HISTORIA MATHEMATICA 21 (1994), 280–305

On Connecting Socialism and Mathematics: Dirk Struik, Jan Burgers, and Jan Tinbergen

GERARD ALBERTS

University of Nijmegen, Science & Society, P.O. Box 9108, NL-6500 HK Nijmegen, The Netherlands

The Dutch mathematicians, Dirk Struik, Jan Burgers, and Jan Tinbergen, each struggled to find ways to combine their political and scientific aspirations. Although they came from similar social backgrounds and shared much the same scientific training—all were pupils of Paul Ehrenfest—their later approaches to this dilemma varied markedly. Struik's views on mathematics were the most radical, asserting that mathematical conceptions can better be understood in conjunction with larger social and intellectual processes. By contrast, of the three his mathematics changed the least under the influence of external factors. The approaches taken by Burgers and Tinbergen illustrate ways in which the social context can affect a mathematician's work. Their novel ideas helped launch a new paradigm for using mathematics to address social problems, viz., the notion of mathematical modeling, which superseded the conventional approach to applied mathematics.

Die holländischen Mathematiker Dirk Struik, Jan Burgers, und Jan Tinbergen bemühten sich alle drei darum, einen Weg zu finden ihre politischen und wissenschaftlichen Ambitionen miteinander zu verbinden. Obwohl sowohl ihr sozialer Hintergrund, als auch ihre wissenschaftliche Ausbildung vergleichbar waren—alle drei waren Schüler von Paul Ehrenfest—unterschied sich ihr späteres Herangehen an diese Fragestellung. Struiks Ansichten über die Mathematik waren die radikalsten: Er bestand darauf, daß mathematische Ideen am besten im Zusammenhang mit dem sozialen und intellektuellen Kontext verstanden werden könnten. Im Vergleich der drei wandelte sich seine Mathematik am wenigsten unter äußeren Einflüssen. Die Antworten Burgers und Tinbergens auf die Frage, wie Mathematik und Sozialismus zu vereinigen seien, sind Beispiele dafür, wie der soziale Kontext die Arbeit eines Mathematikers beeinflussen kann. Ihre neuen Ideen halfen eine Auffassung einzuführen, welche die Mathematik dienstbar machen wollte, um soziale Probleme anzusprechen. Dies geschah durch den Begriff des "'mathematischen Modellierens,"' der die konventionelle Annäherung an die "'Angewandte Mathematik"' ersetzen sollte.

Drie Nederlandse wiskundigen, Dirk Struik, Jan Burgers, en Jan Tinbergen, poogden ieder hun politieke en wetenschappelijke ambities op een lijn te brengen. Hun sociale achtergrond en wetenschappelijke opleiding, ze waren alledrie leerlingen van Paul Ehrenfest, was volkomen vergelijkbaar, maar de keuzes die ze maakten verschilden wezenlijk. Struiks opvatting over wiskunde was de meest radicale, namelijk dat (de historische ontwikkeling van) wiskundig werk slechts begrepen kan worden in relaties tot een sociale en intellectuele context. Zijn eigen wiskunde, echter, veranderde van de drie het minst onder invloeden van buiten. De antwoorden van Burgers en Tinbergen op de vraag hoe wiskunde en socialisme te verenigen, laten zien dat de sociale context inderdaad zijn weerslag heeft op het werk van de wiskundige. Hun vernicuwende ideen mondden uit in een nieuwe visie op het maatschappelijk dienstbaar maken van wiskunde. Zij brachten het begrip "wiskundig model" naar voren, dat algemener was en in de plaats kwam van de traditionele benadering van "toegepaste wiskunde."

