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THE ROLE OF STUDENTS IN PIONEERING NEW FIELDS
OF SCIENCE AND TECHNOLOGY

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THE ROLE OF STUDENTS IN PIONEERING NEW FIELDS OF SCIENCE AND TECHNOLOGY

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ABSTRACT

This paper examines students involved in pioneering a new field and the factors that influence them in their choice of a problem area and their determination to continue working on it. Empirical evidence is presented from an international survey of more than seven-hundred scientists in the field of neural networks. Comparisons are made between pioneers who initiate their work in the field as students with pioneers who have graduated and hold positions as academic scientists. Comparisons are also made between pioneers and their colleagues who enter the field after it becomes legitimate within the scientific community. The results show that pioneering students are remarkably similar to other academic pioneers in their motivations to enter and persist in the field.

INTRODUCTION

A recent international survey of more than seven-hundred scientists working on the development of neural networks provides evidence that “pioneering” scientists are different in both their motivations to enter and their persistence to remain in the field.¹ Pioneers are defined as those scientists who initiate and continue working in a field before it is widely recognized as significant, or perhaps even legitimate by their peers. In comparison to other scientists, pioneers are more deeply influenced by the intrinsic intellectual appeal of the subject matter and are less influenced by the social dynamics of the research community. This conclusion holds when controlling for a scientist’s age and years of professional experience. The results lend support to the contention that scientists’ problem choices are determined by cognitive factors that are “internal” to science, while at the same time show the relevance of social factors operating broadly within a research community. Hence, pioneers may be an important factor to consider when sorting-out the long-standing debate over problem choice in science (for example, see Zuckerman, 1978; Gieryn, 1978; Ziman, 1987).

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¹ See Rappa and Debackere (1991) and Debackere and Rappa (1991) for details regarding the original study.

A further investigation of institutional differences among neural network scientists shows that academic scientists demonstrate pioneering characteristics more clearly than scientists in industrial or government laboratories. In addition, the survey reveals that a disproportionately large percentage of pioneering scientists were graduate students when they first began research in neural networks. Nearly 70 percent of the pioneers were students (principally pursuing doctoral degrees) when initiating work in neural networks, in comparison to about 40 percent of the control group (see Table 1). It is not surprising that university laboratories are frequently home to pioneers; nor is it surprising that large numbers of scientists continue to work in an area of research they initiate as students. However, it is intriguing to find that pioneers are more likely to be students when they start their research than their colleagues who follow afterward.

<i>Educational status when entering:</i>	PIONEER		CONTROL GROUP	
	N	%	N	%
student	98	67.6	200	41.9
graduate	47	32.4	277	58.1

TABLE 1: *Cross tabulation of pioneer and control group respondents by educational status at the time of entry* (N=622; $\chi^2=28.31$; $p<.001$).

Reflecting upon the distribution of respondents in Table 1, it is interesting to speculate about the contribution students might make to the emergence of new fields of science and technology. Historical accounts of emerging fields frequently emphasize the role of students in readily expanding the corps of researchers working in a new area. For example, in his analysis of molecular biology, Mullins (1972) describes how the flow of recruits helps to sustain the momentum of the new specialty. Lemaine, et al. (1976) also find evidence across a number of different fields that show that the recruitment of graduate students is an important mechanism for the successful growth of a field.

Nonetheless, our understanding of the contribution students make to new fields is largely superficial. Why are students important to emerging fields, in particular? The assumption that seems to underlie each of these accounts is that students come to a field intellectually innocent, untainted by the gospel of conventional wisdom derived from existing research paradigms. As Kuhn (1970) suggests, a paradigm is as much a way of

seeing reality as it is a way of not seeing reality. The same theoretical principles that enable scientists to shed light on empirical findings, might also blind them to alternative interpretations of data. What is more, scientists can become so imbued with their theories, that it is difficult for them to accept the validity of conflicting perspectives. Thus, newly emerging fields based on unorthodox ideas may have a hard time attracting scientists who are heavily invested in other theoretical approaches.

Furthermore, students are more likely to embrace a new field without the hesitancy that comes from being too cognizant of prevailing opinions of what is or is not a legitimate area of research. Such naïveté may work in their favor, helping to sustain students' enthusiasm for grappling with what others might consider to be insurmountable problems at the frontier of science. Insofar as they become "true believers," students may play a vital role in meeting the challenges that face nascent fields.

