SCIENCE EDUCATION IN THE 21ST CENTURY

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Outline of this talk

- My view on the goals of university education
- What are the problems of current science education
- What have we done to achieve these goals
- Reactions from students, staff, and others
- Other movements elsewhere in the world

What is a university?

- University is *not* a trade school. The goal of a university is not to provide vocational training.
- The goal of a university is to develop the student as a person, to prepare him/her how to think and for life-long self learning and self improvement

Mismatch with student expectations

- Many of our students have worked hard to get to university. But very few have thought about why are they are here
- Most regard universities will provide them a meal ticket for a better job
- University is *not* a diploma mill. Students are here not to just to get a degree or a certificate, but to learn and be educated.

Talking to alumni

- While almost all alumni are very proud of being graduates of HKU and have made many valuable professional connections with other HKU alumni,
- many said that they found little use of the things they learned at HKU, some even admitted that they have forgotten everything that they ever learned in university
- This confirms the preconception of the students that universities are nothing more than a diploma mill, giving them a piece of paper but not relevant knowledge.

Does it have to be this way?

Things are better in US universities, but the best courses students find useful are often not in their majors

Problems of science education in schools

- Science education at all levels of schooling is seen as abstract and irrelevant to real life
- Students fail to see that science is all around us and the scientific method is widely applicable
- Students can calculate very fast and very accurately, but they have no idea what mathematics is for. To them, it is just an academic exercise.
- Science subjects are segregated and seen as unrelated
- Other well-known ills: memorization, rote-learning, keyword marking
- Schooling is just a game to be won

What are the essentials?

- Rapid technological change and artificial intelligence are making certain occupations obsolete
- Fundamentals will stay with students
- Language skills, comprehension, expression, communication
- Quantitative skills to analyze, see hidden patterns, identify variables, formulate solutions

Reform at HKU

- HKU has changed a lot in the last 10 years, and hopefully will change even more in the future
- A community of *scholars*, for the creation and sharing of knowledge
- An *international* institution with a diverse teaching staff

Curriculum reform

- HKU used to have a very British system, where students received a narrow, specialized education
- The US has a liberal education philosophy centered around a designated major, distribution requirements, and electives
- Canada also inherited the British system, but went through reforms in the 1970s to created a hybrid of US and British curriculum
- Our goal: a broader education with more flexibility in the curriculum
- We have learned from the North American system, but try to go further

Training in science

- Mastery of the scientific method and techniques of quantitative logic
- Mastery the method of solving problems through learning of previous work
- Free, bold, independent, and creative thinking
- Ability to make rational judgment, rise above ignorance and prejudice

Quality of a scientist

- Curious, always asking questions
- Suspicion of authority, non-conformity
- Creative thinking
- Perseverance (nothing worthwhile is easy)

A student educated in science should be

- Knowledgeable (be aware of the state of nature and how it works)
- Able to think analytically (and quantitatively)
- Open minded
- Creative
- Independent (from conformity and public opinion)
- Versatile (can take on any job or vocation)

Rationale for reform

- Most science curricula are designed to train students as next generation of academics. But in fact only a small fraction of our graduates go onto Ph.D.s and become professors.
- Many of our students become leaders in government and private sectors. Our science training should help them to fulfill these roles.
- To train students as people of intellect, not as a trainees to a vocation
- To lay the ground work for life long learning (encouragement of curiosity, development of rational thinking)

Reform objectives

- To prepare students as holistic individuals who can think analytically, able to solve a diverse set of problems, and to communicate the results
- To provide opportunities for students to take advantage of our community of scholars
- To expose students to a diverse academic environment (teachers and fellow students from all parts of the world)
- To provide a broad experience, not just in one specialized science subjects, but in all sciences

How to achieve these goals?

