Evo Edu Outreach (2011) 4:589–594
DOI 10.1007/s12052-011-0363-0

CURRICULUM AND EDUCATION ARTICLE

# On Designing Courses in Evolutionary Medicine

**Stephen C. Stearns**

Published online: 27 October 2011


**Abstract** Can one develop a syllabus for a course in evolutionary medicine that covers both its diversity and its depth? What topics generate the most interest and the best discussions? How can such a course be structured to help transform students into colleagues as fast as possible? Here, I draw on my experience teaching three courses in evolutionary medicine—one a traditional lecture course, one an advanced seminar with several unusual features, and one a week-long course for professors and doctors—to answer those questions.

**Keywords** Course design · Course structure · Evolutionary medicine

## Introduction

Designing an interdisciplinary course in an area where the connections between the fields are still being forged presents some special challenges. For two years, several colleagues and I have offered an advanced, year-long seminar in evolutionary medicine open to Yale College juniors and graduate students. I have also taught a semester-long lecture course on evolutionary medicine, once at Copenhagen and twice at Yale, which uses a more traditional format and aims at a broader audience, and as part of a team, I have taught a week-long course for professors and medical doctors interested in catching up on evolutionary medicine and teaching courses in it. Here I draw on these experiences to address several questions: What is a reasonable balance of breadth and depth in the course syllabus? What topics generated the most interest and the best discussion? What teaching methods were most successful? The answers varied with the audience.

Before getting into the pedagogy, it is important to emphasize that evolutionary medicine is no more a field than is physical medicine or chemical medicine, for like physics and chemistry, evolution is a basic science that informs many issues in medical science. Medical science is a large, complex intellectual object, and so is evolutionary biology. Evolutionary medicine refers to all the diverse places where the two endeavors intersect productively. Courses in evolutionary medicine therefore cover a broad set of topics where evolutionary insights into medical issues have brought important advances that have the potential to reduce suffering and save lives. Let us begin with their structure and content—their syllabi.

## Course Structure and Content

The lecture course is designed to be open to any undergraduate in Yale College who can meet the minimal prerequisites. Some students take it to receive one of the two required distributional credits in science. The class meets in four one-hour sessions per week. In two of those sessions, I give lectures; in the third, students present and discuss papers from the original contemporary literature relevant to that week's lectures; and in the fourth, students meet in sections of 12 to 15 to discuss the course content with a graduate teaching fellow. Two one-hour examinations cover the content of the lectures and the readings, and there is a 15- to 20-page semester paper organized as either a review paper or a research proposal in which the student

S. C. Stearns (✉)
Department of Ecology and Evolutionary Biology, Yale University,
Box 208106, New Haven, CT 06520-8106, USA
e-mail: stephen.stearns@yale.edu

addresses a question that she has posed. The course grade is composed of 30% from each examination, 30% from the paper, and 10% from paper presentations and discussions. The readings are drawn from two books—Stearns and Koella (2008) and Gluckman et al. (2009)—and from many PDFs downloaded from journals and posted in an online course library. Lectures are fairly traditional, consisting of presentations organized around slides with pauses to pose questions and discuss responses.

Because not all the students taking the course have had a previous course in evolutionary biology, the first four lectures cover the main issues of that field: selection, drift, evolutionary genetics and epigenetics, evodevo, reaction norms, phylogenetics, and paleontology. We then settle into a rhythm of lectures on Monday and Wednesday and student presentation of papers on Friday, covering the topics listed in Table 1.

Thus the sequence of the lecture course is roughly (1) a review of evolutionary biology, (2) the medically relevant evolutionary biology of humans, and (3) the medically relevant evolutionary biology of pathogens. The prerequisite for the lecture course is one semester of introductory biology, either molecular–cellular or evolutionary–ecological. In practice, many students with advanced placement credits place out of introductory biology; they are eligible for the lecture course. Many of the 20–25 students per year who take the lecture course are pre-medical, but there is a substantial minority of other students coming from diverse majors that include economics, history of science and medicine, anthropology, and psychology as well as the various biology majors.

