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An Element of Controversy

The Life of Chlorine in Science, Medicine, Technology and War

Edited by Hasok Chang and Catherine Jackson

from research by undergraduate students at
University College London

British Society for the History of Science

2007

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Front cover illustration: Blueprint for a chlorine chamber for the cure of respiratory diseases. Reproduced by permission of Edward G. Miner Library, Rocherster, New York.

Back cover illustration: Chlorine gas, courtesy of the Department of Chemistry, University College London. Photo by Gretchen Siglar.

Contents

Epilogue

Turning an Undergraduate Class into a Professional Research Community[1]

Hasok Chang

This book is the product of a unique educational experiment, a pilot project aimed at a full integration of teaching and research at the undergraduate level. The chief innovation was the mechanism of *inheritance:* each year students received a body of work produced by the previous group of students, and made improvements and additions to it; this process was repeated until publishable materials were produced. This is a system of learning that enables students to function as a real and evolving community of researchers, which I intend to develop and apply further in the years to come. Here I describe the pilot project in more detail, and make a consideration of the pedagogical and methodological issues that have emerged in the course of it.

1. Motivation and origins

Having had inspiring experience of independent research during my own undergraduate years, I have always been in favour of making research an integral part of learning.[2] When I started actively encouraging students to do original research in my courses at University College London, the outcome was very pleasant: no more tedium of marking large piles of predictable and uninspired essays churned out in response to standard questions! Even the unexceptional students often found out

[1] This is a significantly updated and revised version of an article by the same title published in *Teaching in Higher Education*, vol. 10, no. 3 (July 2005), pp. 387–394.
[2] At the California Institute of Technology, there was already a very successful programme of undergraduate research by the 1980s, called SURF (Summer Undergraduate Research Fellowships). I also spent one year at Hampshire College, where all undergraduate students undertake extended research projects; there I attempted original research in theoretical physics, guided by Herbert Bernstein.

some things that I did not know before, so assessment became a clear learning process for myself as well as the students. However, I also came face-to-face with a frustrating problem: after assessment, these valuable essays simply sat in piles collecting dust, then eventually got thrown out. I felt that there should be a way of getting them published, but the reality was that most students working within the confines of a course-unit or even a final-year dissertation were not quite able to bring their works to the publishable level.

This frustration served as a catalyst around which a pedagogical experiment crystallized. I took a pre-existing course-unit for final-year undergraduates, called "Topics in the History of the Physical Sciences" (HPSCC313, Department of Science and Technology Studies), and I re-shaped it in the academic year 2000–01 for this purpose.[3] The basic idea was that each student taking the course would carry out an independent research project, but all the projects would share a common theme, and individual projects would be handed down from year to year. The course ran for five years, until 2004–05. In the final year of the course I was assisted by Catherine Jackson in all aspects of teaching and supervision.

It was important to choose a theme that was focused yet flexible, to be conducive to building a community that could accommodate students with various interests and inclinations. And "object biography" seemed a particularly appropriate genre, as it would be able to integrate approaches from the history, sociology and philosophy of science, technology and medicine. This was especially important in our context, given the wide variety of inclinations among our students in the Department of Science and Technology Studies and also students from a variety of other departments who took the course. Chlorine was a perfect theme because it has been involved in many interesting and important controversies throughout its life, the investigation of which promised to yield many interesting insights.

[3] For a full description of this course, see the course website from 2004–05: www.ucl.ac.uk/sts/chang/chlorine/C313.htm.

2. The directed community model

Our project was based on a new model of teaching–research integration. It will be helpful to contrast our model with the following common models. (1) In the "budding genius" model, we recognize that the best of our undergraduate students are already capable of attempting professional-level research. With such students, all that one has to do is to give them freedom and inspiration, and provide occasional guidance. (2) In the "graduate seminar" model, we introduce students to our own ongoing research, in order to expose them to cutting-edge work; they may also give valuable feedback. This is usually done with graduate students, but there is no reason why the model cannot be applied at the advanced undergraduate level. (3) In the "graduate slave" model, students are put to work, performing time-consuming routine tasks that are essential but we prefer not to do ourselves; in this model students function as research assistants, not as independent investigators.