Curriculum Reforms

- 2006: credit-based major/minor system, away from the highly specialized program format
- 2007: faculty common admission, students free to choose any of the 15 majors after admission
- 2007: compulsory experiential learning
- 2007: student advisory system
- 2008: academic induction
- 2010: Common Core courses
- 2012: 4-yr curriculum and Science Foundation courses
- 2012: service courses to engineering and medicine
- 2015: honours seminar and Big History elective course

Freedom to choose

- Students do not need to declare their majors until after completing two years
- They have a chance to learn about each major, some are unfamiliar to them (e.g., earth science) and some have an misunderstanding (e.g., mathematics)
- Previously each program (often associated with a department) was given a quota, and they admitted students until the quota was full. There was no incentive to make efforts to recruit the best students
- Now all majors have to compete for students, leading to a huge change in teachers' mentality and increase in efforts (reaching out to schools, orientation day)

Result: JUPAS score improved incredibly

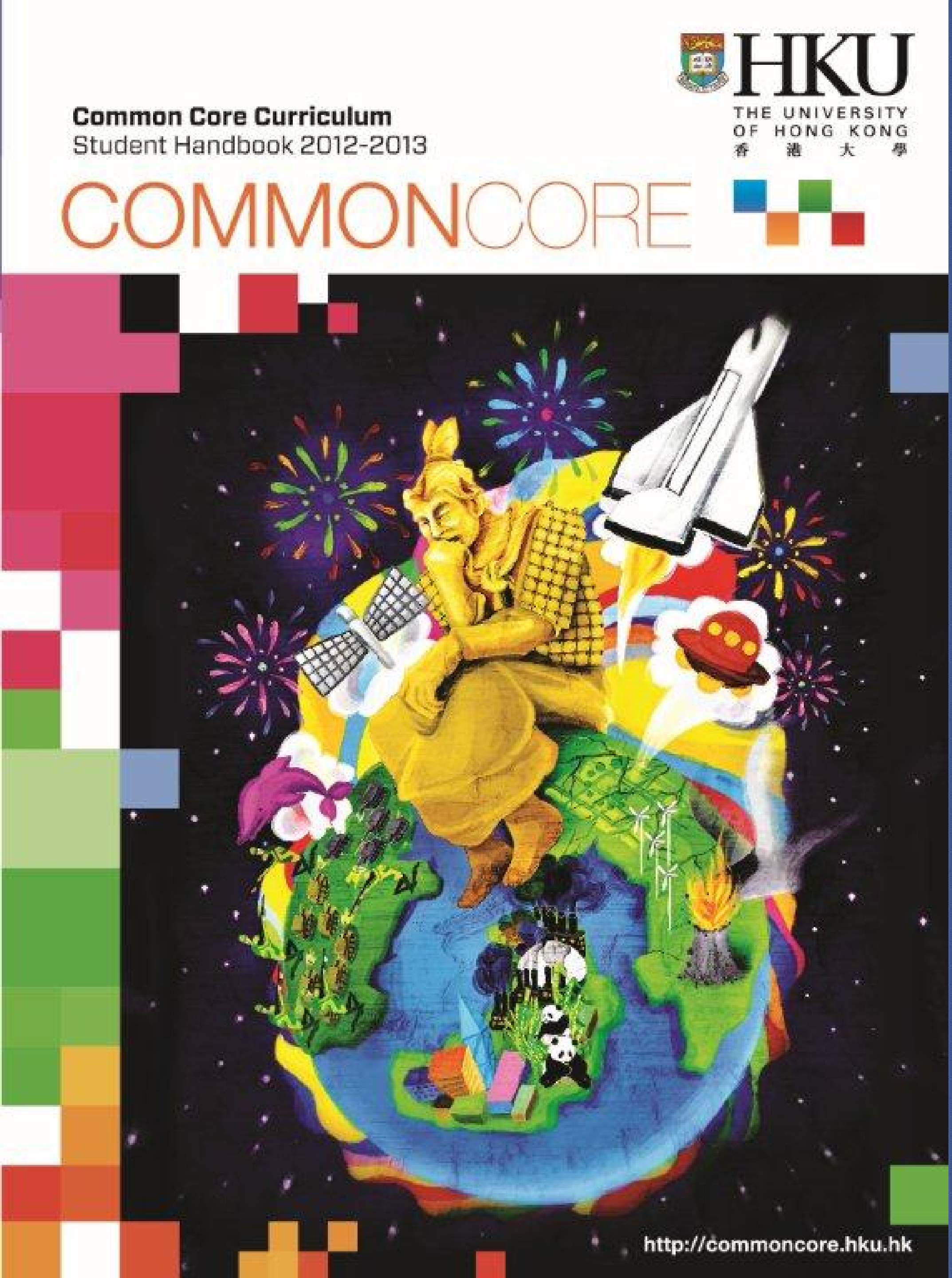
Student benefit from a broader experience

