Institution: University of Leeds		
Unit of Assessment: 30 – Philosophy (cross-referred to History panel as History of Science)		
Title of case study: *Genetics for the Real World: Benefits to Teaching Practice and Public Awareness from Research into the Counterfactual History of Genetics*		
Period when the underpinning research was undertaken: 2003-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by the submitting HEI:**
Gregory Radick	Professor of History & Philosophy of Science	2000-present
Annie Jamieson	Research Fellow, *Genetic Pedagogies Project*	2012-2014
Period when the claimed impact occurred: 2012-present		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact (indicative maximum 100 words)

Geneticists long ago rejected the idea that genes are destiny. Yet an exaggerated picture of the power of genes – known as "genetic determinism" – remains influential, in both educational materials and popular narratives. **Professor Gregory Radick's** original research into a foundational debate in genetics has provided new support for an alternative emphasis on the variable effects that a gene can have in different developmental and environmental contexts. **Radick's** research has had impacts on: (i) science teachers and educators in the UK, Brazil, US and New Zealand, enabling the development of alternative genetics curricula, and (ii) science communicators whose work informs public awareness.

2. Underpinning research (indicative maximum 500 words)

Professor Gregory Radick has contributed over a decade of research on the early history of genetics, a key strand of which re-centred the little-known Oxford biologist W. F. R. Weldon (1860-1906) and his critique of Mendelism (**I**). The struggle over the foundations of the science of heredity raged in the early twentieth century following the rediscovery of Gregor Mendel's research on peas in 1900, with William Bateson eventually winning out on behalf of the more reductive and genetically-determinist Mendelism. In contrast, **Radick** has highlighted Weldon's emphasis on how differences in internal and external environments can modify the effects of a gene (**1**, **2**), and has used the well-known concern that Mendel's data were "too good to be true," as first pointed out by Weldon, in order to publicise the conceptual critique that Weldon saw as the real lesson to draw from Mendel's data problems. As such, **Radick** has steered the contemporary debate back to the issues that Weldon was highlighting: the non-binary variability of actual organisms, and the multifactorial interactions which explain that variability (**3**).

Could the Bateson-Weldon debate have gone differently? In his 2015 British Society for the History of Science Presidential Address (a summary of which was published in the science journal *Nature* in 2016), **Radick** urged peers to move past the stalemate of whether or not anything can be known about the might-have-been (counterfactual) past and get on with the job of improving knowledge of it, creatively and constructively (**4**). Alongside **Dr Annie Jamieson** and Dr Jenny Lewis, **Radick** took up his own provocation in the *Genetics Pedagogies Project* (2012-2014, **II**). The project explored effects on student attitudes and learning had Weldonian rather than Mendelian emphases become fundamental in genetics. The team produced and tested an experimental Weldonian curriculum that stressed the role of developmental and environmental contexts in modifying the effects of genes (as against the usual stress on "gene for" Mendelism). They found that students taking a Mendelian course were on average just as determinist about genes at the end as they were at the start, whereas students taking the Weldonian course were on average less determinist, to a statistically significant degree (**5**, **6**).

The award of a Leverhulme Major Research Fellowship to **Radick** (2017-2019, **III**) enabled him to expand his research into the significance of these findings, inspiring him to develop and run three Continuing Professional Development (CPD) events for secondary-school teachers of genetics in 2020. His research into the wider project of "Weldonizing" the genetics curriculum has continued thanks to a $1.2 million grant from the US National Science Foundation, *Honoring the Complexity of Genetics* (2020-2023), funding a collaboration with genetics-education specialists at Cornell and Biological Sciences Curriculum Study, and involving genetics teachers at over 50 colleges and universities across the US (**IV**).