Considering the potential contribution of students not yet encumbered by the intellectual rigidities that form over a scientist's career, it is possible to envision them as more than mere apprentices. Indeed, it may very well be that students have an even greater latitude to do pioneering work than their faculty supervisors do. After all, being in a position of responsibility—both within their university and the scientific community—means that there is much more at stake for faculty when choosing to pursue a new area of research. Faculty may shy away from more riskier lines of research that, if leading to failure, may sully their professional reputation. Although tenure provides intellectual freedom, it cannot ward-off the stigma of collegial scrutiny that arises when pursuing research that is seen to be well outside the mainstream and with little chance of succeeding. Clearly, the choice of a problem area has serious consequences for getting papers accepted into the literature, receiving promotion to higher ranks, and obtaining funding.

By comparison, the consequences for venturesome students are far less severe. Students have no established reputations as scientists to protect and they are relatively immune to the intellectual controversies within research communities. The misfortune of pursuing futile avenues of research is, understandably, an integral part of learning and nothing to be overly embarrassed about. Furthermore, the challenge of being accepted in the literature and securing research funding is, at least momentarily, remote to most students. Thus, not only are they less bound by prevailing theories, students are more able to act on their intuitions of what is interesting research to pursue. When coupled with the good fortune of having a supportive supervisor and an ingenuity for employing slack resources, students may have an unparalleled opportunity to initiate pioneering work.

When viewed in this light, one might expect that major contributions by students would be a more common occurrence. To the contrary, such episodes as when Watson and Crick discovered the structure of DNA are rare in science.² The reason for this may lie with the process by which students choose their dissertation research problems. Striking a balance between a supervisor's interests and personal autonomy is inevitably difficult, but as it has been suggested, students are quite ready to yield responsibility for problem choice to their supervisors. In a Carnegie study of graduate education in the United States, Berelson (1960) observes "Graduate instruction is not conducted in a way which forces students into habits of independent study, reflection, and inquiry. The atmosphere is one of supervised, regulated and controlled study." In his recollections of his tenure as a physics professor, Ziman (1981) echoes Berelson's sense of passivity on the part of students:

We often forget that the most commonest occasion for asking the question "What research shall I do now?" is when the graduate student goes to a research supervisor for advice on a topic for his dissertation; i.e., to be given a scientific problem that is both "do-able" and "worth doing."

Be this as it may, we should not overlook the role of students as independent actors in the context of emerging fields of science and technology. Their potential contribution warrants a closer examination into the factors that might influence their choice of a research topic and their determination to stay with it. Is there something special about being a student that makes one more inclined to initiate pioneering research, or is pioneering behavior largely independent of a researcher's educational status? Building upon the prior analysis of neural network scientists, in this paper we will examine this question by contrasting respondents who are students when they initiate neural network research to respondents who start neural network research after graduation.

PIONEERS IN NEURAL NETWORK RESEARCH

We selected as the basis for this examination the field of neural networks research, which is one of nearly a dozen fields of science and technology that we are studying concurrently. The decision to examine neural networks holds no special significance other than the opportunity to do so presented itself first. After a preliminary investigation of the neural network field, we concluded it would be interesting to conduct a comprehensive study with a primary focus on pioneering researchers.

² To be precise, although venturesome in spirit, Watson was not a student but rather a new postdoc at the time he arrived at Cavendish Laboratory. More than ten years Watson's senior, Crick was indeed a student at the time, having been interrupted in his doctoral program by service in the Second World War (Watson, 1968).

A neural network is a type of information processing system that is inspired by models of the human brain. By using a biological model in its design, a neural network system has certain features that make it unique in form and function from conventional computers. For example, a neural network is not programmed in the usual sense, but rather it is trained with data. This implies that the computational performance of a neural network improves with experience: as it processes more and more information in performing a task, it becomes increasingly more accurate in its response. Another feature is its degree of parallelism in processing a task. Unlike a normal computer with a single or small number of sophisticated central processing units, a neural network has a very large number of simple processing elements that operate simultaneously on a computational problem. These features allow it to perform certain tasks that otherwise might be very difficult using existing computer technology. Neural networks are also referred to as connectionist systems, adaptive systems, or neurocomputers. For further details, refer to the recent report by DARPA (1988).