- Previously a student in biochemistry only took courses from biochemistry and a biochemistry teacher only teaches students in biochemistry
- Now students can take courses from any department and some teachers are finding themselves to be teaching students of other departments of faculties.

Curriculum reforms

- University Common Core curriculum
  - Science and technological literacy, humanities, global issues, China: culture, state and society
- Academic advising
  - a new academic advising system to provide academic support and advice to students to face the increased choices in the new major-minor system.
- Experiential learning
  - a compulsory element in our BSc curriculum
  - A variety of learning programs such as exchange, field trips, internships, or undergraduate projects, is made available to students to help them expand their horizon, enhance their communication skills and cultural understanding.

Both now adopted by University



- Non-discipline based
- To develop broader perspectives
- Critical assessment of complex issues
- Appreciation of our own culture
- Member of global community

- *Specifically designed new courses, not introductory disciplinary courses*
- *Not "great books" model*

http://commoncore.hku.hk/

An example of a Common Core course

- Changing perceptions of our place in the universe as the result of astronomical development. Illustration of the development of the scientific method and how science has influenced the evolution of our philosophical thinking and cultural development;
- Ancient models of the universe and the early philosophical and religious interpretation of celestial objects;
- The development of concepts of time and calendars through the observation of solar, lunar, and planetary motions;
- The Copernican revolution and the change from geocentric to heliocentric cosmology and from a bounded to an infinite universe;
- The application of scientific method and a physical interpretation of the universe through the work of Kepler, Galileo and Newton;
- The expansion of the spatial scale of the universe as the result of modern astronomical observations;
- Expansion of the time domain in cosmic history through the study of the history of the Earth, biological evolution, and cosmic evolution

The approach

- The course uses the historical development of astronomy to illustrate the process of rational reasoning and its effect on philosophy, religion, and society.
- Because celestial objects followed regular patterns, astronomical observations gave humans some of the first hints that Nature was understandable. The complicated nature of these patterns also challenged our intellectual powers.

How it is different

- In our education system, science is often presented to our students as a series of **facts**. In fact, science is about the **process** of rational thinking and creativity.
- What we consider to be the truth is constantly evolving and has certainly changed greatly over the history of humankind.
- The essence of science is not so much about the current view of our world, but how we changed from one set of views to another. This course is not about the outcome but the process.

- I begin with a description of basic observations, summarize the patterns observed and the problems they pose, and discuss the suggested theories and their implications. The pros and cons of these theories are evaluated alongside alternate theories.
- This approach differs from typical science textbooks, which usually take an axiomatic approach by first stating the correct theory and deriving the deductions before comparing them with experimental results.
- I hope this historical approach allows students to better understand the scientific process and learn from this process when they tackle real-life problems in their careers.

Train to think

- Students ask whether they will be handicapped without previous training in physics or astronomy
- In fact, science and engineering students have the most difficulty because they were told all the modern notions but have never learned how we arrived at those conclusions

Example: "how do we know that the Earth evolves around the sun?" No student could answer this question other than "this is what I was told by my teacher".

If science education is supposed to promote an enquiry mind, what we have been doing is exactly the opposite

- Science teaching has been authoritative, beginning with the correct model and derive all its consequences
- Students get the mistaken idea that truth is easy to arrive at and self evident

Does the earth revolve around the sun?

- The apparent motions of the Sun, the Moon, stars and planets are regular but complicated
- The geocentric model was extremely successful in explaining and predicting these motions
- Copernicus' model was more complex, not more accurate, and was contrary to physical evidence and common sense
- The advantages of Copernicus' model is subtle and evidence came much later
- Answer to the above question is not easy, same for evolution and climate change

Train to observe and be aware

Modern people have many more tools at our disposal, but we are less aware of our surroundings than our ancestors

- Many students think the moon can only be seen at night, but in fact the moon is equally seen during the day and at night
- Many think that the Sun rises in the east, but in fact the Sun only rises in the east two days of the year. The position of sunrise changes everyday.
- Many students believe that we learned that the Earth was round a few hundred years ago, but in fact it was known over 2500 years ago.