3. References to the research (indicative maximum of six references)

1) G. **Radick** (2005) "Other Histories, Other Biologies." In *Philosophy, Biology and Life*, ed. A. O'Hear. Cambridge: Cambridge University Press, 21–47. Supplement to *Philosophy*, Royal Institute of Philosophy Supplement: 56. Submitted in REF 2008.
2) G. **Radick** (2011) "Physics in the Galtonian Sciences of Heredity." *Studies in History and Philosophy of Biological and Biomedical Sciences* 42: 2, 129–38. https://www.sciencedirect.com/science/article/pii/S1369848610001123?via%3Dihub
3) G. **Radick** (2015) "Beyond the 'Mendel-Fisher Controversy': Worries about Fraudulent Data Should Give Way to Broader Critiques of Mendel's Legacy." *Science* 350: 6257 (09.10.2015), 159–60. https://science.sciencemag.org/content/350/6257/159
4) G. **Radick** (2016) "Presidential Address: Experimenting with the Scientific Past." *British Journal for the History of Science* 49: 2, 153–72. https://doi.org/10.1017/S0007087416000339. First presented by **Radick** in lecture form in July 2015 when President of the British Society for the History of Science.
5) A. **Jamieson** & G. **Radick** (2013) "Putting Mendel in His Place: How Curriculum Reform in Genetics and Counterfactual History of Science Can Work Together." In *The Philosophy of Biology*, ed. K. Kampourakis. Dordrecht: Springer, 577–95.
6) A. **Jamieson** & G. **Radick** (2017) "Genetic Determinism in the Genetics Curriculum: An Exploratory Study of the Effects of Mendelian and Weldonian Emphases." *Science and Education* 26: 1261–90. https://link.springer.com/article/10.1007/s11191-017-9900-8

Grants

I) AHRC Award: *Owning and Disowning Invention* (Sept. 2007–Sept. 2010, **£388,971**). PI: Graeme Gooday (UoL); Co-Is: Gregory **Radick** and Christine MacLeod (Bristol).
II) Faraday Institute for Science and Religion Award: *Does the Teaching of Mendelian Concepts Promote Genetic Determinism? The Differential Effects of Mendelian and Non-Mendelian Pedagogies* (Sept. 2012–Aug. 2014, **£119,385**). PI: Gregory **Radick**; Co-I: Jenny Lewis (UoL); Research Fellow: Annie **Jamieson** (UoL).
III) Leverhulme Major Research Fellowship: *Disputed Inheritance: The Battle over Mendel and the Future of Biology* (Oct. 2017–Sept. 2019, **£95,122**). PI: Gregory **Radick**.
IV) National Science Foundation (US) Award: *Honoring the Complexity of Genetics: Exploring How Undergraduate Learning of Multifactorial Genetics Affects Belief in Genetic Determinism* (Jan. 2020–Jan. 2023, **$1.2 million**). PIs: Brian Donovan (BSCS), Michelle Smith (Cornell); Co-PI: Gregory **Radick**.

4. Details of the impact (indicative maximum 750 words)

i) Continuing professional development for biology teachers: supporting the design and implementation of "real world" genetics curricula

Building on the pilot module at Leeds providing undergraduate students with an alternative Weldonian curriculum (developed by **Radick**, **Jamieson** and Lewis in 2012-14), **Radick** has since adapted and extended the approach to underpin a series of CPD events for school-level teachers. Overall 27 secondary school teachers, from trainees to department heads and teacher educators, participated in **Radick** and colleagues' free "Refresh your Genetics Teaching" courses, introducing them to the Weldonian curriculum and its potential impact and significance for class teaching. Three iterations of the course – one local, one national, and one international (01.07.2020; 14.11.2020; 11.12.2020) – drew teachers from North and West Yorkshire, London, Somerset and New Zealand, with an average class size of 25 students per teacher (**A**).

The CPD sessions were enthusiastically received across the board, meeting a need articulated by both UK- and New Zealand-based teachers for curricula that reflect up-to-date "*real world*" genetics, by embracing the complexity of inheritance rather than ignoring it. A Yorkshire-based teacher (Appleton Academy) observed: *"One of the vision statements for our department is that we prepare students for science in the real world and our current method of genetics teaching doesn't do that."* The Weldonian curriculum provided a means *"to combat the confused faces when teaching genetics,"* the *"struggle"* to explain inheritance using *"examples like eye colour when students can clearly see that what we are telling them about genes doesn't work,"* and instead allowing *"our students […] a clearer more accurate understanding of genetics and giv[ing] them the tools to be better prepared to understand the topic in the 'real world'"* (**A**). This was affirmed by a New Zealand-based Junior Science and Senior Biology Teacher (Bay of

Islands College), who appreciated *"such a clear and holistic path to changing the way genetics can and should be taught and to giv[ing] our students a more complete, relatable and realistic picture of how genetics works"* (**A**).