Neural networks have a long history of development, stretching back to theoretical explanations of the brain and cognitive processes proposed during the 1940s. In the early years, researchers formulated and elaborated upon basic models of neural computing that they then used to explore phenomena such as adaptive stimulus-response relations in random networks. By the 1960s there were several efforts to implement neural networks, the most notable being the single-layer “perceptron.” Among neural network researchers the perceptron was considered a watershed, but at the same time it served as a lightning rod for criticism from researchers more interested in the burgeoning field of artificial intelligence. The idea of neural networks, as exemplified by the perceptron, quickly became seen as almost antithetical to the symbolic reasoning principles of artificial intelligence. Critical analysis of the perceptron led some highly respected AI researchers to proclaim that the concept was fundamentally flawed, and as such, inappropriate for researchers to waste much effort on. By casting doubt as to its legitimacy, antagonists of neural networks may have effectively dissuaded other researchers from entering the field in larger numbers (Minsky and Papert, 1988).

The controversy surrounding neural networks notwithstanding, work continued during the early 1970s with perhaps no more than a few hundred researchers worldwide in the field. Undeterred in their belief of the potential of neural networks, their persistence over the next decade eventually paid-off. By the 1980s, neural networks began to be viewed in a new light by researchers in a variety of disciplines, such that the field soon achieved a

position of legitimacy within the scientific community. A professional society for neural network researchers was formed, specialized journals and books were published, and the first in a series of international conferences were held. While it is difficult to explain exactly why the perception of the field changed so dramatically, at least four important technical events can be discerned: (1) the evolution of the single-layer perceptron into a multi-layer system; (2) the rapid development of related technologies that enabled researchers to develop, simulate, and diagnose neural networks of greater sophistication; (3) significant progress in theoretical understanding of neuro-biological processes; and (4) the contributions of researchers pursuing the idea of parallel distributed processing, the so-called PDP-group. In light of these developments, as well as others, interest in the field became widespread, such that the number of researchers working on neural networks expanded rapidly. By the end of the decade the size of the field swelled in membership from a few hundred to several thousand researchers worldwide.

The evolution of the neural network research community is not unusual and may even be typical of emerging fields in some of its sociological characteristics. From our research, we have found that it is fairly common for new fields to lack widespread acceptance for long periods, sometimes attracting controversy, other times simply being ignored by researchers. But when they do catch on, fields tend to grow rapidly. This pattern has occurred, to greater or lesser extent, in each of the dozen fields we have examined so far. Given the recent experience within the field of neural networks, this case presents us with an excellent opportunity to examine in greater detail the behavior of pioneering researchers relative to large numbers of researchers who follow in their footsteps.

METHOD AND DATA

Through an analysis of published sources, including books, journal articles, and conference proceedings for the two-year period from 1988 to 1989, we identified more than 3,000 researchers worldwide working on the subject of neural networks. From this material, we were able to determine the exact address for each of 2,037 researchers in thirty-five different countries. Given the scope of the research community, a survey questionnaire was determined to be the most appropriate method of investigation. A twelve-page questionnaire in English was sent to researchers inquiring about (a) their neural network activities, (b) their decision to begin working on neural networks, (c) factors that might lead them to cease their neural network research in favor of another problem area, (d) their interaction with the rest of the neural network research community, and (e) their

demographic characteristics. The questionnaire was pretested in the United States. Additional tests were conducted in Europe to reduce potential interpretational difficulties arising among those respondents for whom English is a second language.

Since there were thirty-seven researchers with more than one address during the time period considered, a total of 2,074 questionnaires were mailed in February 1990. After the third week of data collection, we mailed a follow-up letter and posted e-mail messages on computer bulletin boards to alert neural network researchers of the survey. Of the 2,074 questionnaires, 162 were returned as undelivered by the post office. None of the thirty-seven researchers with more than one address were represented in the undelivered questionnaires. At the completion of the data collection period approximately ninety days later, 720 of the 1,875 questionnaires presumed to be delivered were completed and returned, yielding a final response rate of 38.4 percent. Some of the factors that may have affected the response rate include: the length of the questionnaire, the global scope of the survey, and the institutional mobility of researchers.

The representativeness of the respondent sample was evaluated in three ways: by contrasting respondents with the original survey population in terms of their geographic distribution, their institutional distribution, and the distribution of their disciplinary backgrounds. In each instance, there is no statistically significant difference between the respondent sample and the survey population (for complete details regarding the data, see Rappa and Debackere, 1991).

