Prong 2: Re-designing education for agricultural students and their teachers

Prof. Gregory Radick

We now turn to consider the following question: What sort of education can best support a transition from the current scenario where farmers are mainly technology takers to one where they are the makers of innovations, above all in connection with seeds and sustainability?

At this preliminary stage, raising awareness of the need for a new kind of training should take priority over settling on the exact content of this training. Nevertheless, even now it is possible, in an indicative way, to sketch out reforms in a couple of areas where improvements are not only needed but, thanks to recent research from within the project team, straightforwardly made.

In what follows we shall, for ease, write about farmers themselves as the recipients of the envisaged training. Given illiteracy rates among many Indian small farmers, however, it is more realistic, for the foreseeable future, to suppose that the training is instead for agricultural education service officers and agricultural university students, who can then go on to disseminate appropriately tailored versions of it to the farmers themselves.

(i) From a "genes for traits" to a "genes, environments and variability" understanding of heredity

After presenting the now-standard way of doing things pedagogically, we will describe a recent alternative, then consider how the values acquired in the introductory genetics classroom might translate into farming practice.

<u>"Genes for traits" genetics teaching</u>: Consider a widely used university-level genetics textbook, *iGenetics: A Mendelian Approach*, by Peter Russell. Early on, students are introduced to Gregor Mendel, "founder of the science of genetics," and his famous experiments hybridizing pea varieties. Such a starting point is a global commonplace, at every level where genetics is taught, and has been, to varying degrees, for over a century.[1] Students go on to learn about Mendel's discoveries of dominance and recessiveness, segregation, etc: discoveries made thanks to his purifying his varietal stocks before crossing them, thus revealing regularities that escaped previous investigators. When, for example, purple-flowering and white-flowering stocks were crossed, all the hybrids had purple flowers, showing purpleness to be dominant over whiteness. And when those hybrids self-fertilized, their offspring showed not just purple but also white flowers, in the ratio 3 to 1. Then the students get to see for themselves how wonderfully well explained this pattern is on Mendel's simple hypothesis that there are just two kinds of underlying factor, one for purpleness and one for whiteness.[2]

Russell's textbook itself comes in two varieties. There is *iGenetics: A Molecular Approach* as well as *iGenetics: A Mendelian Approach*.[3] But both books have the same chapters, just in a different order. In the *Molecular Approach* book, as soon as whole organisms come up, we are back with Mendel and his pea hybrids. That is what an intellectual monoculture looks like.

What is the problem? Judged on its own terms, there is no problem at all with this pedagogy. On the contrary, it works amazingly well. If you want to experience how good science teaching can be when it is at its best, take a well-taught introductory genetics course. A century of honing has made this

---

[1] Jamieson and Radick, (2013).

[2] On Mendel's explanation, all the hybrids are purple because when purple-making factors from the purple-flowering plants meet white-making factors from the white-flowering plants, purpleness is dominant. Only when white-making factors meet a white-making factors – as will happen, by the rules of probability, in a quarter of hybrids' offspring, given the segregation of white-making and purple-making factors into separate gametes – will the resulting plant produce white flowers.

[3] Russell, (2006).

pedagogy exceptionally effective at inducting good students – the ones who want to do well, who really work at the questions at the back of each chapter in order to master the techniques of reasoning – into the science of heredity under Mendelism, and to do it so comprehensively that they lose more or less any appetite or ability they might have had to think critically about what they are being taught.

But there are worries. A recent survey of college and university teachers of introductory genetics across the United States revealed that they were uniformly concerned that, in the actual delivery of their courses, gene-environment interactions come across to students as a low-emphasis, low-priority topic. From the perspective of these teachers, it would not be at all surprising if, despite their good intentions and best efforts, what their students remember after the course is the long-outdated "genes for traits" notion emphasized at the start-with-Mendel beginning.[4] Part of what makes the standard beginning so permanently attractive is that it is so simple. To understand why a flower has the color it does, you need to pay attention *only* to the combination and recombination of flower-color genes, themselves attractively binary, for-purpleness or for-whiteness. Nothing else matters. Environments, from the genomic to the physiological to the physico-chemical, never get mentioned. Nor is there any interesting variability in the outward characters or "phenotypes." There is just purpleness and whiteness.

