students need the abilities of problem solving, information searching and evaluation, analysis of complex systems, summarizing and construction of knowledge, teamwork, communication, and questioning; therefore they should be trained in these areas as part of the practical application of the new curriculum.

First of all, we need to make a transition from teacher-centred teaching to student-centred learning as a matter of some urgency to enable this change. Greater teacher/student interaction and student/student interaction needs to be promoted. Practical work should be made an important component of a course because it is an ideal way to enable student-centred learning – especially if the practical tasks are well designed and easy to practice. Different teaching techniques should be employed according to the nature of the material taught. Some possible task-strategy pairs are listed in Table 3.

As this discussion of teaching strategies indicates, new courses in the integrated curriculum program could be delivered using a mixture of strategies. Lectures and practical work are suitable for introduction courses, and case study and group learning will work well in the integrative courses. The delivery of core courses can employ many various strategies, such as case studies, problem based learning (PBL), inquiry based learning (IBL), laboratory-aided learning, computer aided learning (CAL), group learning with tutoring, rather than the traditional lectures and practical work that currently dominate the teaching practice at Nanjing.

In respect of changing teaching strategies, appropriate learning environments must be provided to enable the desired ability or skill to be developed. Hence students will use the library, laboratory and the Internet more frequently.

Task of learning and teaching	Strategy of delivery of course
Theory and conception	Lectures
Methods	Practical class
Geo-space concepts	Excursion
Research techniques	Case study
Problem solving ability	Problem based learning (PBL), inquiry based learning (IBL)
Communication ability	Mini presentation
Information analysis and summarizing ability	Review composing on given topic, computer aided learning (CAL)
Teamwork ability	Group learning
Schema development	Concept mapping
Experimental technique	Laboratory aided learning

Table 3. Possible task-strategy pairs

This will require the university to improve the efficiency and use of these resources as well as improve their availability to meet the inevitable increasing demand for them.

Challenging views about assessment

There is some evidence that the choice of inadequate assessment methods make surface-learning approaches more likely although it has not so far been demonstrated that appropriate assessment methods can, in isolation, encourage deep learning. As the interviews above indicated, some students often ‘cram’ for the examination (in less than a week) and forget most of the knowledge as soon as they have completed the examination. In this case the style of assessment is a key factor in determining the quality of learning (a shallow fact-requiring question leads to a shallow fact-recording and fact-returning learning style).

We need to decide what it is that we want our students to be able to do in order for us to be able to assess them properly. Undoubtedly the capacity of someone’s memory is a useful thing but it is not of itself going to make them a good scientist. Why then do we make it such an important aspect of their assessment? The students are correct rote memory is not really a worthy thing to be rewarded, because anyone who can read can quickly find the information in a reference book or on the web easily. It is the quality of the schema in their mind and knowledge of how the basic theories, facts and methods relate to one another that is important. The application of knowledge enables problem solving. And the abilities of problem solving, communication and teamwork are what really count when you work in research or as a scientist.

Therefore the assessment system’s current emphasis on the recall of facts should be reduced and more challenging and interesting examination papers requiring problem solving should be used. As different assessment methods assess different aspects of learning, multiple styles of assessment can be employed in the future to help students acquire a more comprehensive range of skills. At the same time, increasing the frequency of assessments (continuous assessment and formative assessment) will be useful to help students learn from feedback.

Based on the consideration above, a diverse range of assessment methods should be used during the delivery of courses, including: open-book examination + closed-book examination; review-reports + presentation; (group) case study + (collaborative) report; laboratory-based tests; little quizzes before or after lectures; self evaluation; concept mapping; peer assessment; and so on. Among all the methods peer assessment and self assessment are valuable methods which help students to evaluate the outcome of their partners. This will promote teamwork.

Challenge and prospect

This paper is intended to just offer a proposal of ideal curriculum for undergraduate students in earth sciences. In practice it would be hard to achieve in a short period of time. Several important problems stand in its way. Currently our present systems of university administration are not flexible enough to accommodate such change, for instance it is not possible for students to change majors. The infrastructure required for practical classes will require considerable public investment. This will not change quickly. Other problems inherent in the proposed curriculum change are listed below:

- How much content is too much content in a course?
- Where is the balance point between the time that should be spent in lectures and in practical work?
- How do we switch the role of teacher from teacher-centred to student-centred program? And when is this appropriate?
- How do we make earth sciences more attractive and provide more job opportunities?

Perhaps it is not possible to find answers for these questions before reform is attempted. They will present sizable problems for all the teachers and governors who are in charge of learning and teaching. The answers will probably be discovered during the reform process and after deep consideration, and so, a sound curriculum will be established after a series of little changes – step-by-step, step-by-step.

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