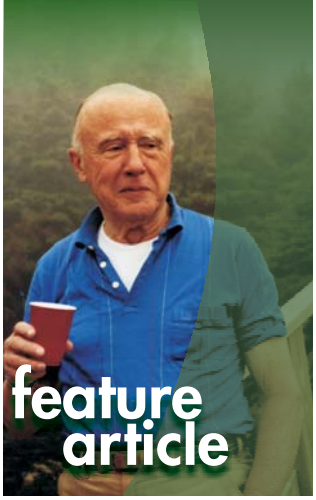

John Wheeler's mentorship: An enduring legacy

Terry M. Christensen

"We all know that the real reason universities have students is in order to educate the professors."
—John Archibald Wheeler, 1976

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> "There was never a professor more ready and able to communicate with students. Immediately grasping the exact point at which a student's understanding broke down, you would offer the perfect analogy to bring the light of understanding. . . . If I can manage to offer my students but a fraction of what you have offered me, I will have served them well indeed."
> —Letter from Charles Patton to John Wheeler[1]

John Archibald Wheeler was one of the foremost physicists of the 20th century, and his influence will long endure. His many important contributions to our body of knowledge (see the articles by Kenneth Ford, page 29, and by Charles Misner, Kip Thorne, and Wojciech Zurek, page 40, in this issue) are matched by his enthusiasm for working with students and their enthusiasm for working with him. I contend that Wheeler's most significant contribution was not to the corpus of physics but rather to the community of physicists.

Physics research is, of course, a cumulative enterprise. Today's magnificent breakthrough is tomorrow's building block, which, in turn, will serve to support the next breakthrough. Along with this summing of ideas comes the multiplicative influence that a skillful mentor has on generations of scientists, whether or not they are adequately aware of their intellectual heritage.

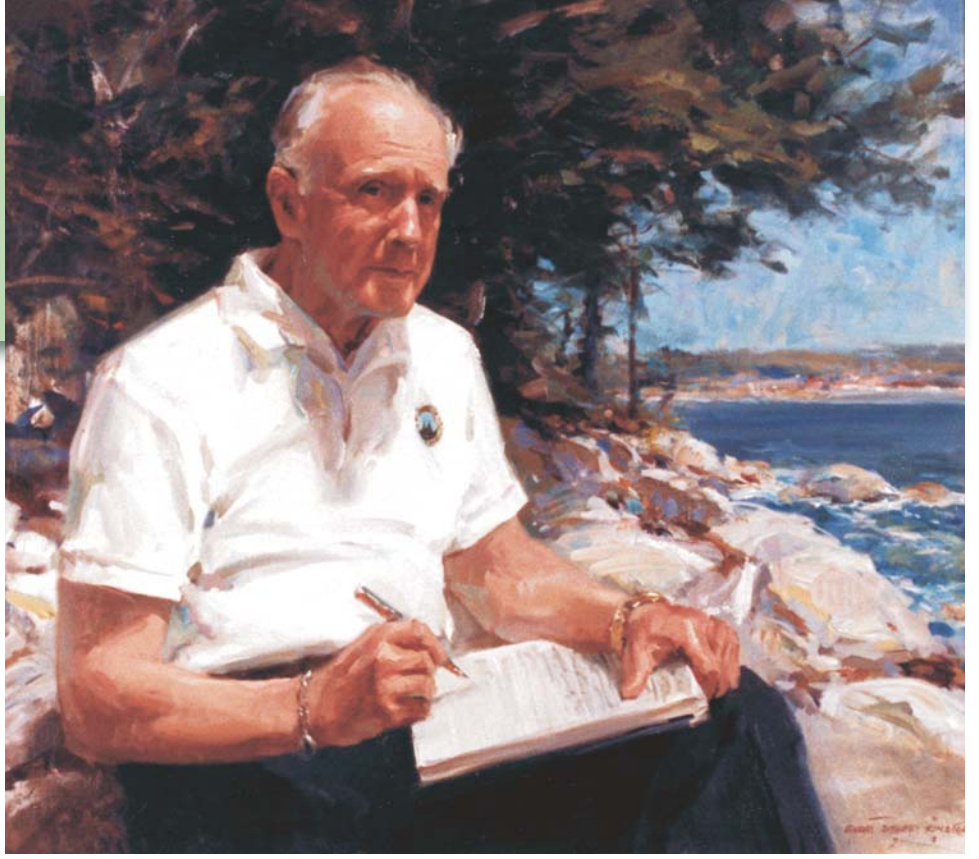
Wheeler's own advisees were surely cognizant of being part of an honored lineage, which passed from Wheeler's own mentors—Karl Herzfeld, Gregory Breit, and Niels Bohr—through Wheeler, and then through them to their own students. In the ceremony accompanying the formal presentation of the 1977 festschrift *Family Gathering*,[1] Misner alluded to "workings of the apprentice system by which research attitudes and methods are passed on." Referring to Wheeler's influence, Ford wrote, "There is an army of physics students in the United States whose view of nature and whose view of physics is more powerfully colored by the personalities and intellects of Niels Bohr and John Wheeler than they know." Still others (a hundred of Wheeler's former students and colleagues contributed to *Family Gathering*) spoke of "Wheelerisms" and the "Wheeler spirit" they later incorporated into their own mentoring. The five separate festschrifts[2] that were created over the years in Wheeler's honor testify to the esteem in which he was held by the more than 113 students he had worked with on an individual basis.