It appears, then, that a misleadingly deterministic picture of how genes work is being instilled through standard genetics pedagogy and its organization around Mendelian hybrids and concepts associated with them. That is problematic in itself, so far as we want students to emerge from teaching with something approximating our own best scientific understanding of how heredity works. It may also be problematic in its implications. We shall refer to implications for agricultural practice below. For now, and more briefly, consider the implications for decisions taken in the context of human health and illness. Increasingly people are acquiring information about their own genetic constitutions.[5] If teaching conditions them to want to ask only whether or not they have the "genes for" certain diseases, say, and not to want to ask in addition about how differences in genetic background may matter, or differences in wider environments, then that incuriosity may lead them to make poor choices, leading to worse outcomes. That is one way in which a persistently Mendelian organization for genetic knowledge can hold us back from reaping maximal human benefit from recent advances in what is increasingly known as "post-genomics."[6] Another is the potential it creates for strengthening a psychological attitude of essentialism: for thinking that people, like peas, come in genetically defined types, some born with a greater capacity for worldly success than others, with well-known consequences for social inequality.[7]

<u>"Genes, environments, and variability" genetics teaching</u>:
There is, fortunately, another way. For some while, PI Radick, as a historian of science, has been re-examining the debate that broke out over Mendel's experiments after the 1900 rediscovery of his paper on them.[8] The debate was most intense between the Cambridge-based William Bateson, who did more than anyone to promote Mendel's work as the foundation for a new, experimental, quantitative science of heredity,[9] and the Oxford-based W. F. R. Weldon, who, before his untimely death in 1906, went further than anyone in developing a serious biological critique of early Mendelism.[10] To Weldon, Mendelism represented a backwards step for biology, at a moment when the most impressive work coming out of experimental embryological laboratories in Germany and elsewhere at that moment was reinforcing a lesson that thoughtful biologists already regarded as well established: that, from organs to organisms, the characters that are manifest, expressed, visible depend

[4] We are grateful to Michelle K. Smith for sharing the results of this not-yet-published survey, conducted in connection with ongoing research by her, Brian Donovan and PI Radick.
[5] Mordor Intelligence, (2018).
[6] Kitcher, (1996), esp. ch. 11; Kronfeldner, (2009).
[7] Donovan, (2014).
[8] Radick, (2005); Charnley and Radick, (2008).
[9] Olby, (1987); Bateson and Mendel, (2013); Bateson, (1928); Darden, (1977).
[10] Froggatt and Nevin, (1971); Farrall, (1975); Radick, (2015).

fundamentally on what is interacting with what. Change the nature of the interaction, and you can change the character. Dominance is not, as with elementary Mendelism, an absolute property of a character, but is relative to conditions, and can be variable as conditions alter. In Weldon's view, the needed science of heredity was one that gave due prominence to the influence of surrounding conditions on the effect of a bit of chromosome on a body, rather than marginalizing it as a (slightly annoying) complication.

Did this debate matter? Perhaps something like a determinist "genes for traits" notion was inevitable, if not in 1900 in Europe, then sooner or later somewhere or other. But then again, perhaps if Weldon's interactionist emphasis had been more successful than it was – had he lived long enough to finish his book about it, had he acquired acolytes who sought to extend and defend it (Bateson attracted brilliant ones), and so on – we might now have introductory genetics textbooks that look different from the likes of *iGenetics*, helping to create students with different ideas about how heredity works, who go out into the wide world and think differently, choose differently, act differently…

