

January 2019

## ***CURRICULUM VITAE***

### **NORMAN R. PACE**

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### **Education**

1964	B.A. (Honors), Indiana University, Bloomington, Indiana
1967	Ph.D., University of Illinois, Urbana, Illinois
1967-69	Postdoctoral Fellow, University of Illinois, Urbana, Illinois

### **Academic Positions**

1969-74	Assistant Professor of Biophysics and Genetics, University of Colorado Medical Center
1969-74	National Jewish Hospital and Research Center, Division of Molecular and Cellular Biology
1975-82	Associate Professor of Biophysics and Genetics, University of Colorado Medical Center
1982-84	Professor of Biochemistry, Biophysics, and Genetics, University of Colorado Medical Center
1984-92	Professor of Biology, Indiana University
1992-94	Distinguished Professor of Biology, Indiana University
1994-96	Distinguished Professor of Biology and Chemistry, Indiana University
1996-99	Professor of Plant and Microbial Biology, and Molecular and Cell Biology, UC Berkeley
1999-08	Professor of MCD Biology, University of Colorado, Boulder
2008-15	Distinguished Professor of MCD Biology, University of Colorado, Boulder
2015-	Distinguished Professor Emeritus, MCD Biology, CU-, Boulder

### **Professional Societies and Some Activities**

National Academy of Sciences (Selman A. Waksman Award, 2001; Stanley Miller Award, 2019).  
American Society for Microbiology (Lifetime Achievement Award, 2007).  
American Society of Biological Chemists; Editorial Board of "J. Biol. Chem.," 1980-84.  
National Speleological Society, Fellow (Bicking Award, 1987).  
NRC/Space Science Board Committee on Planetary Biology and Chemical Evolution, 1985- 1989.  
Space Science Board Mars Rover/Sample Return Advisory Committee, 1987-88.  
Office of Technology Assessment Human Genome Mapping Review Board, 1987-88.  
Co-Chairman, 1988 Gordon Conference on Nucleic Acids.  
Co-Organizer, 1989 Cold Spring Harbor Meeting on RNA Processing.  
Canadian Institute for Advanced Research, Program Associate, 1993-  
NRC/Space Studies Board Committee on Planetary and Lunar Exploration, 1989-1995.  
Co-Organizer RNA '96, 1996 RNA Society Meeting  
Editorial Board, "RNA," the Journal of The RNA Society, 1995 -  
Board Scientific Counselors, Natl. Center for Biotechnology Information, Natl. Lib. Medicine, 1994- 2000.  
Editorial Board, "Environmental Microbiology", 1998 -  
Scientific Advisory Council, Paratuberculosis Awareness and Research Association (PARA), 2000-2005.  
Board of Directors, Monterey Bay Aquarium Research Institute (MBARI), 2000-2016.  
NRC/Space Studies Board Committee on Origin and Evolution of Life, 1999-2004.  
NRC/SSB Committee on Astrobiology and Planetary Sciences, 2014-2016.

### **Some Recognition**

1987, Bicking Award for Contributions to American Caving, National Speleological Society.  
1989, Fellow, American Association for the Advancement of Science.  
1991, Member, National Academy of Sciences

1991, Fellow, American Academy of Arts and Sciences.  
1995, Fellow American Academy of Microbiology.  
1996, Procter and Gamble Award in Applied and Environmental Microbiology (Am. Soc. for Microbiol.).  
1997, D. Sc. (Honorary), University of British Columbia.  
2001, Selman A. Waksman Award for Excellence in Microbiology (National Academy of Sciences).  
2001, Fellow, John D. and Catherine T. MacArthur Foundation.  
2007, Abbott-American Society for Microbiology Lifetime Achievement Award.  
2008, RNA Society Lifetime Achievement Award.  
2008, International Society for Microbial Ecology Tiedje-ISME Lifetime Achievement Award.  
2017, Massry Prize in Microbiome Science (shared).  
2018, D.Sc. (Honorary), Indiana University.  
2019, Stanley Miller Award in Early Earth and Life Sciences (National Academy of Sciences).

### Recent Research Support

1984-2012 Principal Investigator, USPHS Grant GM 34527; MERIT Award, 1993  
2006-2011 Principal Investigator, NIOSH Grant R01 0H009064  
2006-2015 Investigator, Alfred P. Sloan Foundation

### Research Activities

Research interests revolve about the synthesis, structure and function of RNA; and the application of molecular biological tools to problems in environmental microbial biology.