The CPD sessions introduced a new, complexity-first structure in genetics teaching alongside easily integrated materials that allowed for immediate changes to be made in individual teaching practice. *"I will immediately start teaching in a more flipped model and will incorporate the Weldonian model and [use it] to link my other science topics together,"* wrote one teacher (Bay of Islands College). Another wrote: *"For me the instant change I could make is to the teaching sequence. Rather than teaching these simple examples, […] what about instead starting with that bigger picture and then talking about removing variables to make it simple?"* (Appleton Academy). (**A**) A Special Educational Needs Coordinator (SENCO) and teacher (Rastrick High School, West Yorkshire) even revised her lesson plan for the next day; in line with her new ambition *"to stress the importance of environmental influence and the lack of single-gene traits,"* she incorporated a news story she had found about identical twins who did not look at all similar. The PowerPoint slides she amended in response to the CPD session went far beyond the use of this new example in emphasising variability and complexity in genetics as the rule rather than the exception (**B**). The teacher fed back that the *"class [of 25 students] were very engaged with [the lesson] and it felt quite liberating to be teaching it in such a different [way] […] I am certainly going to carry on adapting lessons now and put more emphasis on the environmental impact. It is mind-blowing that we [have been] teaching such out of date (and incorrect) concepts!"* (**B**)

Another teacher (Halifax Academy, West Yorkshire) circulated a detailed summary to her departmental colleagues following the CPD session, in which she wrote:

> *we discussed how students having an overstated idea of how our phenotype depends on on our genes can lead to them having a fixed mindset, which can be very dangerous. I thought of the example where our students say 'I have hot blood', which translates from Urdu/Punjabi to mean they are passionate or have a short temper. I wondered if our students may think that this is genetic, and therefore there is nothing they can do about it, and in fact whether they also think that intelligence or 'being good at science' is also genetic. This idea may act as a barrier to our students ever having a growth mindset.* (**A**)

She subsequently reported that her colleagues' "*feedback was that this was really useful and interesting, and reflected that we may tweak our KS3 scheme in the light of this."* (**A**)

Teachers observed that the CPD material could easily be adapted and integrated, enabling them to meet formal assessment requirements while nevertheless effecting social change. As one teacher commented: *"students can still get those marks in the exam but actually they've got a broader view of how genetics works in the real world."* (Appleton Academy) (**A**). For new teachers the CPD fostered confidence in teaching a more complex story. As one wrote:

> *As a new teacher to the profession the course challenged the way I deliver my lessons and the order in which I scaffold the learning. Most importantly it changed my thoughts on how to address the complexity of scientific concepts and has made me more confident in sharing the complex nature of science with my students. I believe this viewpoint will not only enhance my genetics teaching but also my teaching of science in general.* (Science Teacher, Nayland College, NZ) (**A**)

Beyond the CPD programme, **Radick's** research has also been influential for teachers of genetics from graduate down to secondary level in Brazil, the US and – independently of the CPD – New Zealand. In Brazil, the intermediary has been an eminent professor of science education and Darwin scholar at the University of São Paulo (USP, Brazil's largest public university and its most prestigious, ranked first by *THE* in 2019), who has been using **Radick's** work as *"a central reference"* in his postgraduate courses since 2013. In 2017 he created a postgraduate module inspired by **Radick's** *"radical"* take on counterfactual history, joined by c.20 students per year (c.60, since its inception) (**C**). The video of **Radick's** 2012 inaugural lecture at the University of Leeds is used to kick off the module, with various publications included as key course reading (such as **6**). The professor has delivered lectures and conference papers that include discussion of **Radick's** counterfactual historical research at science education conferences and events across Brazil, as well as in Portugal and Spain; he estimates reaching c.1,000 attendees per year since 2013 (**C**).