The sense of shared intellectual heritage that Wheeler's former students have so often articulated is well founded. Sociologists of science have determined that patterns of thought and ways of seeing—intuitive as well as concrete—are often transmitted from mentor to apprentice. Sociologist Harriet Zuckerman has examined the master–apprentice relationship of Nobel laureates and noted that among the elite of any scientific community, skillful mentors and talented apprentices tend to seek each other out.[3] In addition to pointing out

Mentoring at Princeton University 1938–78*

Professor	PhD theses supervised	PhDs per year	Extra acknowledgments†	Senior theses supervised
John Wheeler	46	1.22	19	46
Thomas Carver	16	0.76	13	21
Robert Dicke	25	0.81	8	11
Val Fitch	15	0.71	5	5
Marvin Goldberger	19	0.95	10	4
Rubby Sherr	14	0.45	17	11
Sam Trieman	24	1.04	16	4
Arthur Wightman	24	0.93	14	11
Eugene Wigner	25	0.83	16	0

* Physics PhD and senior theses supervised during 1938–78 at Princeton by the nine professors who supervised the most doctoral theses during that period.
† Acknowledgments in PhD theses thanking a professor other than the adviser of record.



John Wheeler in 1989 at his summer home on High Island, Maine, painted by Everett Raymond Kinstler. The portrait hangs in Princeton University's Jadwin Hall and is reproduced here with the artist's permission.

Wheeler's intellectual lineage, she traces that of biochemist Hans Krebs (1900–81) through seven generations (including four Nobel laureates) all the way back to Antoine Lavoisier (1743–94).

So what sets Wheeler apart? Sheer numbers, for one thing. In his 3 years on the faculty at the University of North Carolina (1935–38) and 38 years at Princeton University (1938–76), Wheeler supervised 47 doctoral dissertations and was a coadviser on 4 more. Then, at the University of Texas at Austin (1976–86), he supervised 4 more doctorates and served as a cosupervising professor on 1 more. That comes to about 1 dissertation per year throughout his five-decade professorial career. For calibration, consider a 1993 estimate by Caltech's David Goodstein that over the course of a career, a professor at a major research university will, on average, supervise 15 dissertations.[4]

Comparing the PhD production of any particular group of professors is complicated by the fact that even senior professors migrate from one institution to another. Again, Goodstein supplies calibration. In 1993, the year of his estimate, physicists received their PhD at a median age of 30.4. Presuming a retirement age of 65, Goodstein's average professor would supervise a PhD dissertation every 2.3 years. One wonders if Wheeler's higher rate is characteristic of Wheeler or of the institutions where he taught. The table on page 55 compares his PhD production at Princeton with those of the eight physics-department contemporaries who, after Wheeler, supervised the most PhD theses.

Not just dissertational obstetrics

The table's rightmost column is especially revealing. Mentoring, for Wheeler, was far more than simply dissertational obstetrics. Welcoming the opportunity to work with undergraduates, he supervised far more senior theses than anyone else on the list. And later at Texas he supervised more than his share of master's theses. In consequence of their relationships with Wheeler, many of those seniors and master's candidates went on to establish long-term, collaborative relationships with other Wheeler progeny, regardless of age differences. Among the eminent physicists who were influenced as undergraduates by personal contact with Wheeler are James Hartle, David Sharp, Bruce Partridge, Anthony Zee, and Gary Horowitz.[1]

Wheeler also served as mentor to a number of postdoctoral fellows, and he supervised a good many "junior papers" (a requirement for third-year physics majors at Princeton). Those mentoring activities are not systematically documented, but there's much anecdotal evidence of his work with juniors and postdocs. Yale University science historian Daniel Kevles recalls working on his junior paper under Wheeler's direction at Princeton. "It was my first experience doing independent work on a theoretical project. Wheeler was generous with his time and encouraging with his criticism. I came away from the project with more confidence and fond memories."