If ancient people could do it, so can you

Goals of this course

- Not to teach astronomy (just to illustrate how humans developed rational thinking)
- Not to teach facts (just to illustrate that our world is complex)
- But to teach

It is not about the end results, but the process

- How to observe (to be curious, to be aware)
- How to think (logically, analytically)
- How to solve problems

Student comments

- the course has inspired me in my daily lives, not only in the aspect of astronomy knowledge, but also in the aspect of critical thinking and combination of science with philosophy and history.
- This course helps us to appreciate our own culture, and the interrelationship among cultures..
- As a social science student, studying the "philosophical shifts" in the course allows me to question more about how our society or social norms are created and formed to what it is today.
- This course has taught me to do something meaningful with my life.
- The course inspired me that different conclusions can be drawn from the same reality from different perspectives.

http://www.scifac.hku.hk/about/dean/column/ccst9012

Other examples of common core courses designed by science teachers

- Hidden order in daily life: a mathematical perspective (Patrick T.W. Ng)
- Simplifying complexity (Tim Wotherspoon)
- Mathematics: a cultural heritage (N.K. Tsing)
- Statistics and society (W.K. Li)

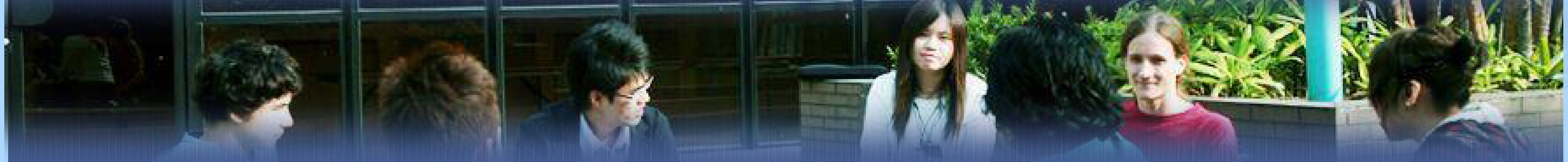
All designed to show that science/mathematics is all around us and are useful and relevant

Negative reactions

- Many students still think that universities are there to train them for a profession or a trade and do not see the relevance of the CC.
- Not accustomed to the methods of assessment beyond reproduction of facts
- "All my years of schooling, I was told to memorize, now you want me to think and I can't do it."
- In general, students don't like being required to take 6 CC courses.
- Unwillingness to read
- Some have the preconception that CC courses should be easier than disciplinary courses

Science foundation courses

- To give students a broad view of science in terms of its nature, its history, its fundamental concepts, its methodology, and its impact on civilization and society.
- Two new science foundation courses have been offered beginning in 2012 using an integrated science approach.
- compulsory for all first-year students
- A departure from their previous segregated way of learning science
- Help students to make a more intelligent decision on the selection of the major.



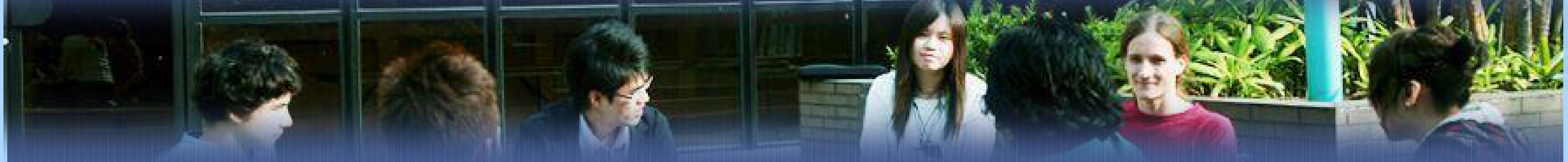
Science Foundation 1: Scientific Method and Reasoning