For former students of the module, **Radick's** research has had longstanding effects on their careers in science education. Currently Pedagogic Coordinator at Univesp (Virtual University of São Paulo State) one former student (and trained teacher) observed:

> *when it comes to [**Radick's** critique of] Mendelian genetics, it had remained on me a strong message: as teachers and curriculum designers we can not ignore proper explanations about dominance and inheritance, nor the need to avoid oversimplification.* (**D**)

This has driven him to design science curricula that allow for complexity. Another former student, a teacher and current PhD candidate in science education, noted that because of **Radick's** work, in the classroom:

> *I 'lost the fear' of starting discussions about heredity without Mendelian inheritance. Mendelian genetics is the traditional approach (at least in Brazil) and has a historical assumption in starting the discussions about heredity through Mendel's work. Counter-factual history allows us to challenge this static curriculum.* (**E**)

In the US, for the associate professor who convened Illinois State University School of Biological Science's graduate seminar on post-secondary biology teaching (2018-19), **Radick's** research has been crucial for fostering reflexive science educators and providing the basis of a toolkit for redesigning genetics curricula. The associate professor wrote:

> *discussion of your article* [**6**] *[…] was nothing short of earth-shattering for the future biology professors in the graduate seminar. Not only did it inspire a discussion of the dangers of not situating scientific discoveries into their cultural contexts, but we were able to identify specific actions they could take as instructors teaching genetics* (**F**)

Radick and **Jamieson's** 2017 article (**6**) *"has provided me [with the] inspiration to continue [addressing how genetics is taught], and I like to think several future educators' ideas about how genetics should be taught have been influenced by the discussion of this single article."* (**F**).

Radick's *Nature* article (**G**) prompted a US high-school science teacher to get in touch and observe: *"Whenever teaching the conventional approach to genetics, I always felt the students did not fully appreciate the complexities of the interactions that occurred. I had never thought of approaching the topic as you describe, but it makes perfect sense*" (cited in **6**, p.124 fn3). Moreover, since 2018, an adapted version of the Weldonian curriculum produced in the *Genetics Pedagogies Project* has been run for Year 10s (14-15 years) at ACG Parnell College, a secondary school in New Zealand. The teacher – the Head of Middle School Science (ages 11-15) – who introduced it was *"inspired by"* **Radick's** research and used it *"as a justification to change up my school's current genetics curriculum."* The Weldonian curriculum

> *is particularly relevant in New Zealand both because the availability of genetic testing is on the rise and we have had issues in the past with the 'Warrior gene' controversy which was to some degree textbook genetic determinism* [suggesting that Maori people are genetically predisposed to violence; he expands on the changes made, for] *example, I introduced the teaching of complex, multifactorial traits and placed it in the teaching schedule before the teaching of Mendelian traits. I removed the teaching of dominance from the curriculum, introduced a section on genetic determinism, genetic testing and the concept of relative risk, among other changes.* (**H**)

The school has c.150 students in its Year 10 programme and *"getting the curriculum right is important, particularly as it is the last year they have to take Science."* (**H**) The teacher has also drawn upon **Radick's** research in presentations at Science Teacher Conferences in New Zealand, and was instrumental in organising his peers to participate in the 3rd CPD event.

ii) Changing and helping complexify public awareness of genetics

Radick's re-centring of Weldon in the history of genetics has reached various publics through several popular scientific channels. An overview by **Radick** of the *Genetics Pedagogies Project* appeared in the leading scientific journal *Nature* (2016; online readership c.3 million unique readers per month; **Radick's** research was the subject of one of that issue's editorials, and an interview with **Radick** was included in a linked podcast with Kerri Smith) and subsequently in German translation in the leading German science education journal, *Der mathematische und naturwissenschaftliche Unterricht* (2017, trans. U. Kattman) (**G**). His revival of Weldon's critique of Mendel has also been taken up by prominent British science journalists in their own attempts

to complexify popular understandings of genetics and thereby change public understanding of genetic determinism. In her critique of Mendelism's role in race science, the award-winning writer Angela Saini quoted from her interview with **Radick** on his historical research on Weldon in her critically acclaimed 2019 book *Superior: The Return of Race Science* (**I**; a *Financial Times*, *Guardian*, *New Statesman*, *Sunday Times*, *Telegraph* and Smithsonian Book of the Year; included in *Nature*'s 10 best books of 2019). A US postdoctoral researcher in biology education discovered **Radick's** research via Saini's book in early December 2020 and now plans to "Weldonize" her own future biology teaching, as it transformed her understanding of genetics:

> *Mendelian genetics were such a fundamental part of my biology education that I had never thought to question the conditions and assumptions that would have been necessary to get the Mendelian ratios of phenotypic ratios. Reading about Dr.* ***Radick's*** *research on Weldon prompted me to think about what our frameworks for genetics might have looked like had he lived longer and been able to popularize his ideas.* (**J**)

Radick's research similarly featured in award-winning science journalist and podcaster Kat Arney's popular genetics book *Herding Hemingway's Cats* (2016; reviewed in *Science*, *The Guardian*, *BBC Focus*, *National Geographic*), where again Weldon featured in the narrative of the early days of genetics in order to problematise genetic determinism. Crediting **Radick**, Arney wrote: *"The rediscovery of Weldon's peas owes much to the persistence of science historian Greg* ***Radick*** *at the University of Leeds*" (**G**). Canadian cultural psychologist Steven J. Heine also cites **Radick** to support his critique of Mendelism in his popular book on genetic literacy, *DNA is not Destiny* (**G**). While most recently, in *Are we Slaves to our Genes?* (2020), a critique of genetic determinism aimed at general readers seeking to understand the latest in genetic discoveries, the Cambridge-based biochemist Denis Alexander discussed the findings of the Weldonian curriculum taught in **Radick's** *Genetics Pedagogies Project* (**G**). Other science writers to draw attention to **Radick's** revisionist account include Karen Zusi (*The Scientist,* 31.01.2016; c.1,674,330 users monthly (July 2019)) and Javier Sampedro in 2015 (*El Pais;* c. 56.6m unique users monthly worldwide (2020)). **Radick's** role in framing current popular understandings of Weldon's contribution to genetics is evidenced by keyword searches using "Weldon peas" or "Weldon genes" on Google, Bing and Yahoo search engines: the top five results across the board include articles or podcasts that review, cite or are indeed links to **Radick's** own research outputs (02.06.2020, **G**).

Collectively, these impacts demonstrate the importance of **Radick's** revisionist interpretation of the history of genetics across multiple national contexts. His work in actively popularising this approach in education and society has resulted in extensive adoption of new, Weldonian-inspired curricula and narratives of genetics, with significant longer-term consequences for eroding the perception that genes determine critical aspects of individual destiny.

5. Sources to corroborate the impact (indicative maximum of 10 references)

- **A)** "Refresh your Genetics Teaching," 3-hour CPD Sessions Feedback (01.07–11.12.2020).
- **B)** *SENCO & Science Teacher, Rastrick High School, email correspondence with PowerPoint attachments, showing adaptations to her genetics lesson (27.11.2020).
- **C)** *Professor and Scientific Co-ordinator, NAP EDEVO/ Darwin, USP, letter (05.01.2020).
- **D)** Pedagogic Coordinator at Univesp, email correspondence (05.04.2020).
- **E)** Teacher and PhD Candidate, Brazil, email correspondence (28.03.2020).
- **F)** Associate Professor and Director, Center for Mathematics, Science and Technology, Biological Sciences, Illinois State University, email correspondence (12.10.2020).
- **G)** "Media & Popular Science Reach Report, 2014-2020: Professor Gregory **Radick**" (UoL, 2020), composite evidence, including G. **Radick** (2016) "Teach students the biology of their time," *Nature* 533: 7603, 293 (19.05.2016); Anon (2016) Editorial: "Second Thoughts: Revisiting the past can help to inform ideas of the present," *Nature* 533: 7603, 291-92; plus PDF of search engine rankings. (02.06.2020)
- **H)** *Head of Middle School Science, ACG Parnell College, New Zealand, email correspondence (03.09.2019).
- **I)** *A. Saini (2019) *Superior: The Return of Race Science* (Boston: Beacon), pp. 71-4. Available on request.
- **J)** Postdoctoral Research Associate, Biology Education Research Lab, Arizona State University, email correspondence (06.02.2021).