The respondents were classified as pioneers based upon when they entered the field. The cut-off date was determined through an historical analysis of the field and an examination of the cumulative entry over time of respondents into the field. As a result of these procedures, twenty-five percent of the respondents were classified as pioneers and the remaining seventy-five percent were placed in a control group. The control group was used to contrast the behavior of pioneers with non-pioneering respondents. A sensitivity analysis of the categorization scheme, including a discriminant analysis on the core items, indicates that the dichotomy between pioneers and the control group is robust.

Given the focus of this analysis, the respondent sample ($N=720$) was reduced for the present analysis to include only those respondents employed in academic institutions and who report their primary or secondary position to be one of the following: professor (all ranks), post-doctoral fellow, graduate student, and staff scientist or engineer. The sample was then divided into two groups—students and graduates—depending upon their

educational status when initiating neural networks research. The student category includes respondents who began research on neural networks while pursuing a university degree (principally, a doctorate). The graduate category includes respondents who received their highest academic degree prior to initiating their neural network research. Respondents who started working on neural networks in the same year they graduated were omitted from the analysis.

This procedure yielded a sample of 377 respondents: 95 (25.2 percent) pioneers and 282 (74.8 percent) control group respondents (see Table 2). Among pioneers, nearly 70 percent were students when entering the field, whereas about 54 percent of the control group were students when they entered ($\chi^2=6.44$, $df=1$, $p=.011$). The average pioneering student was 24.3 years old when entering the field, compared with 25.8 years for control group respondents who were students when entering the field. The average pioneer entering the field after graduation was 34.3 years old, compared with 37.0 years for control group respondents entering the field after graduation. For those respondents who entered the field after graduation, the length of professional experience for pioneers and the control group is similar: 8.1 years for pioneers and 8.8 years for the control group ($t_{diff.} = -0.47$; n.s.).

<i>Educational status when entering:</i>	PIONEER		CONTROL GROUP	
	N	%	N	%
student	66	69.5	152	53.9
graduate	29	30.5	130	46.1

TABLE 2: *Cross tabulation of pioneer and control group respondents by educational status at the time of entry (N=377; $\chi^2=6.44$; $p=.011$).*

RESULTS

Decision to enter the field

Previously, we reported significant differences between pioneers and the control group in terms of the factors that have continued to influence their decisions to work on the subject of neural networks. Pioneers, in comparison to other scientists, are more influenced by their cognitive perception of what is interesting and less influenced by factors pertaining

to the decisions and opinions of others in the research community. The differences between pioneers and the control group persist even when taking into account the age and length of professional experience of respondents when they initiate neural networks research.

Using the same core items as in the earlier studies (see APPENDIX), the present analysis further partitioned the data according to whether or not a respondent was a student when starting neural network research. The analysis, which consists of a two-factor ANOVA with educational status (student/graduate) and the usual dichotomy between pioneers and control group as independent variables, is shown in Table 3. The results indicate that the pioneer/control group dichotomy accounts for many significant main effects, thereby confirming the findings of our previous research. Compared to the control group, pioneers are more influenced by their intellectual interest in neural networks and less influenced by such factors as the opinions of leading researchers, successes of other researchers, potential for peer recognition, availability of funding, and lack of other topics to pursue. Moreover, pioneers are less concerned with the number of other researchers in the field, as well as how fast the field is growing.

The independent variable for educational status provides less of a contrast between respondents. There are no statistically significant interaction effects between the independent variables. Significant main effects occur in only two instances: the availability of funding and financial entry requirements, both of which have less influence on a student's entry decision than on the entry decision of graduates. With each of the other items, we find no evidence that students are different from graduates with respect to the factors that influence their decision to work on neural networks.

A one-way ANOVA, using Tukey-HSD and Scheffé tests to examine differences between the four groups, yields a significant difference between students and graduates in only one instance: the availability of funding item for control group respondents. This result is also confirmed by t-tests that compare students to graduates within the pioneer and control groups. For pioneers, the t-tests reveal significant differences between students and graduates in only two instances: students are less influenced by the intellectually compelling nature of the field ($p=.028$) and are more influenced by the opportunity to build a company ($p=.006$). For the control group, there are also two significant differences, albeit on different items: students are less influenced by the availability of funding ($p=.002$) and financial entry requirements ($p=.006$). Similarly, when controlling for educational status, we continue to find significant differences between pioneers and the control group.