One effort of the laboratory has been the study of Ribonuclease P, an RNA processing enzyme responsible for removing the 5' termini of tRNA precursors during their maturation. This is a particularly interesting enzyme because the catalytic element is itself RNA; RNase P is a ribozyme. Studies have included determination of the molecular structure of RNase P RNA, the nature of its interaction with tRNA precursors and other substrates, and the mechanism of the RNA-catalyzed reaction.

A second emphasis of the laboratory has been on development and use of molecular methods for analysis of phylogenetic and quantitative aspects of natural microbial communities without the requirement for laboratory cultivation. This is an important direction because only a few environmental microorganisms are cultured using standard techniques. Consequently, before the molecular developments, there was little access to the natural microbial world. The application of molecular technologies such as sequencing ribosomal RNA (rRNA) genes for phylogenetic analyses and the use of rRNA-based hybridization probes for *in situ* identification of microbes have revolutionized microbial ecology. Investigations have been broadly directed, for instance toward high-temperature environments, unusual symbioses, little-known (at the time) microbial ecosystems such as endolithic communities and marine picoplankton, environmental bioremediation, selected human diseases and the indoor environment all around us. Collectively, molecular results from this laboratory and others have dramatically revised our understanding of microbial diversity.

### Publications:

1. Fraser, D., C.J. Pfau, and N.R. Pace. (1960). Identification of the protoplast-infecting and cell-infecting agent derived from T2 bacteriophage. Proc. Indiana Acad. Sci. 69:101-105.
2. Pace, N.R. and S. Spiegelman. (1966). The synthesis of infectious RNA with a replicase purified according to its size and density. Proc. Natl. Acad. Sci. USA 55:1608-1615.
3. Pace, N.R. and S. Spiegelman. (1966). The *in vitro* synthesis of an infectious mutant RNA with a normal RNA replicase. Science 153:64-67.

4. Mills, D.R., N.R. Pace, and S. Spiegelman. (1966). The *in vitro* synthesis of a non-infectious complex containing biologically active viral RNA. Proc. Natl. Acad. Sci. USA 56:1778-1785.
5. Spiegelman, S., I. Haruna, and N.R. Pace. (1966). Properties of a purified RNA replicase. Biochim. et Biophys. Acta. Lunteren Symposium. The Netherlands, pp. 3-28.
6. Spiegelman, S., I. Haruna, and N.R. Pace. (1966). Studies on the synthesis of a viral nucleic acid with a purified enzyme. Second International Symposium for Cellular Chemistry.
7. Bishop, D.H.L., J.R. Claybrook, N.R. Pace, and S. Spiegelman. (1967). An analysis by gel electrophoresis of Q $\beta$  RNA complexes formed during the latent period of an *in vitro* synthesis. Proc. Natl. Acad. Sci. USA 57:1474-1481.
8. Pace, N.R., D.H.L. Bishop, and B. Spiegelman. (1967). Examination of the Q $\beta$  replicase reaction by sucrose-gradient and gel electrophoresis. J. Virol. 1:771-778.
9. Pace, N.R., D.H.L. Bishop, and B. Spiegelman. (1967). The kinetics of product appearance and template involvement in their *in vitro* replication of viral RNA. Proc. Natl. Acad. Sci. USA 58:711-718.
10. Pace, N.R. (1967). *In vitro* studies of viral RNA replication. Ph.D. Thesis, The University of Illinois. Urbana. 139 pp.
11. Spiegelman, S., I. Haruna, N.R. Pace, D.R. Mills, D.H.L. Bishop, J.R. Claybrook, and R. Peterson. (1967). Studies in the replication of viral RNA. J. Cell Physiol. Suppl. 70:35-64.
12. Pace, N.R., I. Haruna, and S. Spiegelman. (1968). The preparation of an RNA replicase capable of synthesizing biologically active viral RNA. In "Methods in Enzymology," vol. 12, pt. B, Colowick and Kaplan (eds.), pp. 540-555.
13. Spiegelman, S., I. Haruna, N.R. Pace, D.R. Mills, and D.H.L. Bishop. (1968). The development and the use of an *in vitro* system for RNA replication. In "The Biochemistry of Virus Replication," Univesitets-forloget. Oslo, pp. 1-35.
14. Bishop, D.H.L., N.R. Pace, and S. Spiegelman. (1967). The mechanism of replication: a novel polarity reversal in the *in vitro* synthesis of Q $\beta$  RNA and its complement. Proc. Natl. Acad. Sci. USA 58:1790-1797.
15. Pace, N.R., D.H.L. Bishop, and S. Spiegelman. (1968). The immediate precursor of viral RNA in the Q $\beta$  replicase reaction. Proc. Natl. Acad. Sci. USA 59:139-144.
16. Pace, N.R., D.H.L. Bishop, D.R. Mills, M. Taylor, and S. Spiegelman. (1968). *In vitro* replication of viral RNA. Arch. Roum. Path. Exp. Microbiol. 27:519-540.
17. Spiegelman, S., N.R. Pace, D.R. Mills, R. Levisohn, T.S. Eikhom, M.M. Taylor, R.L. Peterson, and D.H.L. Bishop. (1968). The mechanism of RNA replication. Cold Spring Harbor Symp. Quant. Biol. 33:101-124.
18. Spiegelman, S., N.R. Pace, D.R. Mills, R. Levisohn, T.S. Eikhom, M.M. Taylor, R.L. Peterson, and D.H.L. Bishop. (1969). Chemical and mutational studies of a replicating RNA molecule. Proc. 12th Internatl. Congr. Genetics 3:127-154.
19. Pace, B., R.L. Peterson, and N.R. Pace. (1970). Formation of all stable RNA species in *Escherichia coli* by post transcriptional modification. Proc. Natl. Acad. Sci. USA 65:1097-1104.
20. Doolittle, W.F. and N.R. Pace. (1970). The synthesis of 5S ribosomal RNA in *E. coli* treated with rifampicin. Nature 228:128-129.
21. Pace, B. and N.R. Pace. (1971). Gene dosage for 5S ribosomal RNA in *E. coli* and *B. megaterium*. J. Bacteriol. 105:142 -149.