The advanced seminar covers similar topics without lectures and without textbooks, with all instruction based on discussions of original papers. Two or three times per semester, we ask the students to select the papers for discussion, and there is greater representation of topics in epidemiology and public health, for the course is co-taught with professors from the Yale School of Public Health. The prerequisite for the advanced seminar is junior or graduate standing and evidence of substantial preparation in biology, but not necessarily in evolutionary biology. Admission to the advanced seminar is competitive, requiring a written application, and enrollment is capped at eight undergraduate and four graduate students. The undergraduates who take the advanced seminar are mostly pre-medical, but they include some planning to attend graduate school rather than medical school, and the graduate students who take the course are headed for doctorates or master's degrees in subjects that include epidemiology and public health, immunobiology, and anthropology. The course begins in spring semester, continues with fully supported summer research projects conducted at a qualified laboratory anywhere in the world, and concludes in the fall. Performance is assessed on the basis of class discussion, a research proposal in the spring semester, and a scientific paper based on summer research results in the fall semester.

The week-long course for professors and medical doctors was taught by eight faculty members. It consisted of four lectures each morning and discussions of research projects each afternoon in working groups of 7 to 12 participants, each group being accompanied by two faculty members. Each working group delivered a report on their plans in plenary on Friday afternoon. The course began with an overview of key evolutionary concepts. Because only one week was available, some topics had to be emphasized at the cost of others. In this iteration, the emphasis was on reproductive biology, reflecting the expertise of the faculty, with lectures covering the evolution of the human life history, menstruation, menopause, the hormonal basis of trade-offs, and the evolution of aging. There were additional lectures on mismatches to the modern environment and the evolutionary origins of physiological processes.

**Table 1** Topics discussed in the evolutionary medicine lecture course

| Lectures | Presentations |
|---|---|
| Hominid evolution, human life histories | Menstruation |
| Reproductive conflicts, atresia, miscarriages | Miscarriages and mate choice |
| Aging, menopause, and cancer | Cancer as an evolutionary process |
| Developmental origins of adult disease | The metabolic syndrome |
| Evolutionary immunobiology | Helminths and multiple sclerosis |
| The Hygene Hypothesis, the microbiome | Gut microflora and autoimmune disease |
| Variation for resistance and drug metabolism | Personal medicine |
| Virus genetics and evolution | HIV origins and evolution |
| Bacterial genetics, experimental evolution | Virus niche evolution and emergence |
| Pathogen evolution, resistance, virulence | Imperfect vaccines and virulence |
| Ecology and evolution of emerging diseases | Evolutionary epidemiology of influenza |

## Topics that Elicit Strong Interest and Good Discussions

Undergraduates are consistently fascinated by evolutionary conflicts within the family and their connections to the diseases of pregnancy (Haig 1993), to issues of parental investment in offspring (Haig and Graham 1991), and potentially to a partial explanation of mental disease (Crespi and Badcock 2008). When they realize that every cancer is an independent evolutionary process (Yachida et al. 2010) in which clones differing in their somatic mutations compete for host resources and for resistance to chemotherapy (Crespi and Summers 2005; Merlo et al. 2006), and that a combination of mutation and selection is required to produce metastases (Greaves 2010), they can have a eureka moment that leads them to commit to a research topic. They find the Hygene Hypothesis (Zaccone et al. 2006, 2008) intriguing, often relating experiences that their relatives, and sometimes themselves, have had with autoimmune diseases (Correale and Farez 2007). It does not hurt that the helminthes involved are disgustingly photogenic. The messages of the evolution of aging are sobering (Ackermann et al. 2003; Williams 1957), not exciting, but seen as important, and the controversies over the evolution of menstruation (Profet 1993; Strassmann 1996) and menopause (Profet 1993; Shanley et al. 2007) resonate particularly strongly with the female students. Undergraduates find the idea that leaky vaccines can promote the evolution of greater virulence (Gandon et al. 2001; Mackinnon et al. 2008) in human papilloma virus and *Plasmodium* both frightening and attractive as research topics. The other topics are regarded by most as interesting background but not necessarily something to which they want to devote their lives (the papers cited here are a tiny fraction of those available; I currently maintain a PDF library of about 300 papers for these courses and add to it every week).

The reactions of professors and medical doctors in the one-week course were similar, but with an important novelty: they were deeply struck by the existence of evolutionary explanations for many structures and processes that they had only previously considered from the proximate, mechanistic angle. As someone who has been teaching evolutionary biology for 34 years, this came as a surprise to me, for I have never seen such a response in undergraduates who belong to a group that has all encountered evolutionary thinking. It brought home to me how many doctors and professors have never been exposed to evolutionary thought in their formal education, making the force with which evolutionary insights hit all the greater for having been delayed.