In contrast to all of the above, what we have developed is a "directed community" model of research–teaching integration. In this model, students take ownership of their research projects, but they are strongly directed by the teacher and by their predecessors. Students have individual projects and work independently, but they are formed into a community; the collaboration is both synchronic (on the basis of a shared overall theme), and diachronic (through the inheritance mechanism). Ordinary students are enabled to carry out original research through close supervision and guidance, not only on research methods but on the social norms and customs of academia. Embodied in the directed community model are the following key ideals.

(1) *Learning is doing, not merely practice in preparation for something else that is "real".* At present, much of university education is dedicated to the rote learning of things that do not benefit anyone directly. The currently fashionable emphasis on "transferable skills" only reflects an underlying worry that the content of university education is useless for most students' lives. Even students destined for academic careers are supposed to be in training, therefore not expected to produce new knowledge. But trainee doctors treat real patients, and trainee hairdressers cut real people's hair (admittedly with less-than-ideal results sometimes). There is no reason why students, who are trainee scholars,

should not learn their trade through a process of producing real knowledge. Learning can take the form of knowledge-*production*, going beyond knowledge-*acquisition*. (Imagine just how much good work would be produced if a large group of bright, energetic young people would spend three years in an academic version of national service instead of going to university — even the "graduate slave" model dismissed above could serve a useful function.)

(2) *There is continuity between students and experts.* One of the most innovative features of the directed community model is that students treat their predecessors' and peers' works as pieces of secondary literature. This enhances their confidence in doing original work, because it breaks down the imagined sharp barrier between themselves as students and "real" scholars as famous people. It also increases their confidence in engaging productively and critically with secondary literature. Students also gain a better sense of how expert knowledge grows in real scholarship, by participating in the accumulation, extension and refinement of knowledge through the inheritance mechanism. In this way we do not merely simulate a research community, but build a real one that is continuous with the community of scholars "out there".

(3) *Originality is relative.* Research at the undergraduate level (or any level) is often hindered by the idea that originality means coming up with something that nobody anywhere has ever said before in the whole history of scholarship. This absurd idea has actually contributed to the desiccation of scholarship by driving researchers into esoteric details that are new and therefore easy to publish although they may lack interest or importance. Imagine that somewhere there is a book of Truth that has never been read, or that was once available but has been lost, or that is known to other communities but entirely unknown to us. For any of us to discover things that are stated in that book would have to count as an act of original research; it would not be fair to dismiss the result as unoriginal just because somewhere someone has written it down before. What this imaginary tale illustrates is that originality is a relative concept: we must count as original whatever we cannot simply take from sources that are readily available to our epistemic community. Depending on the situation, "our community" may be the group of most expert scholars in the whole world, or our own immediate social peers, or anywhere in between.

In the context of a class, the rule of thumb is that if students are discovering things that are unknown to the teacher, then they are doing original work.

3. Enabling and community-building methods

We have employed various practical methods in order to facilitate the students' work, and we are still seeking to develop them further. Several are worth highlighting here, since they point to insights and challenges with some general relevance.

(1) Original research should be made to appear doable. It is important to stress that research is merely the process of setting oneself a question and going about finding an answer. Students are also reminded that small contributions can be valuable. It is important that students do not set themselves impossible tasks on the assumption that they are required to produce something earth-shattering.

(2) A frank admission of ignorance on the part of the teacher can be a very effective empowering technique. Very often in this course the most useful thing I could say was: "I don't know — can you find out?" It works to choose a research area in which the teacher is less than a leading expert, which makes the teacher's ignorance genuine, not feigned. But this technique is effective only if there is sufficient basic trust; otherwise, students may simply treat the teacher's ignorance as incompetence. The key is to give a message of confident humility: the field of learning is vast, and even the best experts cannot know everything.