0315-0860/94 $6.00

MSC 1991 subject classifications: 01A60, 01A70
KEY WORDS: mathematical modelling; applied mathematics; socialism; science and society; social influence on mathematical practice; Dutch science

INTRODUCTION

In 1934, Jan A. Schouten, Dirk Struik's former teacher and long-time collaborator at the Technical University in Delft, sought to bring Struik back as a visitor. Upon Schouten's instigation, the Department of General Studies proposed his name to fill a guest professorship in probability theory. However, when the government informed the University that Struik's candidacy would meet with political objections, the institutional authorities at Delft advised the Department that they should withdraw his name from their proposal. "Solely scientific achievement must be considered," Schouten angrily reproached his colleagues, but the majority of them failed to raise a protest against such political blacklisting [AW 1, AW 2]. Later, in 1947, Struik touched on this issue when he casually remarked in a letter to Schouten that professional competence, not character, should decide the merits of a candidate for a professorship in mathematics [Sch 3].

These are but two instances illustrating the strong consensus among mathematicians that mathematics and politics do not mix. Or don't they? Struik belonged to a whole generation of science students who were very strongly inspired by socialism. In fact, Paul Ehrenfest, Struik's teacher at Leiden University and strictly speaking a nonsocialist, enjoyed local fame as "the red professor," simply because he opened his house to such young idealists—or should we say materialists? This article will compare the careers of three Dutch mathematicians who were pupils of Ehrenfest—Dirk Struik, Jan Burgers, and Jan Tinbergen—and the varied approaches they took in their attempts to integrate socialism and mathematics in their lives. The solutions they sought for combining political and mathematical aspirations present a telling picture not only of their own personal views and careers but of the evolution of mathematical practice as well.

Beyond the similarities in their political views and scientific training, Dirk Struik (1894–), Jan M. Burgers (1895–1981), and Jan Tinbergen (1903–1994) shared the same social background. Born the sons of, respectively, a Rotterdam schoolteacher, an Arnhem post office employee, and a schoolmaster in The Hague, each of them entered university after attending a Hogere Burgerschool, a special type of high school. Moreover, each went on to combine brilliant studies of mathematics and physics with leftist political activities. The Hogere Burgerschoolen, or HBS, were a typically Dutch type of high school created by the 1863 education reform. They served the interests of the upwardly mobile portion of the middle class, particularly those with civil service positions, so well that one might claim these institutions brought about a good part of that upward mobility themselves. A supplementary examination in Greek and Latin permitted HBS pupils access to the universities, which were otherwise reserved for Gymnasium pupils.

Once enrolled at the University of Leiden, Struik, Burgers, and later Tinbergen found in Paul Ehrenfest, a professor of theoretical physics, their most influential

FIG. 1. The invitation to the 25th annual meeting of the University of Leiden student club for the physical sciences, "Christiaan Huygens," held in 1920. The drawing shows Paul Ehrenfest guiding little Christiaan Huygens around the fairground of theoretical physics.

teacher and mentor. Ehrenfest was "different," an unconventional figure in the Leiden academic community. He organized a weekly physics colloquium, and inspired the students to revive their society for the physical sciences "Christiaan Huygens" (see Fig. 1), while simultaneously dissuading them from joining the elitist Student Corps. He had a reading room for staff and students installed at his institute, the "Leeskamer Bosscha," inspired by the example of the Mathematisches Lesezimmer in Göttingen. Hendrik A. Lorentz, whose chair he had assumed, soon appreciated his efforts to put the students on their own feet, remarking that "[h]e has already managed, in this short time, to accomplish what I tried in vain to do during all the years of my professorship. He has gotten the students talking" [29, 211]. Although Ehrenfest would disagree with the views of his leftist students for the most part, he and his wife Tatyana took an avid interest in discussing political issues with them. In one such conversation with Jan Tinbergen, Ehrenfest remarked: "Jan, I simply cannot assume that all men are equal" [Tin 2]. Nevertheless, in his abstinence from alcohol and smoking [29, 205] and his financial support for a market gardening project started by one of Tinbergen's friends [ESC 373], Ehrenfest was firmly situated in the milieu of cultural socialism in the Netherlands during the 1920's. He also did not hesitate to involve himself in the lives of his students. Characteristically enough, Ehrenfest persuaded Struik to give up commuting to Rotterdam and move to Leiden. Martin Klein has described Ehrenfest's close working relationship with Burgers, his first doctoral student [29, 207], and Tinbergen later recalled:

> To Ehrenfest I owe a great deal. I studied physics at a time when a number of fascinating persons were there together. Ehrenfest would not instruct as such, as he preferred dialogue. Thanks to him I could participate in discussions with Albert Einstein. Also Kamerlingh Onnes, Lorentz and Zeeman were present. Being a student in the hands of such teachers, you are fortunate indeed. [Tin 1]

Yet however personal Ehrenfest's imprint may have been, his commitment to the highest scientific ideals represented the true core of his impact as a teacher. When Struik, Burgers, and later Tinbergen studied with Ehrenfest, theoretical physics was in a state of turmoil and Leiden was one of the major centers grappling with these tumultuous developments. Ehrenfest strove to attain physical insight above all else, which implied rethinking the role of mathematics and logic as key subsidiary tools for physical theories. At the time, when others were tempted to rely simply on formalisms, Ehrenfest acted as the better conscience of the community of theoretical physicists. It was this aspect of his teaching, namely his new vision of the role of mathematics, that was to leave the most lasting mark on these three students.

Following their student years in Leiden, the lives of these three young scientists began to diverge. Dirk Struik's social concerns eventually found expression in a second career that went side by side with his work in mathematics, namely, his activities in the sociology and history of science and mathematics. Jan Burgers enjoyed a lustrous career in theoretical aerodynamics while at the same time attempting to integrate this work into a larger philosophical framework via an early, but wholly neglected, reception of Alfred North Whitehead's process philosophy. Finally, Jan Tinbergen managed to meld his scientific approach with the very objectives of his political program. In the process he not only had a hand in creating a new science but also gave the notion of "scientific socialism" a new meaning. (See Figs. 2–4 for portraits of the three.)

STRUIK'S DILEMMA: PROFESSIONAL SOCIALIST OR SOCIALIST PROFESSIONAL?

In the years 1915–1916, before graduating from Leiden University, Dirk Struik struggled to answer a difficult personal question: how to reconcile doing mathematics with his recently acquired Marxist convictions. As he later wrote:

> It was in those days that I first asked myself whether I should go permanently into party work or continue my mathematical career, follow either Wijnkoop and Van Ravesteyn or my professors Kluyver and Ehrenfest, to be a professional socialist or a socialist professional. [59, 210]

The question is, of course, a nearly universal one—what to do with the rest of your life?—and often a pressing one at that age. For Struik, the more precise

FIG. 2. Dirk Struik, ca. 1920.

question concerning how to combine Marxism with mathematics took a very palpable form. He was at the time an active member of the Sociaal Democratische Partij (SDP), the radical left wing of the socialist movement, and prominent in its youth organization.

A brief sketch of the left end of the political spectrum in the Netherlands may serve to clarify his position. The Dutch labour party, Sociaal Democratische Arbeiderspartij (SDAP), had been founded in the very year of Struik's birth as a reaction against radicalizing syndicalism within the Sociaal-Democratische Bund (Social Democratic League or SDB), which till then had functioned as the fulcrum for Marxist thought in the Netherlands. Even within this parliamentary-oriented SDAP there were latent tensions between reformists and revolutionaries. Antagonisms eventually reached a critical stage. Of course these cracks, bursts, and the eventual explosion of the Social Democratic movement were by no means a purely Dutch phenomenon. In the Netherlands, the major fissure occurred at the famous Deventer convention of 1909. There, D. J. Wijnkoop, W. van Ravesteyn, and

FIG. 3. Jan Burgers, ca. 1920.