Importance of ...	PIONEER				CONTROL GROUP				P/C	S/G	INTER-ACTION
	STUDENT (62/65)		GRADUATE (27/29)		STUDENT (147/152)		GRADUATE (118/127)				
	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.			
intellectually compelling nature of field	6.17	1.3	6.59	0.7	5.85	1.5	5.74	1.4	**	n.s.	n.s.
positive opinions of leading researchers	3.30	1.8	2.66	1.9	3.68	1.9	3.65	2.0	*	n.s.	n.s.
successes of other researchers	2.87	1.8	2.66	1.8	4.07	1.8	4.22	1.9	***	n.s.	n.s.
potential for peer recognition	2.79	1.5	2.52	1.6	3.09	1.8	3.45	1.9	*	n.s.	n.s.
dissatisfaction with previous research	2.76	2.1	2.59	1.9	2.97	1.9	2.64	1.9	n.s.	n.s.	n.s.
opportunity to solve a societal problem	2.77	2.0	2.24	1.7	2.55	2.0	2.50	1.8	n.s.	n.s.	n.s.
availability of funding	1.94	1.4	2.17	1.5	2.33	1.7	3.00	2.0	*	**	n.s.
lack of other research topics	1.94	1.4	1.83	1.5	2.64	1.8	2.31	1.7	**	n.s.	n.s.
potential for financial rewards	1.74	1.4	1.66	1.3	1.96	1.5	2.24	1.7	n.s.	n.s.	n.s.
opportunity to build company	1.60	1.2	1.17	0.4	1.66	1.3	1.62	1.2	n.s.	n.s.	n.s.
growth rate of the field at time of entry	1.98	1.4	2.43	2.1	4.00	1.9	3.90	1.9	***	n.s.	n.s.
size of the field at time of entry	1.68	1.1	1.93	1.5	3.21	1.7	3.02	1.6	***	n.s.	n.s.
intellectual entry requirements	3.70	2.1	3.96	2.1	3.77	2.2	3.48	2.0	n.s.	n.s.	n.s.
financial entry requirements	2.25	1.3	2.67	1.9	2.13	1.6	2.62	1.7	n.s.	**	n.s.

TABLE 3: Two-factor ANOVA on factors influencing respondent's decision to enter the field for pioneers/control group and student/graduate independent variables.

Notes: scale: 1=not at all important ; 7=very important
p-values: ***p<.001; **p<.01; *p<.05

Respondents were also asked to report the extent to which their supervisor and colleagues were aware of their decision to work on neural networks and the extent to which these individuals gave them encouragement (see Table 4). A two-factor ANOVA reveals significant main effects for the independent variables in only one instance: encouragement from supervisor is weakly significant ($p=.046$) for the comparison between students and graduates. There are no significant interaction effects between independent variables. For the supervisor items, only those respondents who report having a supervisor at the time they enter the field were considered. Controlling for the pioneer/control dichotomy indicates a difference on supervisory encouragement for students and graduates only for those respondents in the control group ($t=-1.68$, $p=.046$). Controlling for the student/graduate dichotomy, however, does not yield significant differences between pioneers and the control group. Thus, in terms of supervisor and colleague awareness and encouragement, the pioneer and control groups are virtually homogeneous in their responses.

Persistence in the field

The above analysis is made somewhat more complicated by the fact that respondents are reporting about a decision they may have made several years earlier. Clearly, the element of time may create some distortion. Thus, we sought to balance our analysis by examining an issue that is more contemporaneous with the survey's administration; namely, how determined are respondents to remain in neural networks research. We posed the question of persistence to respondents in two ways: first, we asked respondents to rate the importance of factors that might influence them in their decision to discontinue working in the field (see APPENDIX); and second, we asked respondents how long they would be willing to continue neural network research, given the current rate of progress in the field. Once again, we compared students with graduates, but now we classified respondents according to their current educational status and not their educational status when entering the field. Since few pioneers are students at present, the analysis focused on the differences that might exist between pioneers ($N=87$) and the control group, which was divided into students ($N=104$) and graduates ($N=178$).