## What Teaching Methods Have Been Most Successful?

In the lecture course, student presentation and discussion of papers usually proceeds like this: I ask them what is important and what they have not understood, appoint students to write the lists on the board, then step out for ten minutes. When I return, I go through the lists, ask who mentioned each point, have them explain why they thought it was important or what it was that they did not understand, then pick another student at random to ask whether they agreed with the explanation of the topic's importance or could explain what was not understood. We continue until the lists are exhausted or time runs out. In such a class, every student can expect to be called on to explain something. If it becomes clear that they need information, I step in with a brief lecture, but for no more than 5 minutes. To build their confidence, I often ask one of the class to join me at the board to discuss a projected figure or table from the paper while we stand together, at the same level. At the start, it is hard for students to do this: they feel exposed. But as they learn that I support them and deal gently with any mistakes, they usually relax and start to enjoy it. The key move is stepping out of the classroom to give the students time to organize their thoughts and take ownership of the discussion. Often I have returned to the classroom with the board covered with lists of interesting ideas and an excited discussion in progress that I felt no need to interrupt before class was over.

In the seminar course, we start by using the method described above for the lecture course: we ask students what is important and what they have not understood, appoint students to write the lists on the board, leave the room for ten minutes, then return to discuss the lists. After they get used to that kind of interaction, we try another structure, splitting them into two groups, putting each group in a different room, and giving them 20 minutes to come up with the outline of a lecture on the topic under discussion—no more than ten bullet points or headlines (they do far more than that). We then ask the two groups to project their outlines and compare them. The results are often professional—as good as we could do.

In a third structure, we tell them in advance, when we assign the readings for the week, that one group will read one paper, a second group another, and they will have the first 15 minutes of class to prepare to tell the other group what is important, interesting, or flawed, about their paper by discussing its figures and tables in detail. Each group then makes a presentation to the other group in which they go to the board, talk about the figures and tables, and field questions from the students and faculty.

After about ten weeks of such experiences, we let the students choose the readings for a specific week. They always come up with something interesting and more or less appropriate. After having taken the entire course, they could probably do that every week, at which point we could just hand their education over to them and go find some other line of work.

Students in such a class do not need a final examination, for they have been in an oral examination for the entire semester, regularly encountering a general principle of learning: you remember best things you have explained under constructive emotional stress. The stress, here generated by having to perform in front of others, has a role like a chemical fixative in developing a photo: it fixes in the brain the content of what is explained. This does not happen when a student reads a paper alone, even if taking extensive notes.

The seminar course consists of much more than discussions of current research. Right from the start, the students begin to plan their summer research projects. The undergraduates get support for research done at labs at Yale or outside the United States; the graduate students usually do a project under the supervision of their thesis or rotation mentor. They are asked to initiate the arrangement of those projects themselves; we only step in with supporting e-mails if necessary. The written work in spring semester is a research proposal in which we ask students to develop their own ideas. The written work in fall semester is an original scientific paper based on the data they collect over the summer.

There is always tension between their ideas and the ongoing work in the host labs that students join for the summer. We try to get them to stake out a strong starting position in the negotiation of that work with their host lab, a position that allows them to end up feeling that they own a significant portion of the work that actually gets done.

We want them to have the freedom to succeed or fail with their own ideas and thus to learn about the properties of a good question and a feasible project. From having the freedom and privilege to learn from their own mistakes, participants discover that it is not just all right to make mistakes—mistakes are essential, for science consists of making intelligent mistakes and learning from them as efficiently as possible.

Another feature of the course structure is designed specifically to accelerate the transformation of students into colleagues. A key element in that transformation is social contact with intellectual heroes in a supportive environment in which the heroes are by their presence and attention valuing the students' ideas by contributing to their development and refinement. Each semester, we invite three or four distinguished visitors, people whose work the students have been reading, to come to Yale, teach a session of the course, and go to dinner with the students and faculty in a Yale residential college. The dinners are quite successful, with both students and faculty inclined to linger in discussion long after dessert has been finished. Two topics of conversation always come up at dinner: how the visitor made the transition from undergraduate student to successful professional and what the students planned or did for their summer research. The experts often reveal personal details of their lives that bring home to the students that careers are built by complex human beings whose trajectory is not one of unobstructed success but of resilience in negotiating obstacles and exploiting unexpected opportunities. For their part, over the course of the year, the ability of the students to explain their ideas concisely and convincingly steadily increases as their confidence grows. Knowing that they will be explaining their ideas to visitors three or four times each semester motivates them to think clearly and deeply about what they plan or have done.