J. H. Ceton were expelled from the SDAP and thereafter founded the SDP, which in 1918, following the lead of its counterpart in Russia, renamed itself the Communistische Partij in Holland (CPH). It should be noted that all SDAP and SDP members called themselves social democrats, thereby associating themselves with the platform of Kautsky's Erfurt Programme. And although some of the written attacks exchanged between SDP's *De Tribune* and SDAP's *Het Volk* were hardly less poisonous than the gases unleashed in neighbouring countries during the war—unlike Belgium's, the neutrality of the Netherlands was respected throughout 1914–1918—the two factions could still be considered as defining the extremes within a single movement. By the end of World War I, disputes over such issues as the SDP's appeals against nationalism and for demobilization exacerbated tensions between the political party organizations to the point that no further cooperation was possible. All the same, the social democratic movement at large, comprised of a multilayered network of unions, youth movements, debating clubs, and publications, was slower to split up than the established political parties. Dirk Struik was at this time a close follower of Van Ravesteyn and Wijnkoop, and he helped organize *De Tribune*, a publication in the thick of the political fighting

FIG. 4. Jan Tinbergen, undated.

zone. At the same time he organized a much more open student study group on socialism in Leiden, and he became a prominent member of *De Zaaier,* a leftist youth movement [20, 127].

The Bolshevik Revolution in Russia led to a rapid resolution of some of the principal conflicts underriding the social-democratic movement in the Netherlands. One of the key turning points came in November 1918 when Pieter Jelles Troelstra, the leader of the SDAP, inspired by German events, proclaimed revolution on November 11th and 12th, only to withdraw his proclamation on November 14th—an event that has since become known as "Troelstra's mistake." Anti-socialist crowds rallied in The Hague in the following days pledging their allegiance to the queen. Thereafter, the SDP followed its own "revolutionary" path, and in 1918 identified its program as communist, becoming the CPH (Communistische Partij Holland, later CPN or Communistische Partij Nederland). Taking its lead from Moscow, the CPN began organizing the West-European Bureau of Komintern (WEB). Struik gave an account of the semi-secret efforts to organize the first WEB conference in early 1920 [59, 234].

These background events and political struggles are particularly relevant to the question of combining Marxism and mathematics because of the fundamental tenets of scientific socialism. This doctrine claimed to be grounded in scientific principles that offered insight into the general unfolding of history. The immanent contradictions in the capitalist mode of production were to cause its dissolution and eventual collapse, and thereafter capitalism was to be superseded by socialist structures. A series of supposed signals would harken the coming collapse. The first signal would be strikes, which were to expand from one branch of industry to the next, culminating in a general strike as a prelude to "the revolution." Strikes came, of course, and even a general strike around the turn of the century, but the great collapse did not occur. Instead, the railway strikes of 1903 in the Netherlands were broken by force, and left-wing socialists reproached the SDAP for the treason of not having taken a firm stance against the repression. Monopolistic business practices and extreme concentrations of wealth were considered another signal intimating the onset of the final stage of capitalism. Within leftist circles fierce debates raged over whether to support antitrust legislation, which according to one view meant slowing down the course of history, whereas the other side urged efforts to improve the slave-like plight of the workers. Economic depression was seen as a highly significant signal that gave rise to a wide variety of expectations for some kind of revolution, expectations that were followed by an equally diverse set of political sects, dreams, and disappointments. Every sign of a depression unleashed speculation among social democrats of all persuasions about the permanent or transitory character of the phenomena in question. Was "the final crisis" to be welcomed or was it just another, albeit particularly severe, business cycle? What were the implications of the Great War with its backlash of nationalism? What kind of signal was this: a crisis of humanity? of civilization? of capitalism? or was it a crisis for the international solidarity of the working class? And was socialization of the means of production a feasible proposition? Could one legitimately "proclaim" the socialist phase of history? Although no one really proposed passive waiting, the widely varying views on strategy were embodied in the divergent factions of the social-democratic movement.