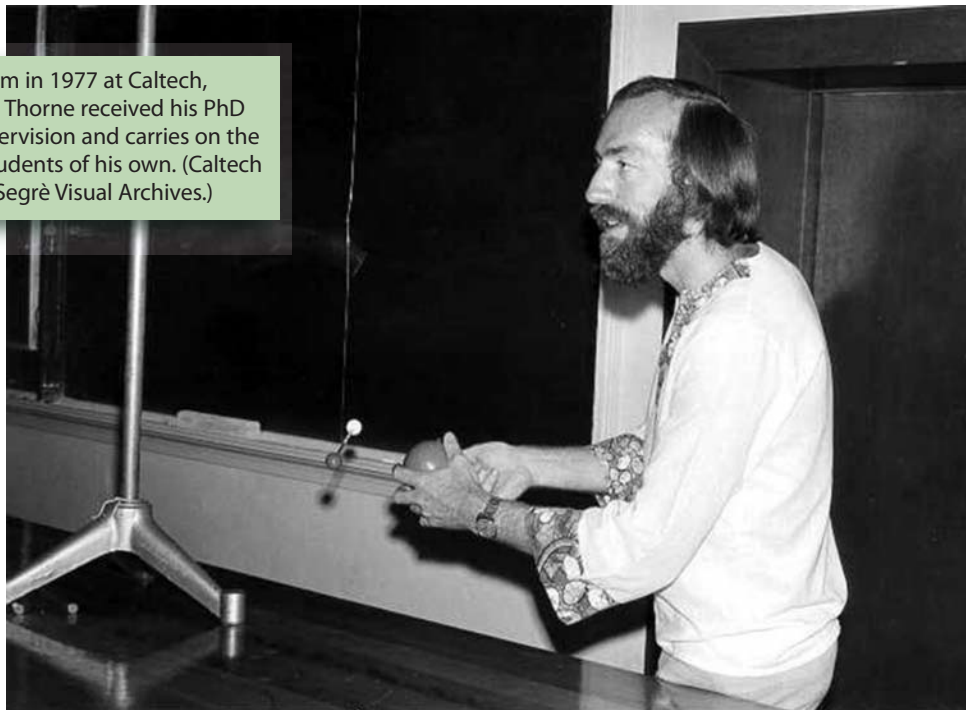
Wheeler was also known to make himself readily available to assist students who were not his advisees. His assistance and counsel were acknowledged in quite a number of dissertations for which he was not the adviser (see the fourth column in the table on page 55). For example, William Wootters, in the acknowledgments of his 1980 PhD thesis on quantum measurement theory, wrote,

> Professor Wheeler, having awakened my interest in the foundations of quantum mechanics, generously gave much of his valuable time to discuss with me the problems and prospects of physics at its most fundamental level, and transferred to me his belief that the hardest problems can yet be solved.

Paul Boynton, though not a Wheeler advisee, described him to me as "one of the most memorable and effective mentors I ever encountered. He has been an inspiration to me throughout my life, and not just my professional life." Claudio Bunster (formerly Teitelboim), whose thesis adviser at Princeton was Karel Kuchar, acknowledged in his 1973 PhD thesis on general relativity that

> I have been struggling for a long while to find words for expressing my deepest gratitude to John Wheeler. I have not found them. He has given me so much that any acknowledgement seems insignificant. I can only say that, through my contact with him, I have discovered a new world. I shall remain indebted to him forever.

Moreover, Wheeler significantly influenced many peo-



Kip Thorne delivering a colloquium in 1977 at Caltech, where he is a professor of physics. Thorne received his PhD in 1965 under John Wheeler's supervision and carries on the mentoring tree with many PhD students of his own. (Caltech photo, courtesy of the AIP Emilio Segrè Visual Archives.)

ple with whom he had comparatively little individual interaction. Three weeks before his death in April 2008, he received a letter from astrophysicist Adam Burrows, who had just joined the Princeton faculty. Noting that although he had merely been a Princeton undergraduate in three courses taught by Wheeler, the teacher's enthusiasm was contagious and he caught the bug.