To test this second possibility in a preliminary way, Radick and colleagues ran a pilot-scale teaching experiment, for which they developed teaching materials designed as if they had come from a "counterfactual" past in which genetics had become Weldonian rather than Mendelian.[11] In this experimental curriculum, students were not launched on the study of genes with a look at what now appear to be wholly unrepresentative systems, e.g. crossings with artificially purified pea varieties. Instead the students were taught from the beginning, and throughout, that genes always have the effects they do against particular genetic backgrounds and within a given range of environments, with "environments" glossed as expansively as possible. For these students, the first, exemplary case for thinking about genes was in relation to the condition of a human heart, where genes, themselves of diverse kinds with diverse interactions, are just one of a large range of heterogeneous elements in the causal mix. And when these students did meet Mendelian patterns, they encountered them not as the Truth around which to hang everything else, but as a special case, interesting precisely because so unusual. Rather than being taken for granted as what heredity looks like when environments do not interfere, Mendelian patterns should excite curiosity about the special circumstances under which they can come about.[12]

Both before and after teaching, students on the Weldonian course were assessed as to their levels of "genetic determinism." The same was done with students taking a traditional start-with-Mendel introductory course in genetics. What Radick and colleagues found was that, in line with their predictions, students on the Mendelian course were just as deterministic about genes at the end of teaching as at the beginning – there was even some evidence of increased determinism – whereas students on the Weldonian course were less deterministic about genes at the end of teaching.[13]

In sum: a Mendelian curriculum is no longer the only option when it comes to introductory genetics teaching. The Weldonian curriculum shows promise as a curriculum that, in better alignment with 21st-century understandings, helps students grasp gene action as always taking place in a context, with results that in consequence can be hugely variable.

How values acquired in the genetics classroom might translate to farming practice

Near the beginning of this position paper we gestured briefly toward some links between Mendelian genetics, with its distinctive emphasis on hybrid seeds, and post-Green-Revolution high-yield, industrially farmed, chemically saturated agriculture. With the two genetics pedagogies in view, we can now pursue a further question: What, exactly, might the affinities be between a start-with-Mendelism, "genes for traits" training in genetics and "farming-as-spraying" industrial agriculture? Or, to put the same question from the opposite direction, what, exactly, might the affinities be

---

[11] Radick, (2016).
[12] The Weldonian curriculum can be sampled at https://arts.leeds.ac.uk/geneticspedagogiesproject/gpp-lectures/
[13] Jamieson and Radick, (2017).

between a more Weldonian, interactionist, "genes, environments and variability" training in genetics and the more sustainable style of agriculture envisaged in this position paper?

We shall proceed by addressing the latter form of the question. Our answer to it, in brief, is that a farmer taught well within a Weldonian curriculum has a better shot than a Mendelism-trained farmer at acquiring the following three, sustainability-promoting cognitive attitudes or biases:

• No indifference to the role of the environment in bringing about phenotypic effects
• No presumption in favour of hybrid seeds
• No presumption against a variety whose attractive character is region-specific

Let us consider each in turn:

• *No indifference to the role of the environment in bringing about phenotypic effects*. Imagine our farmer in an Agricultural Extension classroom where, from the start and throughout, it is hammered home that a bit of chromosome has its effect on a body *in a context*, under conditions – and that is always the case – it is never *not* the case – and if it seems that you can forget about the conditions, that is because environments have become standardized.[14] Indeed, one perspective on post-Green-Revolution agriculture sees it as an agriculture which seeks to adapt local environment to globally distributed seeds, with the adaptation taking place thought the use of machinery, pesticides, herbicides, fungicides, intensive irrigation, etc. Farmers are never invited to see what they are doing in that way;[15] rather, they are invited to see the seeds they buy as genetically superior, full stop, and to see all the accessories that are needed to bring out that superiority as merely damping down whatever might inhibit the full realization of that superiority. By contrast, a Weldonian farmer would be alert to how profoundly dependent the marketed seeds are on re-engineered surroundings, and so be better positioned to compare and contrast the environmental toll of using those seeds as against that of using local seeds already adapted to local conditions.[16]

• *No presumption in favour of the superiority of hybrid seeds.* The vocabulary of "F1 hybrids" was introduced by Bateson, as a way of labelling the offspring of an initial cross: the first "filial" generation.[17] When two lineages are crossed, sometimes the character of the hybrid will resemble one parent or the other, as with Mendel's peas. But as Mendel knew, there are also crossings where the hybrid character is unlike either parent but is instead distinctive, sometimes even attractively so. It had been a perennial frustration for farmers and breeders and horticulturalists that such hybrids tended not to "breed true" but instead to have offspring with a mix of the characters. As Bateson was the first to point out, Mendelian principles explained that "breaking-up" of the hybrid character, and even, via segregation, explained why the resulting characters included the parental characters and came in the proportions they did.