22. Sogin, M., B. Pace, N.R. Pace, and C.R. Woese. (1971). The primary structural relationship of P16 and m16 ribosomal RNA in *E. coli*. *Nature New Biology* 232:48-49.
23. Doolittle, W.R. and N.R. Pace. (1971). Transcriptional organization of the ribosomal RNA cistrons in *Escherichia coli*. *Proc. Natl. Acad. Sci. USA* 68:1786-1790.
24. Peterson, R.L., C.W. Radcliffe, and N.R. Pace. (1971). RNA synthesis in *Escherichia coli* treated with toluene. *J. Bacteriol.* 107:585-588.
25. Averner, M. and N.R. Pace. (1972). The nucleotide sequence of marsupial 5S ribosomal RNA. *J. Biol. Chem.* 247:449-4493.
26. Pace, N.R., M.L. Pato, J. McKibbin, and C.W. Radcliffe. (1973). Precursors of 5S ribosomal RNA in *Bacillus subtilis*. *J. Mol. Biol.* 75:619-631.
27. Erikson, E., R.L. Erikson, B. Henry, and N.R. Pace (1973). Comparison of oligonucleotides produced by RNase T1 digestion of 7S RNA from avian and murine oncornaviruses and from uninfected cells. *Virology* 53:40-46.
28. Pace, N.R. (1973). The structure and synthesis of the ribosomal RNA of prokaryotes. *Bacteriol. Rev.* 37:562-603.
29. Sogin, M.L., C.R. Woese, B. Pace, and N.R. Pace. (1973). The relationship between precursor and mature forms of the 23S ribosomal RNA. *J. Mol. Evol.* 2:167-174.
30. Pace, N.R., T.A. Walker, B. Pace, and R.L. Erikson. (1974). The nucleotide sequence of chicken 5S ribosomal RNA. *J. Mol. Evol.* 3:151-159.
31. Pace, N.R. and M.L. Sogin. (1974). *In vitro* maturation of precursors of 5S ribosomal RNA from *Bacillus subtilis*. In "The 1974 Brookhaven Symposium in Biology," Vol. 26, Dunn and Studier (eds.), pp. 224-239.
32. Walker, T.A., N.R. Pace, R.L. Erikson, E. Erikson, and F. Behr. (1974). The 7S RNA common to oncornaviruses and normal cells is associated with polyribosomes. *Proc. Natl. Acad. Sci. USA* 71:3390-3394.
33. Sogin, M.L. and N.R. Pace. (1974). *In vitro* maturation of precursors of 5S ribosomal RNA from *Bacillus subtilis*. *Nature* 252:5987-6000.
34. Pribula, C.D., G.E. Fox, C.R. Woese, M. Sogin, and N.R. Pace. (1974). Nucleotide sequence of *Bacillus megaterium* 5S RNA. *FEBS Lett.* 44:322-323.
35. Walker, T.A., J. Betz, J. Olah, and N.R. Pace. (1975). The nucleotide sequence of dolphin and bovine 5S ribosomal RNA. *FEBS Lett.* 54:241-244.
36. Marotta, C.A., F. Varricchio, I. Smith, S.M. Wiessman, M.L. Sogin, and N.R. Pace. (1976). The primary structure of *Bacillus subtilis* and *Bacillus stearothermophilus* 5 S ribonucleic acids. *J. Biol. Chem.* 251:3122-3127.
37. Sogin, M.L., N.R. Pace, M. Rosenberg, and S.M. Weissman. (1976). The nucleotide sequence of a 5S ribosomal RNA precursor from *Bacillus subtilis*. *J. Biol. Chem.* 251:3480-3488.
38. Sogin, M.L., B. Pace, and N.R. Pace. (1977). Partial purification and properties of a ribosomal RNA maturation endonuclease from *Bacillus subtilis*. *J. Biol. Chem.* 252:1350-1357.
39. Walker, T.A. and N.R. Pace. (1977). The transcriptional organization of the 5.8S ribosomal RNA cistron in *Xenopus laevis*. *Nucleic Acids. Res.* 4:595-601.
40. Schroeder, E., M.L. Sogin, and N.R. Pace. (1977). The mode of degradation of precursor-specific RNA fragments by *Bacillus subtilis*. *J. Bacteriol.* 130:1000-1009.