> So, I have come full circle back to Princeton. . . . I am writing this letter to thank you for the inspiration you provided me during my salad days, for the stimulating courses you taught, for your generous mentorship, and for the glimpse you provided me of physics at its best. I have often thought over the years about your role in sparking my interest in gravitation in particular, but astrophysics in general, and wanted to send you this modest note of gratitude upon my return to Old Nassau.

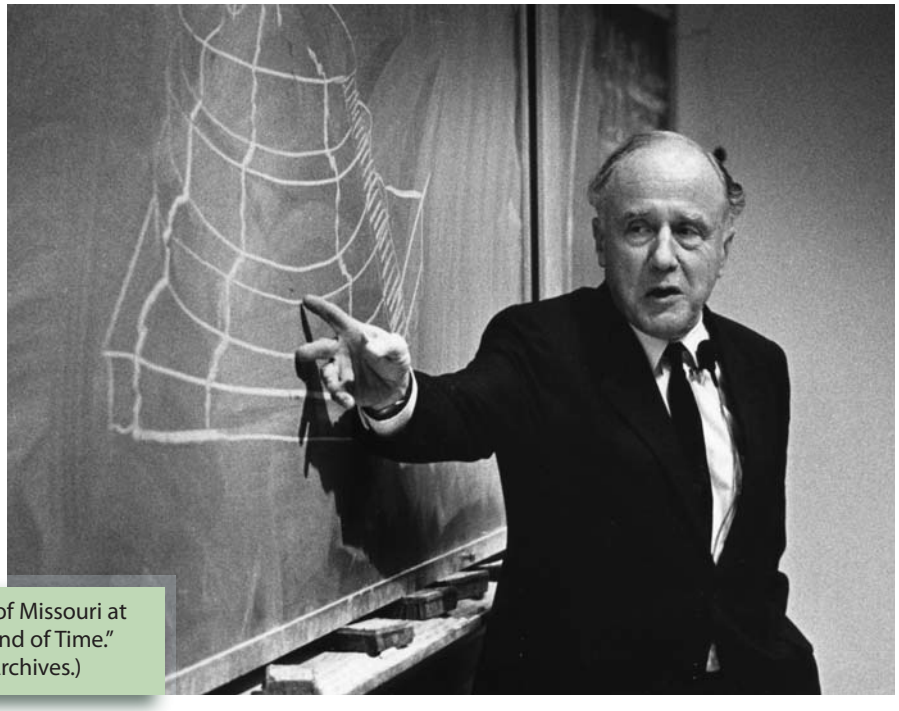
Ye shall know them by their fruits

What is the substance on which all those testimonials stand? How is mentoring different from straightforward teaching? An important part of mentoring is teaching students how to think about the information already in their possession. One of the physicists interviewed by Zuckerman put it this way:

> I knew the techniques of research. I knew a lot of physics. I had the words, the libretto, but not quite the music. In other words, I had not been in contact with men who were deeply imbedded in the tradition of physics. . . . This was my first real contact with first-rate creative minds at the high point of their power.[3]

Such sentiments are often expressed by Wheeler's students. But testimonials are highly subjective. Are there more objective criteria for measuring a mentor's efficacy? One gauge is the quality of the scientific output by a mentor's former students. Nobel laureate Richard Feynman got his PhD under Wheeler in 1942. In his 1965 Nobel lecture, Feynman credited Wheeler for inspiring a new perspective on electrodynamics.[5] Of course, Nobel prizes are rare. A more widely applicable measure of one's scientific workmanship would be citation data, specifically the number of times one's work is cited by other scientists.

Here again, some calibration is in order. MIT science historian David Kaiser has suggested adopting the classification standards of SLAC's SPIRES database of particle-physics literature and employing those standards in evaluating the impact of publications in all fields of physics. In the SPIRES scheme, papers that are cited at least 500 times are classified as "renowned," a category that includes less than 0.5% of all particle-physics papers. Papers cited 250–499 times are "famous," and those cited 100–249 times are "very well known."



John Wheeler in 1981 at the University of Missouri at Rolla, giving a talk entitled "Beyond the End of Time." (Courtesy of the AIP Emilio Segrè Visual Archives.)

Recollections of Wheeler

John Wheeler's mentoring style is captured in the following quotes from his former students, compiled by Kip Thorne. To set the time frames, which span 50 years, we indicate the year that each student completed his study with Wheeler.