<i>Respondent's work environment at entry:</i>	PIONEER						CONTROL GROUP						P / C	S / G	INTER-ACTION
	STUDENT			GRADUATE			STUDENT			GRADUATE					
	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N			
awareness of supervisor [†]	5.41	1.9	54	5.33	1.9	12	5.26	1.9	129	5.46	1.9	35	n.s.	n.s.	n.s.
awareness of colleagues	4.37	2.0	62	4.26	2.0	19	4.01	2.0	146	4.08	2.0	107	n.s.	n.s.	n.s.
supervisor encouragement [†]	5.52	1.6	54	4.92	2.1	12	5.81	1.5	129	5.31	1.7	35	n.s.	*	n.s.
encouragement of colleagues inside organization	4.53	1.4	66	4.28	1.5	29	4.55	1.5	148	4.31	1.4	128	n.s.	n.s.	n.s.
encouragement of colleagues outside organization	4.06	1.4	64	3.97	1.3	29	4.27	1.3	144	4.39	1.3	126	n.s.	n.s.	n.s.

TABLE 4: *Two-factor ANOVA on awareness and encouragement of colleagues and supervisor upon respondent's decision to begin working on neural networks.*

Notes:

Scale: 1 = not at all; 7 = very much.

N's reported are for the two-factor ANOVA.

[†]Only those respondents who had a supervisor at time of entry.
p-values (one-tailed): ***p<.001; **p<.01; *p<.05.

Using ANOVA techniques, we compared the three subgroups across a dozen items in order to identify factors that might influence them to cease work on neural networks. The results, shown in Table 5, indicate that statistically significant differences between pioneers and the control group occur in all but two items: diminished intellectual interest and increased cost of research. In most cases, pioneers differ from both graduates and students in the control group. By comparison, there are no significant differences between students and graduates within the control group. Thus, with respect to respondents' persistence in the field, the relevant distinction is between pioneers and the control group and not between students and graduates. This finding further confirms the results of the preceding analysis of the respondents' decision to work in the field, even though different subsets of respondents were used.

In a similar manner, an analysis of how long respondents are willing to continue working on neural networks primarily highlights differences between pioneers and the control group. The results of a non-parametric Kruskal-Wallis comparison of the three groups are provided in Table 6. Pioneers express a determination to remain in the field which is unmatched by both graduates and students in the control group. Pioneers plan to continue neural network research for more than ten years, compared to two-to-five years for both student and graduate respondents in the control group.

Using non-parametric Mann-Whitney tests, we compared pairs of each of the three groups, with similar results. The difference between pioneers and students is highly significant ($z = 4.9589$, $p < .001$), as is the difference between pioneers and graduates ($z = 6.2442$, $p < .001$). However, when comparing students and graduates, no significant difference is found ($z = .0927$, n.s.). Thus, once again the dichotomy between pioneers and the control group alone accounts for the significant differences between respondents. In a more thorough analysis using cohorts based on years of professional experience and age (in which one cohort consists solely of students), the differences between pioneers and the control group remain statistically significant for each cohort (for further details, see Rappa and Debackere, 1991).

Importance of ...	PIONEER (77/85)		CONTROL GROUP				p	TUKEY-HSD AND SCHEFFÉ PAIRWISE MEAN COMPARISON ($\alpha=.05$)
	MEAN	S.D.	STUDENT (102/104)		GRADUATE (160/173)			
			MEAN	S.D.	MEAN	S.D.		
diminished intellectual challenge	5.13	2.0	5.27	1.6	5.47	1.6	n.s.	—
lack of funding	3.89	2.1	4.60	1.8	4.67	1.8	**	$\mu_G > \mu_P$ and $\mu_S > \mu_P$
increased cost of research	3.76	1.9	4.02	1.5	3.99	1.7	n.s.	—
rapid progress in alternative areas	3.22	1.8	3.93	1.7	4.41	1.8	***	$\mu_G > \mu_P$ and $\mu_S > \mu_P$
difficulty in keeping up	3.19	1.7	3.57	1.7	3.81	1.7	*	$\mu_G > \mu_P$
overcrowding of the field	3.07	1.7	3.46	1.5	3.72	1.7	*	$\mu_G > \mu_P$
slow progress in problem solving	2.90	1.7	3.54	1.8	3.97	1.7	***	$\mu_G > \mu_P$ and $\mu_S > \mu_P$
diminished interest among others	2.55	1.4	3.37	1.5	3.33	1.6	***	$\mu_G > \mu_P$ and $\mu_S > \mu_P$
lack of financial rewards	2.49	1.6	3.25	1.8	3.06	1.8	*	$\mu_S > \mu_P$ †
discontinuance at organization	2.45	1.8	3.61	2.0	3.31	2.0	***	$\mu_G > \mu_P$ and $\mu_S > \mu_P$
negative opinion of supervisor†	2.43	1.5	3.78	1.7	3.98	2.0	**	$\mu_G > \mu_P$ and $\mu_S > \mu_P$
unfavorable opinions of leading	2.27	1.4	3.15	1.5	2.97	1.6	***	$\mu_G > \mu_P$ and $\mu_S > \mu_P$