(3) Students can learn from each other. The inheritance mechanism ensures the building of a diachronic community. Synchronically, too, students are encouraged to use and cite each other's work. They are encouraged to share information and ideas with each other, and to hold small-group meetings on their own, especially when they are working on closely related topics. Students who prefer to go and "do their own thing" should be reminded of the community-based nature of scholarship, which does not have to interfere with their independence.

(4) In addition to the final essay, students are required to submit a file containing all of their research records, including an annotated bibliography, reading notes, results of literature searches, photocopies, earlier drafts, work plans, results of free writing, and correspondence. These research records are assessed, and inherited; for both purposes, electronic

formats are encouraged where possible. The inheritance of research records increases efficiency for the inheritors, and also teaches them by example the process of doing research. (The research notes were also invaluable in the process of editing the volume.)

(5) Students are strongly encouraged to consult relevant experts anywhere in the world. They are given advice on academic etiquette, and I made initial personal introductions when I could. External consultations help in establishing a real continuity between the community of our student researchers and the research communities that exists outside.

(6) It may seem odd to have an examination in this kind of course, but it has turned out to be a very useful tool. The first half of the exam required students to answer questions about their peers' projects, forcing mutual interactions. The second half of the exam was a methodological essay describing what students learned about the process of doing research through their work in the course. Other exam formats may be used for different pedagogical purposes.

(6) The prospect of publication is an extremely strong motivator. It also raises interesting issues of authorship and intellectual property rights. From the start of our project it was made clear to the students that their work would be passed on to others, and they were asked to sign a form giving their agreement for such use. Most students were only too happy and proud to pass on their work, but they were also given the option to retain the work as their own exclusive property (one student took that option). In this book, we have listed as authors all the students who made contributions to each chapter. Although the final product has been edited extensively for the sake of overall coherence, the students are clearly the authors of the chapters.

4. Remarks on student performance

I have been strongly encouraged by how well this course has worked out, in both process and outcome. The students registered their satisfaction and enthusiasm, first of all by producing excellent work, and also through anonymous course feedback. Over the five years there has only been one student whose overall assessment of the course was negative. The following comments are more typical: "the insight received by doing research in this way is invaluable experience that should be recommended to all undergraduate students"; "the most interesting as well as the most courageous course one can take [in the department]"; "the whole idea is just so exciting and inspiring and different . . . very challenging but ultimately rewarding"; "a taste of post-grad experience"; "most rewarding course I have ever done."

Overall, the major challenge was to see whether all serious students could actually produce original work. The results from the pilot project are quite encouraging: a total of 36 students enrolled in this course over five years, and 34 of them completed it successfully. It should also be noted that students clearly tended to do better in this course than their overall average; a rough indication is given by the following table of statistics on students based in the Department of Science and Technology Studies (STS).[4]

	First class	Upper second	Lower second
Results in HPSCC313	15	10	1
Overall degree results	9	13	4

It is difficult to say how well the weaker students would have handled this course, since there has been a good deal of self-selection and the low-performing students tended not to sign up. But the few relevant cases we do have are encouraging: the 4 students who got overall lower-second class degrees all scored upper-second marks in this course. It is my belief that this kind of work can be managed by anyone who has sufficient skills and qualification to gain admission to a reasonably competitive university and make it through to their final year, as long as they are willing to accept guidance and put in a sufficient amount of effort.

[4] This excludes students from other departments who were taking this course as an elective incidental to their main degree subjects. Within the STS Department, students were enrolled in one of the following three degree programmes: BSc in History and Philosophy of Science, BSc in Science Communication and Policy, and BSc in History, Philosophy and Social Studies of Science. For readers unfamiliar with the British system of degree classifications: "first class" roughly corresponds to grade A, "upper second" to B, and "lower second" to C.