- The nature, history, methodology of science
- Equips students with basic skills of logical and quantitative reasoning
- Exploration of mathematics and statistics and their applications
- What is mathematics, what kinds of mathematics are there, and what can mathematics do for different disciplines of inquiry
- Emphasis on formulation of problems but not calculations

http://www.scifac.hku.hk/ug/prospective-student/foundation-courses

Examples of course content

- The scientific method: hypotheses and logical deduction, observation and experiments, inductive and deductive reasoning, criteria on "good" scientific theories
- Guesstimation
- Mathematical modelling
- Difference equations, matrices, differential equations, fractals and chaos
- Hypothesis testing and decision making using statistics, correlation and causation
- Regression, predictions



Student reactions

- "Many practical examples are used to illustrate the key concepts. The contents of teaching are well organized."
- "Different interesting mathematical topics are introduced to students."
- "Basic histories and developments of science including the methodology and different mathematical/statistical topics are introduced in the course that can give students a brief idea of the respective applications in their own science subjects."
- "Cover topics that are useful to my future studies."
- "Good examples to illustrate theories and applications."

Science Foundation 2: Fundamentals of Modern Science

- To provide students an overview of the web of knowledge that makes up science
- An integrated approach that encompasses physics, astronomy, earth sciences, chemistry and biology
- to introduce the general principles and unifying concepts to describe the diverse phenomena in the natural world.

Teaching and assessment techniques

- History of the subject
- Start with real life problems, not abstract concepts
- In exam, students are not asked to repeat tasks done in lectures but given new situations that they need to have mastered the taught materials to solve

Student comments

- "Very inspiring and can give detailed information about the topics taught. Very nice and lively lectures are given."
- "It covers a large variety of science topics and strengthens my fundamentals in science."
- "The best things about the course are the processes from the smallest to the greatest of the universe. Such a journey from small to big is amazing."
- "This course is fantastic! It tells me about all kinds of science knowledge, and it’s really interesting! More importantly, we learn a lot about the science method, and thus we can study science on our own later."
- "This course covers a lot of aspects in different field of science. I really appreciate that since this can make me aware of things which I have not pay attention on before. The stories of scientists are really interesting."
- "Lots of basic ideas about many disciplines. Know more about the interrelationship between disciplines."

Negative reactions

- A am a biologist, I don’t want to learn mathematics/I am a mathematician, I don’t want to learn biology
- I want to take more courses in my major biochemistry, everything else is a waste of time
- I am at a disadvantage because others have taken more math/physics/chemistry/biology than me.
- The stuff is too easy (students confuse having seen the technical term to understanding the concept. In school, they were given very hard problems, but did they learn anything?)
- Too much reading
- I don’t want to learn about evolution

Skeptics

- Hong Kong is already doing very well in PISA (programme for international student assessment) results (math #3, science #2, reading #2, in the world, 2012 results). Why change?

My response

- Students may do well in exams, but they don't know science and mathematics are relevant to their lives.
- Students lack common sense, many don't know why it is hot in the summer and many think the Earth is only a few thousands years old

Big history (science elective)

- Based on the course by David Christian and supported by Bill Gates

Students using handheld spectrometers (top), and testing the inverse-square law (bottom)

OTHER REFORMS

- Promotion of interdisciplinary studies
  - The new initiatives include inter-departmental teaching, research collaboration and joint appointments.
  - The curricula and courses in biological science are being significantly revised after the integration of the 3 separate departments into a single School.
  - A new major of environmental science was offered in 2008. This is a truly interdisciplinary major with courses jointly taught by members of 6 departments.
- Academic induction
  - introduced in the academic year 2008-2009

Undergraduate Research

- Undergraduate research symposium, summer research fellowship, overseas research fellowship