Charles Misner (PhD 1957): "When teaching, John focused on inspiration before content. In any course his first lecture would cover something he was very enthusiastic about. This was usually a research project he or his students were working on. He would give an impression of the questions at the forefront and then explain how they were being attacked. Then he would slowly morph that into the subject of the course and begin to get down to brass tacks."[6]

Kenneth Ford (PhD 1953): "In 1949 I took a course on classical mechanics from John Wheeler. This subject, considered dry and lifeless by some professors, came alive in Wheeler's hands, as he tried to wrest new insights from Hamilton–Jacobi theory. His lectures were rarely polished or 'elegant', which was a source of distress for some students. His approach might best be described as 'personal.' He tried to refashion each part of the subject in his own terms. . . .

We learned by watching him learn. Unafraid to stumble before students, he led us down his paths of thinking, including the twisting turns and the retreats."[1]

Wojciech Zurek (PhD 1979, postdoc 1979–81): "Perhaps the greatest lesson I learned in Wheeler's classes came when—after a half hour of carefully calligraphed derivations that covered several blackboards—John discovered an error had crept into his calculations early on. Without hesitation, and in capital letters that were larger than anything else on the blackboards, he wrote 'WRONG,' and crossed out all the boards! A sense of liberation swept the class. It was possible to be a great scientist and admit that you are WRONG, in capital letters." (Letter to Thorne shortly after Wheeler's death)

Kip Thorne (PhD 1965): "At age twenty-two I had just arrived at Princeton as a graduate student. My dream was to work on relativity with John Wheeler, so I knocked on his office with trepidation. Professor Wheeler greeted me with a warm smile, ushered me into his office, and began immediately (as though I were an esteemed colleague, not a total novice) to discuss the mysteries of the gravitational implosion of a star at the end of its life. . . . I emerged an hour later, a convert and disciple."[7]

Daniel Holz (AB 1992): "[In 1990, as an undergraduate looking for a thesis adviser,] I waltzed into Wheeler's office and asked if he had any projects I could work on. I staggered out of his office four hours later, laden with books, a clearly defined project in my hands."[8]

Richard Lindquist (PhD 1962): "I first became aware of your awesome capacity for hard work, John, during the winter and spring of 1956–1957, around the time of the Relativity Conference at Chapel Hill. No one but you would have had the audacity to co-author a dozen or so separate papers on as many separate topics, and with a like number of different co-authors, [all your students and] all for the same conference. No one but you could have had the brilliance and indefatigability to bring it off! You were determined that your students should get credit for these labors; but everyone knew, not least of all ourselves, that the ingenuity and inspiration were yours, and that your strong right arm had been pushing each of us along at the fastest pace he could manage without stumbling." (Letter to Wheeler[1])

Robert Geroch (PhD 1967): "Wheeler had a global view. He forced you to look out and not be too small. 'If you want to know the answer to this,' he would say, 'let's phone Madam Choquet in Paris right now. If you're interested in topic X, then we better fly in Roy Kerr from Texas to explain it to us.' One comes to graduate school with a kind of 'backing off' attitude, an awe of the big names. He was very good at breaking that. . . . I did not find Wheeler useful on technical things. If I wanted to know, 'Is it true that a spacetime with seven Killing fields actually has ten?' it was not useful to ask him. (But it may have been best that way.) He

Papers cited less often are classified as "well known" (50–99 citations) and "known" (10–49 citations).

Applying that classification scheme to Wheeler's students yields striking results. Eleven of his former graduate students have authored (or coauthored) "renowned" papers. They are Feynman, Misner, Thorne, Jacob Bekenstein, Hugh Everett, David Hill, Bei-Lok Hu, John Klauder, William Unruh, Robert Wald, and Arthur Wightman. Nine more have authored "famous" papers, and another nine have contributed "very well known" papers. In total, more than half of Wheeler's former graduate students have made contributions to the corpus of knowledge that are, at a minimum, "very well known" to their peers. For comparison, less than 7% of all particle-physics papers have 100 or more citations. As a group, Wheeler's students were particularly influential in the development of physics in the 20th century.

Let us examine Wheeler's impact in another way. I have analyzed the content of acknowledgments in each of the dissertations and theses submitted—not just by Wheeler's students—during his years at Princeton and Texas. Most of those acknowledgments were largely pro forma—for example, thanking the adviser "for suggesting this problem and for continued advice." A fair number offered more specific expressions of appreciation. There were also a very few superlative acknowledgments, proclaiming that a deep and profound understanding of the craftsmanship of science had been transferred from mentor to apprentice. They typically took forms like "Thanks to Professor XYZ, I now know what it means to be a professional physicist," or "I thank professor XYZ for providing me a wonderful example of how physics should be done." No professor at Princeton and only one at Texas received more of such superlative acknowledgments than Wheeler. One intriguing aspect of the superlative acknowledgments is that Wheeler received two of the warmest expressions of gratitude from students doing experimental-physics theses for whom he was obviously not the adviser.