Hybrids, and above all hybrid corn, went on to become the great emblem of the power of Mendelian genetics to deliver impressive results agriculturally. Hybrids and the Green Revolution went hand in hand. Hybrid seeds were what was offered as salvation in Mexico, India and elsewhere; hybrid seeds were what came to be taken for granted as the only way to get yields up high enough to stave off starvation.[18] Yet for decades, the geneticist Richard Lewontin has been arguing – another instance of counterfactual history of genetics – that there was no inevitability here. We might well have had corn as high-yielding as the hybrid corn that Nikita Kruschev famously came to admire, yet produced through open pollination and selection. But it was not in the financial interests of anyone selling the corn to produce the seeds by those means. The early promoters of hybridization were entirely plain-speaking about the fact that, from the breeder's point of view, the great advantage of using

[14] Jain, (2010).
[15] Conway and Barbier, (2013).
[16] Charnley and Radick, (2013).
[17] Bateson, (1928).
[18] Sebby, (2010); Pingali, (2012).

hybridization is that farmers need to come back to the market – and so to the breeder – year on year if they want to plant those seeds. With non-hybrid seeds, the breeder loses all control after that first sale. With hybrid seeds, control is maintained.[19]

• *No presumption against a variety whose attractive character is region-specific.* Recall the story of the farmer Jitul from Assam, who matches different plants with different parts of the life cycles of silk worms. By conserving geographically highly-delimited varieties of the plants on which his silk worms grow, he has been able to optimize the production process. He is, in the old expression, doing well by doing good: creating a market niche for a unique product in a way which maintains otherwise threatened biodiversity. And the fact that the plants mainly thrive in just a few valleys in Assam does not count against those plants, reducing their value. On the contrary, here is a marvellous example of someone working with gene-environment interactions rather than fighting them.

Of course, training in genetics is just once facet of farmer education, and training for a more sustainable future will require coordinated changes across the curriculum.[20] As a second, shorter example – but one that will lead us towards Prong 3 of this position paper – considers how farmers might usefully be taught to think in fresh ways about their innovations as their property.

From an "IP-narrow" to an "IP-broad" understanding of the ownership of innovation

Until recently, for farmer education, there would have seemed no point devoting any classroom time to intellectual property – "IP" for short. IP meant patents, plant variety protection certificates, and other legal instruments by which innovators acquired the state-sanctioned right to prevent other people from profiting from the innovations. In the world of seeds, such instruments were the province of the so-called "formal sector": the firms and associated laboratories that were in the business of bringing new seeds to market. So, for those concerned to incentivize innovation with seeds, a choice seemed to be faced. Either one could pay attention to the incentivizing role of IP, in which case, automatically, one was excluding farmer-level innovation in favour of the formal-sector firms. Or one could concentrate on farmer-level innovation in the informal sector, where the seed savers and sharers, individual and collective, operated independently (but not in isolation) from the formal sector, and independently (as well as in isolation) from the legal world of IP. After all, the kinds of "open-source", genetically and phenotypically non-uniform seeds in which the seed savers and sharers dealt simply were not the sort of seeds that could satisfy the criteria for even the lowest levels of legal protection.[21] Any concern with innovation in this sector would have to concentrate on other kinds of incentive, most obviously those to do with the enhanced status that comes with being known as an innovator.