TABLE 5: One-way ANOVA comparing factors that might influence respondent's decision to leave the field.

Notes:

Scale: 1 = not at all important; 7 = very important

† Only respondents who have a supervisor, $N_P=21$; $N_G=58$; $N_S=96$.

‡ The Tukey-test also finds $\mu_G > \mu_P$ though it is not upheld by the (more conservative) Scheffé-test.
p-values: *** $p \leq .001$; ** $p \leq .01$; * $p \leq .05$

	PIONEER		CONTROL GROUP			
			STUDENT		GRADUATE	
	N	%	N	%	N	%
less than one year	1	1.2	8	7.8	11	6.4
one-to-two years	7	8.4	22	21.4	25	14.6
two-to-five years	16	19.3	<u>36</u>	<u>35.0</u>	<u>83</u>	<u>48.5</u>
five-to-ten years	17	20.5	15	14.6	29	17.0
more than ten years	<u>42</u>	<u>50.6</u>	22	21.4	23	13.5

TABLE 6: *Distribution of the respondents in terms of willingness to remain in the field given current progress* (Kruskal-Wallis test: $\chi^2=40.41$; $p<.001$).

Note: column percentages add to 100-percent; median values are underlined.

DISCUSSION

Pioneers who enter a field as students largely resemble their non-student pioneering colleagues in terms of the factors that influence their decision to conduct research in neural networks. Student pioneers also resemble graduate pioneers in terms of the support they experience from their supervisors and colleagues when entering the field. With few exceptions, the remarkable similarity between students and graduates is also found to exist among respondents within the control group. Thus, even after taking into account the educational status of respondents when entering the field, the enduring contrast is one between pioneers and the control group.

A comparison of control group respondents who are presently students and graduates further confirms the lack of any significant differences in terms of the factors that might influence their decision to discontinue neural networks research. The basic similarity between students and graduates is also born-out by their expectations of how long they foresee continuing their neural network research. Thus, any differences that exist among respondents in terms of their persistence in the field, exist solely between pioneers and the control group.

The preceding analysis suggests that there is no evidence to support the view that students are significantly different from graduates in terms of their decisions to enter and remain in the field of neural networks. Pioneers demonstrate the same motivations in problem choice and persistence regardless of their educational status. Likewise, among the respondents in the control group, few differences exist between students and graduates. The single most important aspect of these findings is that they reaffirm the previously established notion that pioneers are distinctly different from other researchers in their motivations to enter and persist in a field. In addition, pioneers seem to be uniform in their attitudes regardless of their educational status.

One conclusion that can be drawn from this analysis is that the “pioneering spirit”—namely, an attitude toward doing science that is dominated by the intrinsic intellectual appeal of a problem area and a resoluteness to stay with it irrespective of prevailing opinions—is evident right from the start of a scientist’s career. That a significant portion of pioneers begin their work in an emerging field as students, implies that a pioneering spirit may be a quality which is instilled early-on and remains with a scientist rather than emerging gradually over the course of one’s professional career. If true, the implications for doctoral student education would be enormous. No longer would dissertation research be considered as merely a requirement to demonstrate one’s proficiency as a researcher, but rather as a unique opportunity to influence the movement of science in new directions. The long term intellectual vitality of the scientific community may, therefore, depend equally as much on its students as on its leaders.

While it is interesting to contemplate the potential role of students, a thorough understanding of their contribution to pioneering new fields will certainly require additional variables. For example, it may very well be that the relative stature of a university within the scientific community has some relevance in the pioneering behavior of its doctoral students. On the one hand, prestigious research universities may have the resources that would enable students who are inclined to take chances to more readily explore new fields. On the other hand, prestigious institutions may tend to reinforce among their students a more conservative attitude toward doing science that extends rather than challenges conventional thinking.

