Getting to Mars and Effective Science Education: should training high school teachers be our goal?

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A recent National Research Council (NRC) report considered NASA's efforts to place people on Mars (NRC 2014). Their conclusion? That NASA has an "unsustainable and unsafe strategy that will prevent the United States from achieving a human landing on Mars in the foreseeable future" (Achenbach 2014). One might argue that the development of a more inclusive and effective science education system is at least as important as going to Mars, yet the tone of various NRC reports on science education (see (NRC 2003; 2011; 2012)) lack the practical skepticism needed to tackle what is clearly a more complex task. Various expert groups have been gathered to devise and promulgate new science standards for K-12 students, including the Common Core, the Next Generation Science Standards (NGSS), and its underlying Framework (NRC 2012; States 2013). Yet, these reports contain no serious consideration of the extent to which these goals are realistic (← Common Core insert),[1] and if if they are, what reforms and innovations will be needed in terms of political consensus, resource allocation, teacher preparation, student and parent expectations, and outcomes measures in order for them to be successfully implemented.[2] The situation is a little like planning to go to Mars without carefully designing and testing of the rocket engines required to get there.

The standards are:

1) Research and evidence based
2) Clear, understandable, and consistent
3) Aligned with college and career expectations
4) Based on rigorous content and the application of knowledge through higher-order thinking skills
5) Built upon the strengths and lessons of current state standards
6) Informed by other top-performing countries to prepare all students for success in our global economy and society

Here I consider the specific issue of teacher preparation, the engines that drive the education enterprise. The NGSS set out ambitious goals that center on bringing higher order, cross-disciplinary thinking to science education. Leaving aside for the moment whether such goals are attainable, by what percentage of the student population, and at what cost, there are other more prosaic but nevertheless critical issues to consider, in particular whether the current system by which we educate teachers adequately prepares them to successfully guide students' to achieving the goals of the NGSS.

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[1] http://www.corestandards.org/read-the-standards/

[2] Recent changes in support for and opposition to the "common core" standards suggest that this is no trivial issue. See for example: http://www.huffingtonpost.com/Karin-Chenoweth/wait---tell-me-again-what_b_5758846.html

In particular, consider the current system that trains most secondary school teachers in the US. This system typically involves two independent entities. Training in a School of Education prepares students in the relevant practical and pedagogical models and methods for teaching and managing a wide range of students, with varying capabilities and socioeconomic backgrounds. This process often involves an intensive apprenticeship, typically in the form of unpaid student teaching assignments. The second facet of teacher training occurs within disciplinary departments, where students earn degrees in biology, chemistry, physics, math, etc. These science departments, often housed in separate colleges, rarely consider the preparation of future secondary school teachers as one of their primary, secondary, or (assuming their thinking goes that far) tertiary goals. Ignoring for the moment the fact that few disciplinary degree programs include any objective measures of students' disciplinary competence, it certainly remains to be established whether a newly minted bachelors degree student has mastered their primary discipline sufficiently well to teach it at the level called for in the NGSS. This is critical since a bachelor's degree in a particular science is the highest level of formal education that most secondary science teachers get. Here we ignore (but probably should not) the fact that many secondary school science teachers are also expected to teach subjects outside of their area of disciplinary specialization. These teachers are to be students' guides through complex terrain with which they themselves often have an incomplete and flawed familiarity. Moreover, even a degree in a particular science does not guarantee that students have more than a superficial grasp of that science's basic tenants. As an example, it is possible to graduate with a degree in molecular biology or biochemistry from many (most) institutions with little or no formal grounding in basic evolutionary mechanisms, such as adaptive, non-adaptive, and social evolutionary processes (including social cheating and defenses against it), the effects of gene linkage and selective sweeps through a population, or the role of genome dynamics in the generation of novel traits and as a mechanism for reproductive isolation. The reciprocal situation exists for students graduating from programs in other areas of biology. Based on a number of conceptual assessments, from our own work and that of others, there is a serious concern that many graduating students do not have an accurate working understanding of key biological, chemical, or physical processes, including the nature and roles of intramolecular interactions, entropic drivers of chemical and biological processes, and the stochastic processes involved in gene expression or cellular behavior. All too often students are drilled on what amounts to trivia (for example, memorizing the names of amino acids, lipids, or complex carbohydrates) without mastering the ability to predict a molecule's physical and chemical properties based on its structure (Cooper et al. 2010). There is evidence that a similar level of conceptual fragility is present in students of other sciences as well. This was, after all, the original lesson many science educators took from the results of the Force Concept Inventory in mechanics (see (Mazur 1997)). All too often the ability to apply unifying observations and concepts accurately and appropriately seems to be an afterthought rather than the primary goal of a degree program.

One direct way to monitor student abilities is obvious: can a student teach the core ideas of their discipline? A moment of reflection reveals that the ability to use empirical observations and established scientific concepts is critical for all students, not just those who plan to become teachers. It is central to the critical analysis of scientific ideas and conclusions – it is scientific literacy.

It is, however, important to explicitly recognize the obstacles we face in attaining the goal of scientifically well-educated teachers, teachers capable of helping students in their classrooms reach the goals of the NGSS. One problem is how to incentivize college science departments to recognize their responsibilities and to address omissions or inadequacies that may exist in their curricula. But herein lies the rub. Who will tell departments (professors, and instructors) that they need to revise their course requirements in order to develop and maintain a curriculum that produces students comfortable with teaching their discipline? What pressures or inducements will be needed to facilitate such changes at the departmental level? How will departments accept their responsibility to deliver an effective education following current best practices and explicitly recognize the reality and significance of educational malpractice, both in terms of teaching strategies and poorly conceived course content? How will the higher education establishment address the fallacy that academic freedom is at odds with educational best practices?

Beyond courses taught within a department, these challenges extend to required courses taught by other departments. It is critical that these courses both be and be perceived to be relevant to the disciplinary goals of a degree program. Through the lens of educational best practice, requiring students to take a course in calculus or Newtonian physics, when neither are relevant to (for example) a molecular biology program (Klymkowsky 2014), is analogous to prescribing a drug for a disease a patient does not actually have – a recognized form of malpractice.

In this light, are Provosts and Deans prepare to provide the resources (and institutional incentives) necessary to help departments and faculty redesign their courses and course requirements? These are likely to be contentious discussions, since to be effective, such changes need to be realistic, recognizing that learning to work competently and comfortably with complex ideas requires practice and good coaching. Departments will need to remove a number of topics as students and professors expend more effort on the mastery of core ideas and skills (Klymkowsky and Cooper 2012). Such discussions would greatly benefit from appropriately-trained curricular consultants and discussion mediators who would serve to facilitate the inter- and intra-departmental negotiations involved in designing course content and effective pedagogical strategies.

Perhaps most contentious, but also most critical, is the need for a feedback system that monitors these efforts, reports on when goals are realistic and are being met and when they are not, and provide actionable advice on how to make improvements and revisions. Will administrators act forcefully to insure that departments see students' educational outcomes as a critical measure of a department's success, equal to its research impact? Will we turn the dream of developing a more effective science education infrastructure into a reality by producing the teachers needed to deliver it, or are we willing to watch the whole thing blow up (or simply pretend we have succeeded), because at the end of the day we were never really that serious about the goal or the commit required to attain it?

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