One feature of the seminar course is not yet working well. Because evolutionary medicine consists of an eclectic mix of topics covering all places where evolutionary insights bring added value to medical issues, the students find that the course lacks a coherent overview. We plan to address that problem with two to three 50-minute lectures each semester that introduce the major sections of the course.

In the week-long course for professors and medical doctors, I learned of an innovative teaching technique used by Gillian Bentley at Durham University in England. When teaching a course on evolutionary medicine for the first time, she knew she did not have expertise in certain areas, and so she invited colleagues from medical school who had such expertise to a panel discussion in which she asked them questions in front of the students. It was successful in two ways: the students found it very stimulating, and the panelists realized that their agendas in research and in the clinic could be productively viewed from an evolutionary perspective. She has found that her colleagues in medical school always accept her invitation. It is a structure worth copying.

## Principles of Course Design

People learn best when they take ownership of and responsibility for their own education as active agents rather than passive recipients (Benware and Deci 1984). Their ability to do so is strongly influenced by the structures in which teaching and learning occurs, for such structures embody implicit messages that often have more impact on personal development than do the clarity and interest of the information transmitted—thus the focus on student ownership and agency and the implicit messages of learning structures.

We should aim to help our students become colleagues as fast as possible. A colleague is an equal, a responsible and interested partner: an independent agent. In an ideal world in which students showed up at universities knowing what they wanted to do, articulated options, made choices, and accepted responsibility for those choices, all they would need is access to books and journals, an informal setting in which to discuss them, interested smart colleagues who took time to chat, and, in the sciences, access to the materials and equipment needed to test ideas. In reality, that doesn't work, for most students are not yet independent agents when they arrive. Their sense of agency needs development. How do we help them to transform themselves into colleagues?

I pose the question that way because I see the primary job of a teacher as neither the transmission of information (reading works) nor the development of technical skills, however necessary both may be, but as helping the student grow rapidly into the secure psychological stance of a self-confident adult mind that takes joy in the exploration of its own ideas and responsibility for situating them objectively in the context of what others have thought and discovered. Just as a fencing instructor works hard on improving stance and footwork to provide a secure foundation for the student's more spectacular thrusting and parrying, we should seek to develop the mental confidence and balance of students as the secure foundation for the unfolding of their individual creativity. Once that is accomplished, all else comes more easily.

How are these principles playing out in the lecture and seminar courses? The focus on student ownership and agency is realized in the lecture course in the student presentations and discussions of papers, in the discussion sections, and in the semester paper, but it is not as highly developed there as it is in the advanced seminar, which can go farther in that respect because it is smaller, and the students are more experienced.

In the advanced seminar, we do not use any textbooks, and we hold lectures to a minimum, relying on student presentation and discussion of several papers each week from the original recent research literature—perhaps a review or two to put things in context, but always some detailed, data-rich papers that reveal precisely the claims on which our knowledge is based. These features are not unusual for an advanced seminar at any university. The two features that set this course apart are the dinners with visiting experts and the requirement of a summer research project in an internationally recognized laboratory, leading to the writing of a scientific paper in the fall semester. Both accelerate the development of students as colleagues, and both appear to be having very constructive impact.

## Online Resources

A lecture giving an introductory overview of evolutionary medicine can be viewed at http://oyc.yale.edu/ecology-and-evolutionary-biology/principles-of-evolution-ecology-and-behavior/content/sessions/lecture21.html. Twelve research talks given in the spring of 2008 at the Yale School of Medicine on topics in evolutionary medicine are available at http://www.yale.edu/evomedsymposia/, and another 24 given in the spring of 2009 at the National Academy of Sciences can be found at http://www.nasonline.org/site/PageServer?pagename=Sackler_Evolution_Health_Medicine_program. The research talks could be paired with papers by the speakers as homework assignments on which classroom discussion could be based.

## Discussion

### Addressing Interdisciplinarity

Three features of the seminar course address interdisciplinarity: the readings, the faculty, and the students are drawn from different fields. In the readings, the students encounter some papers with a primarily molecular–cellular focus on mechanisms and other papers with a primarily evolutionary focus on either history or selection. The data are usually better in the molecular–cellular papers; the ideas are often more interesting in the evolution papers. Among the faculty in the seminar course, the students encounter some evolutionary biologists with interests in life history evolution, experimental evolution, viruses, and bacteria; and some epidemiologists with interests in vector ecology, the spatial dynamics of disease, and vaccine management. The distinguished visitors are drawn from many fields. The participants in the week-long course for professors and doctors encounter a larger group of faculty who are even more diverse, including some from anthropology departments and some from medical schools. The students thus see role models who themselves are engaged in trying to forge connections among fields. In their fellow students, they encounter a mixture of viewpoints drawn from molecular and cell biology, ecology and evolutionary biology, immunobiology, medical anthropology, and human evolutionary biology. They are thus constantly aware of the need to articulate the implicit assumptions of their various fields, and we hope that they learn to value diverse contributions from a variety of points of view.