A precursory examination of the relationship between university prestige and pioneers in neural networks is shown in Table 7. Using a ranking of the top-100 U.S. research universities, which is based on the citation impact of publications over a fifteen year period compiled by Small (1990), we compared pioneer and control group respondents

according to their educational status when entering the field. Mann-Whitney tests, comparing the distribution of students and graduates within each group, indicate no significant difference among pioneers. There is, however, a difference between students and graduates in the control group ($p < .025$): respondents who enter the field after receiving their degree are more likely to have graduated from a top-ranked university. An additional Mann-Whitney comparison between pioneer students and control group students also yields a statistically significant difference ($p < .005$): student pioneers are more likely to be at top-ranked universities than are students in the control group.

To the extent that student and graduate pioneers are alike, the fundamental question spurred from the distribution in Table 1 remains unanswered—is there something special about being a student that makes one more likely to initiate pioneering research? An alternative hypothesis might be that the disproportionate representation of pioneering students in the respondent sample is a consequence of time-dependent processes. Given the time span of the field's emergence, graduate pioneers, generally being about ten years older when they start in the field, are more likely to have retired from the field than student pioneers. Whether this can fully account for the difference in distributions is subject to debate, but undoubtedly, a deeper understanding of pioneering behavior will require longitudinal research designs in order to answer this question.

UNIVERSITY RANK†	PIONEER				CONTROL GROUP			
	STUDENT		GRADUATE		STUDENT		GRADUATE	
	N	%	N	%	N	%	N	%
Top-20	20	43.5	7	29.2	33	28.2	53	36.6
Second-20	10	21.7	7	29.2	22	18.8	27	18.6
Third-20	11	23.9	2	8.3	21	17.9	27	18.6
Fourth-20	4	8.7	6	25.0	9	7.7	21	14.5
All others	1	2.2	2	8.3	32	27.4	17	11.7
Mann-Whitney test‡	z = -1.4584; n.s.				z = -2.0999; p < .025			

TABLE 7: *Distribution of respondents in terms of the ranking of the university from which they received their highest academic degree.*

Notes:

†University rankings are based upon citation impact scores for the period 1973-88 for the top-100 U.S. universities. Source: Institute for Scientific Information (Small, 1990).

‡Mann-Whitney test comparing students between pioneer and control group: $z = -2.867$; $p < .005$.

CONCLUSION

An investigation of scientists in neural networks suggests that pioneers are distinctly different in their motivations to enter and persist in the field, irrespective of their educational status. Pioneers who enter a field as students and those who enter as practicing academic scientists, that is after having received their highest academic degree, are, in comparison to the control group, more motivated by the intellectual appeal of the subject matter and less motivated by social forces within the scientific community.

The findings of this study suggest that scientists may develop an inclination for performing pioneering research very early in their professional career. In educating scientists, we should take this possibility into account and seek to nurture the pioneering spirit of students.

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APPENDIX

Items inquiring into the respondent's decision to enter the field of neural networks:

How important were each of the following factors in influencing your initial decision to include neural networks in your research agenda (*respondents were asked to circle on a 1 (not at all important) to 7 (very important) -scale with midpoint 4 (somewhat important)*):

1. intellectually compelling nature of neural networks
2. lack of other promising research topics
3. availability of funding for neural networks research
4. potential for financial rewards
5. potential for recognition by peers
6. dissatisfaction with a previous research agenda
7. positive opinions of leading researchers in the field
8. successes of other researchers with neural networks
9. opportunity to build a commercial enterprise
10. opportunity to solve an important societal problem

Items inquiring into what might lead the respondent to leave the field of neural networks:

How important would each of the following factors be in diminishing your current interest in neural network activities (*respondents were asked to circle on a 1 (not at all important) to 7 (very important) -scale with midpoint 4 (somewhat important)*):

1. slow progress in solving technical problems in neural networks
2. lack of funding for your neural network research
3. diminished interest among other researchers in neural networks
4. rapid progress in alternative areas of research
5. opinions of leading researchers unfavorable to neural networks
6. negative opinion of your supervisor (if any) toward neural networks
7. discontinuance of neural net activities at your organization
8. lack of financial rewards
9. diminished intellectual challenge of neural network research
10. increased financial cost of conducting neural network research
11. overcrowding in terms of the number of neural network researchers
12. difficulty in keeping up with new developments in neural networks

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