Swire Institute of Marine Science

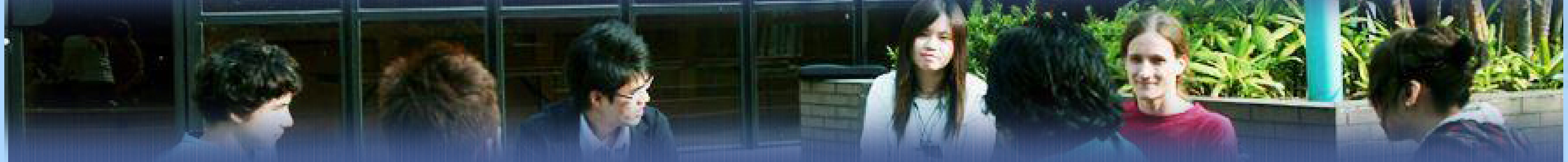
Honours seminar

- Lectures by "star professors" to describe the frontiers of science being carried out at the University
- To encourage students to engage in undergraduate research

EXPERIENTIAL LEARNING

- Student field trips to Australia, British Columbia, Brazil, Cyprus, India, Kenya, Thailand, Okinawa, Tibet, and U.S.

I personally led a field trip 5 years in a row

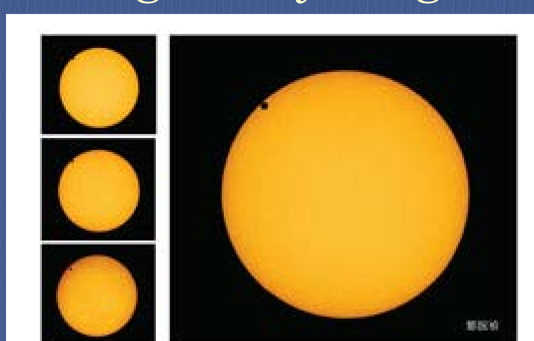


Knowledge exchange and community engagement

- The Faculty of Science maintains strong liaisons with secondary schools, our alumni, the science museums, and the general community. We regard our mandate on education goes beyond the university campus.
- Junior Science Institute
  - with hands on workshops and laboratory exercises for secondary school students
- *Science Corner on Astrobiology* in the Science Museum, which attracted 1.4 million visitors

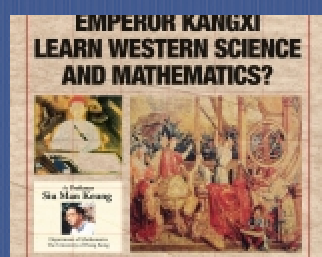
Knowledge exchange

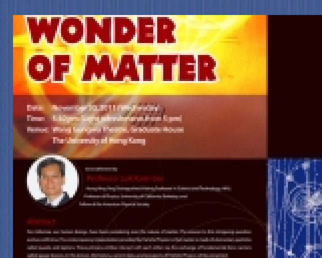
- A Night at the Museum
  - 600 students from 60 schools
- Public viewing of the Venus transit
  - June 5, 2012
  - Over 10,000 members of the general public
- Earth Hour 2013
  - Thousands participated in real-time measurements of night sky brightness



Promotion of science literacy

- Faculty Public Lecture series to introduce areas at the frontier of science in a format that is understandable by the general public
- This series is now in its 7th year and has been extremely popular among our undergraduate students, general public, as well as secondary school students.





Disciplinary major courses

- Much of the factual information (chemical formulae, chemical structures, chemical networks) of science can be found on the internet. Details on facts are less important than concepts.
- Computing devices are commonly used for all mathematical and statistical analysis, so mastery of techniques is no longer important and less time should be spent on drills.
- Are all the courses in our major requirements necessary?
- Focus on the fundamentals, not highly specialized
- Courses should be designed for the benefit of students, not for the convenience of the instructors

Graduate schools

- The program must have the flexibility to allow the most dedicated students to gain an in-depth knowledge of the major to have a successful career in graduate school
- These students will use their elective slots to select major courses and will not be able to do a double major, or major with a minor

Inter-disciplinary studies

- Many new areas of science are inter-disciplinary in nature and our curriculum must reflect this
- Examples: environmental science, astrobiology, global change
- Our traditional major structures need to be re-examined.