5. Prospects for further development

The next major step I am taking is a follow-up project aimed at building a more continuous pathway from learning to research. In the chlorine project, students undertook research-based learning in their third year through a half-unit course not directly connected to any other parts of their degree programme.[5] We had to work very hard and creatively to overcome a number of difficulties in this setup. Students worked under enormous pressure, as they only had one term to spend on a major research project, while also keeping up with 3 other courses at the same time. They had hardly enough time to gain enough background knowledge necessary for pursuing research on their particular topics. The shortage of available time also created difficulties in using the inheritance mechanism to its full advantage, as it took students some time to start getting a real sense of their predecessors' works. Students also had to decide whether to sign up for the course without having a very good sense of what was involved, basically taking my word for it that it would be a plausible and rewarding thing to do. They had to make a quick and abrupt adaptation to a new way of learning, for which their previous courses did not really prepare them. And as the previous cohort had graduated and left, students were generally not able to work directly with their predecessors, although there was full access to their research notes.

On the whole these difficulties were overcome rather successfully, but we had to put in a great deal of extra effort, and we were fortunate to be able to rely on some exceptional personal chemistry. But there is a way to lessen all of the above difficulties significantly, which will be employed in our follow-up project, to be launched in the academic year 2007–08. Once again, we will launch a collection of interrelated individual projects. The unifying general theme this time will be "Electricity: Innovation and Discovery". Like chlorine, electricity will be a versatile theme that can bring together students with interest in various scientific, technological and medical fields. It will also be amenable to analytical approaches from history, philosophy or sociology.

The updated format of the project involves a combination of a special second-year course, and coordinated third-year dissertations. All

[5] A half-unit course at UCL makes up one-eighth of a student's work for an academic year. In the STS Department, all undergraduate students are enrolled in BSc programmes, lasting three years.

of our BSc students in the STS Department are required to do a year-long dissertation project in their final (third) year on a topic of their choice. Many of the students in the chlorine course said they wished they could have done the chlorine projects as their dissertations, and such a wish can easily be accommodated in the new setup. Meanwhile, many students have trouble finding and crafting suitable dissertation projects for themselves, and such students will be helped by the experience of guided research in their second year, even if they should not wish to continue with their particular projects.

In the initial year of the new project (2007–08), we will start with a half-unit course for second-year students, in which students will be taught through quite ordinary lectures and seminars to begin with, to acquire some basic background in the historical, philosophical and social studies of electricity. In the later part of that course students will be required to write a relatively small research paper, not so different from an extended essay they might have to do in an ordinary course in their third year. They will receive close guidance and training in research methods.

In the following year (2008–09), the same students (now in their third year) will be encouraged to do their dissertations on the topic of their second-year research paper. The dissertation is a one-unit project and runs over terms 1 and 2, providing a lot more time for each student to carry out extensive research. New methods for supervising such a co-ordinated set of dissertations will be developed, quite possibly involving collaborations between supervisors as well as students. At the same time, the second-year course will be offered again to the next cohort of students, this time incorporating the best of the previous year's essays as initial reading material, on which students will be examined. That would allow the new cohort sufficient time, help and motivation in learning the previous works, and would also turn previous students' works into full-fledged secondary sources for the new students. The second-year students will be asked to write small research papers, building on the previous year's works; they would craft their research topics in consultation with the third-year students, in order to achieve better coordination and avoid direct overlap with ongoing work.

In the year after that (2009–10), the best results from the dissertations as well as the second-year papers can be incorporated into the second-year syllabus. Again, some of the third-years would write their dissertations further developing their own second-year papers, which would have been on topics already carefully chosen to build on the previous cohort's work.

Thus, in any given year after the initial one we would have students carrying out research at different levels (in their years 2 and 3). Each year we would enrich and strengthen the second-year syllabus with the best results distilled from the previous year's work. Each year the second-year and third-year students would have close interactions with each other, enormously strengthening the diachronic community.

This should be a completely sustainable process, which can be continued as long as desired before moving on to a different subject area. We would create a body of knowledge tangibly growing each year in its scope and sophistication, as well as a growing and strongly connected community of student-researchers. Various publications can be produced as appropriate at various moments, from this growing body of knowledge. Some of the best students would go on to become professional researchers, which would also mean that we would succeed in bridging the gap between students and professional scholars directly and completely.