But there is another and potentially more fruitful way to look at the situation, in line again with Radick's research in the history and philosophy of science. Yes, patents, plant variety certificates and so on are one *form* of IP. Let us call that form "IP in a narrow sense," or "IP-narrow." But the ownership of knowledge can take other forms: "IP in a broad sense," or "IP-broad." And in the sciences, as long ago recognized by the sociologist Robert Merton, public crediting as an innovator, and the status flowing from it, is the major incentivizing form of IP. To be hailed by the community as the discoverer of a new species or law of nature, with one's name appended to it forever more, is the goal for the ambitious, who, in exchange for the promise of a fair deal, willingly share their discoveries with the community as soon as possible. In Merton's view, this credit-distribution

[19] Lewontin (1991), ch. 3.

[20] On room for improvement in the way genetics is taught in India generally, see Gupta, (2019).

[21] In the section of this position paper on "Legal and Ethical Issues in the Current System," Co-I Kochupillai discusses an attempt within Indian law to recognize the work done by farmers in developing new varieties. But the retention of the DUS criteria (Distinctness, Uniformity and Stability) means that it is often difficult for farmers' indigenous seed innovations to get the offered protection. Even more problematically, the criteria are contrary to the embracing of genetic variability as a major asset for sustainable agriculture.

mechanism was absolutely crucial to the ceaseless innovation that has been Western science's trademark since the seventeenth century.[22]

A second form of broad IP identified by Radick are what he has called "productivity claims", asserted on behalf of a body of knowledge. From early days, Mendelian genetics was promoted as the intellectual key to future success in plant and animal breeding. So successful were Mendelism's partisans that it was and remains difficult to tease apart the reality from the PR when it comes to what breeders, and the rest of us, actually owe to Mendelism.[23] As we have seen, in the case of twentieth-century American seed firms, and the scientists who served them, seeds created through hybridization were attractive in the first instance because, in the absence of patent protection for novel varieties, hybrid seeds ensured future profits for the breeders. And once breeders began concentrating on hybrid varieties, innovative activity in the sector increasingly clustered around hybrid seeds, which duly improved.[24] In due course, unprecedentedly high-yield varieties were developed. But the notion that they could *only* have been developed that way is groundless. It is commercial bluster that became Cold War propaganda.[25]

Returning now to farmer education for a more sustainable future: if we ask, "How, if at all, can IP arrangements be used to incentivize farmer-level innovations in plant breeding in India, in a way that not only strengthens the traditional culture of seed sharing and exchange but promotes the wider goals of sustainable agriculture?", where before the answer would have to be "it cannot be done!", now we can say: "consider IP broad as well as IP narrow!" For farmers to understand the systematic crediting of their innovative activity with indigenous seeds not as a kind of ego-boosting bonus, but as an essential part of putting Indian agriculture on a more sustainable basis, will be empowering for them, giving them a greater stake in the system and its good management than they would have merely as individual beneficiaries, even of the monetized, Digital-Ledger-Technology-run version of the system to be described in the next part of this position paper. Likewise, it can only empower farmers to know something of the history of how hybrid seeds came to seem so irresistible, and to see it as a history in which different forms of IP were interacting. It will help them resist talk of how, by failing to embrace hybrid seeds, they are dropouts from scientific and technical modernity. At the same time, it will embolden them to see the value in developing their own productivity claims, in support of the particular seeds they work with, and more generally in support of Traditional Ecological Knowledge (TEK).

To summarize: as with genetics education, so with an education in IP: recent research has opened new possibilities for giving farmers as sustainable seed innovators intellectual tools more fit for purpose than what was available previously.

Literature Cited

Bateson, Beatrice, ed., *William Bateson, Naturalist* (1928).

Bateson, William, and Gregor Mendel. *Mendel's Principles of Heredity.* Courier Corporation (2013).

Charnley, Berris, and Gregory Radick. "Plant Breeding and Intellectual Property before and after the Rise of Mendelism: The Case of Britain." *Max Planck Institute for the History of Science Pre-print Series* (2008): 51-55.

Charnley, Berris, and Gregory Radick. "Intellectual Property, Plant Breeding and the Making of Mendelian Genetics." *Studies in History and Philosophy of Science Part A* 44, no. 2 (2013): 222-33.