### Does Course Structure Increase Interest?

The interest in any particular kind of course depends to a certain degree on the other types of courses that are being offered. Many biology courses at Yale are more traditional, with a greater degree of memorization and written exams. These courses thus stand out, at least in the biological sciences, as places where students can become active agents in their own education, and they are valued as such.

The opportunity to design and execute a summer research project with generous financial support is a major positive feature of the advanced seminar, but it is not easy to finance, which is one of the reasons that course size must be restricted. I heartily recommend such an experience wherever it can be arranged.

## Coda

As stated in the "Introduction," evolutionary medicine is not a field, and I would not want the existence of these courses with that phrase in their titles to suggest as much. Evolution is a basic science for medicine, as are physics and chemistry. The reason that courses in evolutionary medicine currently exist is that it has only recently been appreciated that an evolutionary viewpoint sheds useful new light on many medical issues to yield insights that can reduce suffering and save lives. Until those insights are incorporated into the premedical and medical curricula, there is some catch-up to do. That is one function that these courses serve. They will probably continue to do so for some years to come.

**Acknowledgments** The author thanks Kristin Jenkins, an anonymous reviewer, and students in EEB 460b/461a at Yale in 2011 for constructive comments that improved this paper.

## References

Ackermann M, Stearns S, Jenal U. Senescence in a bacterium with asymmetric division. Science. 2003;300(5627):1920.

Benware CA, Deci EL. Quality of learning with an active versus passive motivational set. Am Educ Res J. 1984;21:755–65.

Correale J, Farez M. Association between parasite infection and immune responses in multiple sclerosis. Ann Neurol. 2007;61(2):97–108.

Crespi B, Badcock C. Psychosis and autism as diametrical disorders of the social brain. Behav Brain Sci. 2008;31(03):241–61.

Crespi B, Summers K. Evolutionary biology of cancer. Trends Ecol Evol. 2005;20(10):545–52.

Gandon S et al. Imperfect vaccines and the evolution of pathogen virulence. Nature. 2001;414(6865):751–6.

Gluckman P, Beedle A, Hanson M. Principles of evolutionary medicine. Oxford: Oxford University Press; 2009.

Greaves M. Cancer stem cells: back to Darwin? Seminars in Cancer Biology. 2010;20:65–70.

Haig D. Genetic conflicts in human pregnancy. Q Rev Biol. 1993;68:495–532.

Haig D, Graham C. Genomic imprinting and the strange case of the insulin-like growth factor II receptor. Cell. 1991;64(6):1045.

Mackinnon MJ, Gandon S, Read AF. Virulence evolution in response to vaccination: the case of malaria. Vaccine. 2008;26 Suppl 3: C42–52.

Merlo LMF, Pepper JW, Reid BJ, et al. Cancer as an evolutionary and ecological process. Nat Rev Cancer. 2006;6(12):924–35.

Profet M. Menstruation as a defense against pathogens transported by sperm. Q Rev Biol. 1993;68(3):335–86.

Shanley DP, Sear R, Mace R, et al. Testing evolutionary theories of menopause. Proc R Soc B. 2007;274(1628):2943–9.

Stearns S, Koella JK. Evolution in health and disease. 2nd ed. Oxford: Oxford University Press; 2008.

Strassmann BI. The evolution of endometrial cycles and menstruation. Q Rev Biol. 1996;71(2):181–220.

Williams G. Pleiotropy, natural selection, and the evolution of senescence. Evolution. 1957;11:398–411.

Yachida S, Jones S, Bozic I, et al. Distant metastasis occurs late during the genetic evolution of pancreatic cancer. Nature. 2010;467(7319):1114–7.

Zaccone P, Fehervari Z, Phillips JM, et al. Parasitic worms and inflammatory diseases. Parasite Immunol. 2006;28(10):515–23.

Zaccone P, Burton OT, Cooke A. Interplay of parasite-driven immune responses and autoimmunity. Trends Parasitol. 2008;24(1):35–42.