This mode of working would serve to effect a complete integration of teaching and research also from the teacher's point of the view, as the process would start with quite ordinary classroom teaching and end with the supervision of advanced research. The growing body of student work would quickly outstrip any research expertise that the teacher(s) had at the start, and soon we would have a process of genuine learning for both students and teachers. Such a mature stage can be reached quite quickly if we employ the principle of "removed expertise" and select a topic area in which the teachers are not already leading experts but would like to start some new research. In that case, teaching can blend seamlessly into the direction of a research team. There would be no need for a large research grant or hiring of research assistants for such a project.

We are also considering whether and how the directed community model of research–teaching integration can be applied elsewhere.

(1) *Other fields of study*. Our model would apply quite well to other areas of history and also to various types of engineering, where there are always plenty of empirical questions to be resolved. It may be more difficult in the natural sciences, mathematics or languages, where a great deal of rule-bound training is necessary before original work can be done. It may also be difficult in fields like philosophy, where true

originality is expected only after a long process of training focused on the critical study of well-known works. However, it is important to remember the relativity of originality, discussed above. Re-discovery is also a form of discovery. It is entirely legitimate and useful to re-invent the wheel, as long as the wheel is not known in one's own community.

(2) *Other locations*. Our pilot project would have been difficult to run in a location lacking the extensive library and archival resources that we enjoy in London. However, in most cases each location would offer its distinctive advantages as well. The aims and methods of research will obviously have to be adapted to local conditions.

(3) *Other pedagogical formats*. There are various ideas on the drawing-board. One idea is to direct a coordinated set of final-year dissertations, which will happen if the follow-up project works out as planned. Another is to apply the inheritance mechanism to essay assignments within a fairly traditional course. I believe that suitable versions of the directed community model of research–teaching integration can be devised for most teaching and learning contexts.

(4) *Other levels*. In the pilot project the course was only open to final-year students, and even in the follow-up project participation will be restricted to second-year students or higher. But that is partly because earlier stages of education do not prepare students well. There is at least some anecdotal evidence that even primary school children can perform original research, given appropriate guidance. Sheila Llewellyn gives a brief account of Mr. W. T. Creswell at Clifton Hampden Primary School, Oxfordshire, who had his pupils make observations on the rotting of fruits, and delivered their observations to Alexander Fleming (of penicillin fame).[6] I have my own experience of Hong-Ik Elementary School in Seoul, Korea, where every student in years 4, 5 and 6 was required to carry out a "free research" project each summer; the authors of the best projects gave presentations to the school assembly. I also experienced two wonderful years at Northfield Mount Hermon School in Massachusetts, where the encouragement of creative and original work was woven

[6] *Fruit News: The Magazine of the Friends of Brogdale*, Autumn 1995, pp. 11–12. For another similar example, see G. C. Britton, G. P. Bulmer and N. G. Smith, "Syrup of violets — Boyle revisited", *School Science Review*, vol. 74, no. 269 (June 1993), pp. 89–90. I thank Julian Perfect for these references.

into the school's educational philosophy.[7] In the other direction, I believe that the directed community model would work very well at the master's or early PhD level. Extending the model to the beginning stages of graduate training would complete the bridging of teaching and research.

We are seeking an active dialogue with interested colleagues in various fields at various levels, and with scholars in the field of education theory. I offer these reflections to stimulate the thinking of practitioners and theorists of education alike, and of students everywhere.

[7] Dr. Glenn Vandervliet demanded a "scholarly article" from every student in his U.S. History course. Mr. Vaughn Ausman had each student carry out an independent research project in his Advanced Placement Chemistry course. I had the privilege of playing around with my own ideas on modern physics in an independent study course directed by Mr. Hughes Pack. Mr. Pack went on to create a hands-on astronomy course, in which three students discovered a new asteroid in the Kuiper Belt in 1998; for an account of the latter event, see "Massachusetts High School Students Discover New Asteroid", news release from the University of California, Berkeley (19 November 1998), http://www.berkeley.edu/news/media/releases/98legacy/11-19-1998.html (last accessed on 27 July 2007).