Education is not a popularity contest

Students' goals may not align with our educational objectives

- Students are not customers
- Driven by the misconception that they are here just to get a certificate, many try to do the minimum and demand the highest grade. Grade, not knowledge, is the primary goal.
- This impacts SETL (teacher evaluation). Junior colleagues are afraid of innovations and try to appease students
- SLEQ (student satisfaction survey) often find students' main satisfaction is in hall life, the personal connections that will help them later in life
- These surveys do not measure the effectiveness of learning

Dissenting opinions

Group 1:

- HKU already ranks very high in university rankings. Why change?
- So long we admit the best students, they will excel no matter what we do
- So long students make personal connections in the halls, they will have the networking to succeed in business

Group 2

- Graduates need to be useful "little screws" in the machinery. They don't need to know everything.
- Thinking makes trouble makers. Students should focus on their major subject

INTERNATIONAL COVERAGE

issues and events

Hong Kong's physics departments adapt to education overhaul

In September universities in the Chinese territory switched from three-year, English-style degree programs to four-year, US-style degree programs.

Less than 3% of Hong Kong's GDP comes from manufacturing. Finance, trade, and other knowledge-based service sectors make up the rest of the economy, which is among the world's wealthiest and healthiest. To keep its economy humming and its population employed, Hong Kong needs a smart, flexible workforce.

As the territory entered the 21st century, its government concluded that the education system it inherited from the British was too rigid, narrow, and elitist to produce such a workforce. After concentrating on one subject for three years, students graduated from university with a bachelor's degree but without being taught the knowledge and skills they might need to navigate the complexities of a modern, globalized society.

Starting this year, freshmen at Hong Kong's eight public universities will study a mix of majors, minors, and required courses—just like their counterparts in Australia, Canada, and the US. Mandated and funded by Hong Kong's government, the new degree structure aims to provide broader, more useful education. As the Chinese University of Hong Kong's undergraduate prospectus puts it, the new structure is "not just 'one more year,' but incorporates a change of emphasis, and a new way of viewing undergraduate education."

Because Hong Kong's high schools prepared students for specialized three-year degrees, reforming tertiary education also entailed reforming secondary education. Instead of leaving high school at 16 or spending the ages 16–18 studying a handful of subjects, students now spend the final three years of high school studying a broader mix of subjects. And they graduate at 17.

High schools made the switch to the new system in 2009. The first cohort of students educated under the new system entered university in September. Because the last cohort of students educated under the old system had to complete an extra year of school, the two cohorts entered university at the same time.

Besides coping with super-sized freshman classes, the six Hong Kong universities that have physics departments have also had to adapt to the new, four-year curriculum. The introductory classes that physics professors teach are now larger than before and have students of more diverse educational backgrounds.

With those challenges, however, have come benefits. The required courses expose more university students to science, including physics. Physics departments have hired or are hiring more faculty members. And, attracted by the new curricula, more foreign students are applying to attend Hong Kong's universities.

Common cores

The new, four-year curricula offered by Hong Kong's public universities conform to broad guidelines established by their funding agency, the University Grants Committee (UGC). Majors in applied physics at City University of Hong Kong, for example, must accumulate at least 120 credits to graduate. Like all other CityU students, those majoring in applied physics have to complete 30 credits of what the university calls gateway education, which includes courses in the English language, Chinese civilization, arts and humanities, sociology and business, and science and technology, along with electives.

CityU physics students may choose a minor in a subject, such as electrical engineering, that complements their major. And in addition to courses in basic physics, students take electives organized in four streams: nuclear environmental physics, photonics, materials physics, and biomedical physics and engineering. Final-year students are also required to work independently on a research project that could involve a local company or government agency.

The curricula at the five other physics universities follow a more or less similar template. Chinese University of Hong Kong's equivalent of CityU's gateway education, the general education foundation, includes an ambitious course called Dialogue with Humanity

The University of Hong Kong, like other universities in the territory, has embarked on ambitious building programs to accommodate the increased influx of students. The buildings in the foreground are part of the university's new Centennial Campus. (Courtesy of Sun Kwok, University of Hong Kong.)

Physics Today, Dec 2012

Global Research Universities

IT'S NOT A FLUKE THAT THE UNITED States is home to most of the leading research universities in the world. But it's also not a given.

Many countries have paid close attention to what it took for the United States to climb to the top of the global academic research ladder in the past half-century. Some have now translated those lessons into national strategies that they hope will lift them up the ladder. What will it take for them to reach the top rungs?