41. Meyhack, B., B. Pace, and N.R. Pace. (1977). Involvement of precursor-specific segments in the *in vitro* maturation of *Bacillus subtilis* precursor 5S ribosomal RNA. *Biochemistry* 16:5009-5015.
42. Pace, N.R., E. Schroeder, and T.A. Walker. (1977). The structure of the 5.8S RNA component of the 5.8S-28S ribosomal RNA junction complex. *Biochemistry* 15:5321-5328.
43. Meyhack, B., B. Pace, O. Uhlenbeck, and N.R. Pace. (1978). Use of T4 RNA ligase to construct model substrates for a ribosomal RNA maturation endonuclease. *Proc. Natl. Acad. Sci. USA* 75:3045-3049.
44. Meyhack, B. and N.R. Pace. (1978). Involvement of the mature domain in the *in vitro* maturation of *Bacillus subtilis* precursors 5S ribosomal RNA. *Biochemistry* 17:5804-5810.
45. Ludi, G.A. and N.R. Pace. (1979). The use of rifampicin to evaluate tRNA gene transcriptional organization in *Escherichia coli*. *Nucleic Acids Res.* 6:1269-1286.
46. Stahl, D.A., T.A. Walker, B. Meyhack, and N.R. Pace. (1979). Precursor-specific nucleotide sequences can govern RNA folding. *Cell* 18:1133-1143.
47. Pace, N.R., B. Meyhack, B. Pace, and M.L. Sogin. (1980). The interaction of RNase M5 with a 5S ribosomal RNA precursor. In "tRNA: Biological Aspects," J. Abelson, P. Schimmel, and D. Soll (eds.), Cold Spring Harbor Laboratory, Cold Spring Harbor, N.Y., pp. 155-171.
48. Stahl, D.A., B. Meyhack, and N.R. Pace. (1980). Recognition of local nucleotide conformation in contrast to sequence by a ribosomal RNA-processing endonuclease. *Proc. Natl. Acad. Sci. USA* 77:5644-5648.
49. Pace, B. and N.R. Pace. (1980). The chromatography of RNA and oligoribonucleotides in boronate-substituted agarose and polyacrylamide. *Anal. Biochem.* 107:128-135.
50. Gardiner, K. and N.R. Pace. (1980). RNase P of *Bacillus subtilis* has an RNA component. *J. Biol. Chem.* 255:7507-7509.
51. Stahl, D.A., K.R. Luehrsen, C.R. Woese, and N.R. Pace. (1981). An unusual 5S RNA, from *Sulfolobus acidocaldarius*, and its implications for a general 5S rRNA structure. *Nucleic Acids Res.* 9:6129-6137.
52. Pace, B., E. Matthews, K. Johnson, C. Cantor, and N.R. Pace. (1981). Interaction between conserved 5S rRNA and tRNA complementary sequences is not required for protein synthesis. *Proc. Natl. Acad. Sci. USA* 79:36-40.
53. Walker, T.A., K. Johnson, G.A. Olsen, M. Peters, and N.R. Pace. (1982). Enzymatic and chemical structure mapping of mouse 28S ribosomal RNA contacts in 5.8S ribosomal RNA. *Biochemistry* 21:2320-2329.
54. Peters, M., T.A. Walker, and N.R. Pace. (1982). Independent binding sites in mouse 5.8S ribosomal RNA for 28S ribosomal RNA. *Biochemistry* 21:2330-2335.
55. Pace, N.R., K. Gardiner, B. Meyhack, B. Pace, M.L. Sogin, and D.A. Stahl. (1982). RNA processing in *Bacillus subtilis*. In "Microbiology," D. Schlessinger (ed.), pp. 32-40.
56. Walker, T.A., Y. Endo, W.H. Wheat, I.G. Wool, and N.R. Pace. (1983). Location of 5.8S rRNA contact sites in 28S rRNA, and the effect of  $\alpha$ -sarcin on the association of 5.8S rRNA with 28S rRNA. *J. Biol. Chem.* 258:333-338.
57. Pace, N.R. (1983). Protein-polynucleotide recognition and the RNA-processing nucleases in prokaryotes. In "Processing of RNA," D. Apirion (ed.), CRC Press, pp. 1-34.
58. Walker, T.A. and N.R. Pace. (1983). 5.8S ribosomal RNA. *Cell* 33:320-322.