Conway, Gordon R, and Edward B Barbier. *After the Green Revolution: Sustainable Agriculture for Development.* Routledge (2013).

Darden, Lindley. "William Bateson and the Promise of Mendelism." *Journal of the History of Biology* 10, no. 1 (1977): 87-106.

[22] MacLeod and Radick, (2013).

[23] Charnley and Radick, (2013); Radick, (2013).

[24] Lewontin, (1991).

[25] Perkins, (1997).

Donovan, Brian. “Playing with Fire? The Impact of the Hidden Curriculum in School Genetics on Essentialist Conceptions of Race.” *Journal of Research in Science Teaching* 51 (2014): 462– 496.

Farrall, Lyndsay A. "Controversy and Conflict in Science: A Case Study—the English Biometric School and Mendel's Laws." *Social Studies of Science* 5, no. 3 (1975): 269-301.

Froggatt, P, and NC Nevin. "The Llaw of Ancestral Heredity'and the Mendelian-Ancestrian Controversy in England, 1889-1906." *Journal of Medical Genetics* 8, no. 1 (1971): 1.

Gupta, P. K. “Teaching Genetics in India: Problems and Possible Solutions.” *Indian Journal of Genetics and Plant Breeding* 79 Supp. (2019): 326–39.

Kitcher, Philip. *The Lives to Come: The Genetic Revolution and Human Possibilities*. Allen Lane (1996).

Kronfeldner, Maria E. “Genetic Determinism and the Innate-Acquired Distinction in Medicine.” *Medicine Studies* 1 (2009): 167–81.

Jain, Hari Krishan. *Green Revolution: History, Impact and Future.* The Green Revolution History (2010).

Jamieson, Annie and Radick, Gregory. 2013. “Putting Mendel in His Place: How Curriculum Reform in Genetics and Counterfactual History of Science Can Work Together.” In Kostas Kampourakis, ed., *The Philosophy of Biology: A Companion for Educators*. Springer (2018), pp. 577–95.

Lewontin, Richard C. *The Doctrine of DNA: Biology as Ideology*. London: Penguin (1991).

MacLeod, Christine, and Gregory Radick. "Claiming Ownership in the Technosciences: Patents, Priority and Productivity." *Studies in History and Philosophy of Science Part A* 44, no. 2 (2013): 188-201.

Mordor Intelligence. "Genetic Testing Market - Growth, Trends and Forecast (2019-2024)." (2018). https://www.mordorintelligence.com/industry-reports/global-genetic-testing-market-industry.

Olby, Robert. "William Bateson's Introduction of Mendelism to England: A Reassessment." *British Journal for the History of Science* 20, no. 4 (1987): 399-420.

Perkins, John H. *Geopolitics and the Green Revoolution: Wheat, Genes, and the Cold War.* Oxford University Press, 1997.

Pingali, Prabhu L. "Green Revolution: Impacts, Limits, and the Path Ahead." *Proceedings of the National Academy of Sciences* 109, no. 31 (2012): 12302-08.

Sebby, Kathryn. "The Green Revolution of the 1960's and Its Impact on Small Farmers in India." (2010).

Radick, Gregory. “Other Histories, Other Biologies.” *Philosophy, Biology and Life,* ed. A. O’Hear. Cambridge University Press (2005): 21–47.

Radick, Gregory. “Beyond the ‘Mendel-Fisher Controversy’: Worries about Fraudulent Data Should Give Way to Broader Critiques of Mendel’s Legacy.” *Science* 350 (9 Oct. 2015): 159–60.

Radick, Gregory. "Presidential Address: Experimenting with the Scientific Past." *British Journal for the History of Science* 49, no. 2 (2016): 153-72.

Radick, Gregory. “The Professor and the Pea: Lives and Afterlives of William Bateson’s Campaign for the Utility of Mendelism.” *Studies in History and Philosophy of Science Part A* 44, no. 2 (2013): 280–91.

Russell, Peter J. *Igenetics: A Mendelian Approach.* Benjamin-Cummings Publishing Company (2006).