In Homer's *Odyssey*, the goddess Athena (disguised as the eponymous Mentor) instills confidence in Odysseus's son Telemachus so that "among people he might win a good reputation." The practice continues among modern mentors. Zuckerman observes that an important aspect of scientific mentoring is the inculcation of professional standards and conduct—a process she calls socialization.[3] Dan Holz, John Wheeler's last advisee of record, summarized his own socialization as follows:

> It is a pleasure to acknowledge the tremendous support and encouragement given to me by

was very good, on the other hand, with research technique. He taught one to try different approaches to problems. You should be a little aggressive sometimes, and sometimes you should be very careful. You should keep the big picture in mind. If a problem got too difficult, you should look for simpler examples. And if your problem is too hard, maybe you should look at the broader picture in search of some other related problem that can be solved. He was great at seeing that a whole set of questions hangs on just one issue, so you should focus on that one. . . . I remember taking lots of walks with him, talking about this issue and that. . . . When you write something with him and it comes back with all those red marks all over it, and it goes through three drafts and still has red marks all over, that really brings home to you the importance of writing well. . . . There was a student who was difficult to talk with because he would interrupt all the time and he spoke with far more assurance than he had any right to. I watched Wheeler train him out of that. Wheeler would just lower his eyes through it all, and when the student finished, he would raise his eyes back up and say something in a completely different direction. In a remarkably short time the student was cured."[9]

Robert Wald (PhD 1972): "[You taught me that] one should always think in a completely down-to-earth manner and decide by physical intuition what ought to be true; then one should obtain a mathematical proof (or disproof) of one's physical conjecture. The first step alone is likely to result in cloudy guesswork; the second step alone may lead only to uninteresting, technical stuff. But the right combination . . . can lead to inspiring physics." (Letter to Wheeler[1])

William Unruh (PhD 1971): "I had just got started working on my first research problem and had a few extremely vague ideas. I mentioned them to Wheeler one day, and he said, 'I've received this invitation to a workshop in Gwatt, Switzerland. Would you like to go and present your results?' I was torn because I didn't have any results to present. And then he said, 'Here, I'll write out this telegram,' and he wrote one saying `Would you please invite Bill Unruh to give a talk.' He handed it to me and said, 'Please phone this in to the telegraph office.' So I wandered around for two or three hours agonizing over whether to send this telegram, because if I sent it, I was committed. I finally did send it and then had three months to get some results worth presenting."[10]

Richard Feynman (PhD 1942): "When I was a grad student with him, Wheeler was sometimes too fast for me. One day we were working on a calculation together. I couldn't see how he got from this point to the next. 'Little steps for little people,' Wheeler said, as he spelled out for me the steps he had omitted." [Comment by Thorne: Feynman told me this in about 1972. I've never heard any other student or colleague describe Wheeler behaving so impolitely; normally he was unfailingly polite. I suspect he knew that Feynman could handle such a cutting remark and thought Feynman needed it. Feynman as a student had a reputation for brashness and arrogance. Twenty percent of Feynman's 1965 Nobel Prize lecture[5] is devoted to inspirations that he derived from discussions with Wheeler and to how those inspirations led to his prize-winning formulation of quantum electrodynamics.]

David Sharp (AB 1960): "One day [when we were working together on a research problem at your summer home on High Island, Maine] a man came to see you. He had a 'theory' of something or other that he wanted to explain. It became clear after about 30 seconds that the man was a 'crackpot.' . . . As the discussion dragged on, I began to seethe with impatience, thinking of all we had to do. But not you. You treated the man with respect. . . . You met his ideas head on and quickly but kindly demonstrated the flaws in them. I'm sure that when the man left he was still convinced of the basic correctness of his 'theory.' But he did acknowledge the flaws (which were devastating) and I'm equally sure that he felt that he had been treated fairly. You never spoke a word directly to me about this incident, but the man with the theory was not the only person in the room who learned a lesson that day." (Letter to Wheeler[1])

> John A. Wheeler. Over the last two years [1990–92] he has introduced me to the world of physics research and shaped the way I think about physics. I have benefited greatly, both as a physicist and as a person, from his example, and will carry this with me always. John Wheeler has had a profound impact on my life and I am deeply indebted.

A great legacy endures.

The online version of this article provides a link to the longer, more fully documented original manuscript.

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