59. Guerrier-Takada, C., K. Gardiner, T. Marsh, N.R. Pace, and S. Altman. (1983). The RNA moiety of ribonuclease P is the catalytic subunit of the enzyme. *Cell* 35:849-857.
60. Zagorska, L., J. Van Duin, H.F. Noller, B. Pace, K.D. Johnson, and N.R. Pace. (1984). The conserved 5S rRNA complement to tRNA is not required for translation of natural mRNA. *J. Biol. Chem.* 259:2798-2802.
61. Stahl, D.A., D.J. Lane, G.J. Olsen, and N.R. Pace. (1984). The analysis of hydrothermal vent-associated symbionts by ribosomal RNA sequences. *Science* 224:409-411.
62. Stahl, D.A., B. Pace, T. Marsh, and N.R. Pace. (1984). The ribonucleoprotein substrate for a ribosomal RNA-processing nuclease. *J. Biol. Chem.* 259:11448-11453.
63. Pace, B., D.A. Stahl, and N.R. Pace. (1984). The catalytic element of a ribosomal RNA-processing complex. *J. Biol. Chem.* 259:11454-11458.
64. Lane, D.J., D.A. Stahl, G.J. Olsen, and N.R. Pace. (1985). Analysis of hydrothermal vent-associated symbionts by ribosomal RNA sequences. *Proc. Biol. Soc. Wash.* 6:389-400.
65. Pace, N.R., D.A. Stahl, D.J. Lane, and G.J. Olsen. (1985). The analysis of natural microbial populations by ribosomal RNA sequences. *Am. Soc. Microbiol. News* 51:4-12.
66. Gardiner, K.J., T.L. Marsh, and N.R. Pace. (1985). Ion dependence of the *Bacillus subtilis* RNase P reaction. *J. Biol. Chem.* 260:5415-5419.
67. Lane, D.J., D.A. Stahl, G.J. Olsen, D.J. Heller, and N.R. Pace. (1985). A phylogenetic analysis of the genera *Thiobacillus* and *Thiomicrospira* by 5S ribosomal RNA sequences. *J. Bacteriol.* 163:75-81.
68. Marsh, T.L. and N.R. Pace. (1985). RNase P catalysis differs from ribosomal RNA self-splicing. *Science* 229:79-81.
69. Stahl, D.A., D.J. Lane, G.J. Olsen, and N.R. Pace. (1985). Characterization of a Yellowstone hot spring microbial community by 5S ribosomal RNA sequences. *Appl. Environ. Microbiol.* 49:1379-1384.
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72. Marsh, T.L., B. Pace, C. Reich, K. Gardiner, and N.R. Pace. (1985). Processing of tRNA precursors by an RNA catalyst from *Bacillus subtilis*. In "Sequence Specificity in Transcription and Translation," R. Calender, and L. Gold (eds.). Alan R. Liss, Inc. pp. 441-450.
73. Pace, N.R., and T.L. Marsh. (1986). RNA catalysis and the origin of life. *Origins of Life* 16:97-116.
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75. Waugh, D.S., and N.R. Pace. (1986). Catalysis by RNA. *BioEssays* 4:56-61.
76. Olsen, G.J., D.J. Lane, S.J. Giovannoni, D.A. Stahl, and N.R. Pace. (1986). Microbial ecology and evolution: a ribosomal RNA approach. *Ann. Rev. Microbiol.* 40:337-365.
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92. Giovannoni, S.J., E.F. DeLong, G.J. Olsen, and N.R. Pace. (1988). Phylogenetic group-specific nucleic acid probes for identification of single microbial cells. *J. Bacteriol.* 170:720-726.
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