Over the next several months, *Science* will examine the key ingredients needed to create and maintain what we have labeled global research universities. Indeed, ranking these universities has become a cottage industry. Although there is little consensus on what metrics to use, most scientists carry around in their heads their own list of top schools, compiled on the basis of anecdotal evidence, reputation, and personal preferences.

The first story in the series explores the role of mobility by focusing on the increasing flow of talent into East Asia, in particular Hong Kong and Singapore. Subsequent stories will look at other important factors that shape an institution's ability to become a global research powerhouse.

More than bragging rights are at stake in this race to the top. A world-class university system is a powerful engine for economic development, and research is the fuel powering that engine.

Flocking to Asia For a Shot at Greatness

Academics from around the world are taking jobs in Hong Kong, Singapore, and elsewhere in East Asia, lured by generous budgets and a welcome sign for foreigners

HONG KONG AND SINGAPORE—Ambitious academics have always been a mobile lot. But Stephanie Wehner has taken mobility to a new level. And her career choices reflect a fundamental shift in where some of the best science is being done around the world.

The 35-year-old quantum information scientist completed her undergraduate degree in her native Germany, earned a master's degree from the University of Amsterdam and a Ph.D. from the Centrum Wiskunde & Informatica in Amsterdam, and did a postdoc at the California Institute of Technology (Caltech) in Pasadena. Then she asked herself: "Where would it be scientifically interesting for me to go?" The answer took her further west, across the international dateline, in fact, to the Centre for Quantum Technologies at the National University of Singapore (NUS).

Online
sciencemag.org
Podcast interview with author Dennis Normile (http://scim.ag/pod_6099).

The center, established in December 2007, is already recognized as one of the world's top institutes for quantum studies. "It is unique" in combining computer science and physics, theory, and experiments, says Wehner, who joined its ranks in July 2010. The institute's generous funding from the government—$126 million over 10 years—means there is money for postdocs and state-of-the-art equipment for experimentalists. It also allows Wehner to concentrate on her research without having to apply for grants. A reduced teaching load of only one course a semester is another bonus. With those advantages, it's no accident that the center's 150 researchers hail from 33 countries.

Such diversity has long been the norm at the top U.S. research universities. For several decades after World War II, top academic talent gravitated to the United States. Researchers were attracted by generous and rising funding and a continually improving infrastructure, the result of broad societal support for higher education and a political consensus that investment in research reaped economic and social dividends.

Foreign-born scientists still come to the United States, but that faith in the benefits of vibrant universities is arguably stronger now in Asia. "Many Asian governments see educa-

Published by AAAS

Science, September 7, 2012

Changes elsewhere

- Many senior administrators (provosts, deans) in other universities recognize the inadequacies of current science curriculum and are eager to change
- Reforms in teaching methods (flipped classrooms, on line learning) are being experimented.
- Reform in the substance (not just the methods) is more difficult
- Curricula are controlled by academic departments, Faculty/college councils, and university senates, all dominated by academic staff, who are resistant to change
- Pressure for change will likely come from governments and employers

CHALLENGES

- In the present climate of external grants, rankings, RAE, all the focus is on research
- Teaching and learning low in priorities in many research universities
- There is a mistaken notion that "good teachers" are "failed researchers". In fact, teaching and research reinforce each other

Summary

- Setting new goals and objectives for university education
- Our science curriculum should reflect the changing scientific and technological landscape
- Our curriculum should meet the needs of all our students, not just a small fraction
- HKU Faculty of Science has taken a number of new initiatives in curriculum structure and reform
- There is a movement across North America to reform the science curriculum

ACKNOWLEDGMENT

- Thanks for my Science colleagues who supported me to push through these reforms
- N.K. Tsing and Eddy Lam who were instrumental in the design of the Science Foundation courses
- Junior colleagues who have been keen to propose new CCC courses
- The many lecturers (non-professorial staff) who helped make the CCC and SF courses a success
- HKU senior administrators who supported our reforms
- Students who respond positively to these changes
- International colleagues who give me encouragement