In the first two decades of the twentieth century each of the "signal events" —strikes, general strike, monopolistic business practices, and the ensuing economic depression, more or less in that order—raised a series of expectations, and with the passing of each event another splinter faction would be cast off within the movement. The Russian Revolution of October 1917 produced the final irremediable rift.[1]

Such was the political context in which Struik had to find his way. The question of how to combine science and socialism was no mere academic exercise. Struik's brother, Anton, a civil engineer, chose to become a professional socialist, and

[1] On The Netherlands in general, including political events such as Troelstra's mistake and the development of the country's social and political structures, see [30, Chap. IX; 10]. For details on the socialist movement, see [20; 21; 26; 27; 39; 59].

along with a number of like-minded colleagues went off to Russia to build a new society. In 1921 Anton Struik joined Project Kuzbas in Siberia and later helped with the construction of the Turksib Railroad before returning to the Netherlands in 1935 to become a senior party professional. His elder brother Dirk, who at one point seriously considered following a similar course of action, later described the difficulties he faced in choosing between mathematics and politics:

> It was a question all young intellectuals in the movement have to face some time or another. Sometimes a party worker brought it up: I remember Metscher asking me why I wanted to study all that "bourgeois science." The question was not raised, as it is now, in horror at the degradation of science by the industrial–military establishment, yet the relationship between science, war and unemployment was already felt in socially conscious circles. But despite all this, it was still easy to see science, especially mathematics, as a noble enterprise of great beauty, and my heart was in it. Moreover, I was convinced that professionals had their own part to play in the struggle for social justice, that Marxism was an enterprise with room for all faculties. An additional factor was that, with all respect for the party leadership, I did not relish the prospect of working permanently under it; it was a little too dictatorial. [59, 211]

Struik had an inkling that Gerrit Mannoury (1867–1956), a well-known SDP–CPN socialist as well as a prominent mathematician and philosopher of mathematics who had stimulated L. E. J. Brouwer's early ideas on intuitionism, might be able to offer a solution to his dilemma. But he was disappointed by Mannoury's lecture delivered before a forum of socialist students in Leiden in 1915. Mannoury, a true maverick, was an active contributor to *De Tribune* and later to *Klassenstrijd,* and published books on Buddhism and mathematics, and on socialism, as well as his famous *Mathesis en Mystiek* [32]. In the further course of political events he was to step down from the board of *Klassenstrijd* in 1928, and in 1929 he was thrown out of the CPN after leveling a protest against political trials in the Soviet Union. Older than Wijnkoop, Van Ravesteyn, and their cohorts, Mannoury maintained close relations with the social democrats of his own generation, among them Theo van der Waerden, a parliamentary representative of the SDAP and leading authority on labour relations and Taylorism. His son, Bartel L. van der Waerden, recalled how in the 1910's Mannoury would stop in to visit the family on Sundays, and how his father, who hated walking (a common Sunday activity was to take a bicycle tour), would stroll alongside Mannoury and debate politics for hours [Wae]. Dirk Struik admired Mannoury's intellectual style and robust spirit, but nothing the latter said gave him the slightest clue as to how one might "combine theory and practice." Instead, he recalled Mannoury as someone who "entertained us with an intensely witty speech strewn with paradoxes . . . , but left me quite bewildered" [59, 207].

Struik, for his part, eventually chose to become a socialist professional, but the systematic question remained. His search for a way to accommodate mathematics and politics led to a balance between, rather than an integration of, the two activities. Moreover, for Struik this approach would remain a constant throughout his career. He did not try to advance new answers on the level of mathematics itself. Burgers and Tinbergen, facing similar questions, responded quite differently, both from Struik and from one another. Thus, while all three became professional scientists, the degree to which they integrated socialist ideals into their mathematical work varied quite dramatically.

Struik's professional career began under the wing of J. A. Schouten (1883–1971), then a young professor in Delft. Schouten's *Grundlagen der Vektor- und Affinoranalysis* [11] represented a significant advance toward developing a systematic tensor analysis based on the principles of Klein's "Erlanger Programm," as Klein himself emphasized in his *Vorlesungen über die Entwicklung der Mathematik im 19. Jahrhundert* [28, 45]. In 1917 Struik became Schouten's assistant, working closely with him on generalized tensor analysis and differential geometry. Together they coauthored a series of articles and finally two books on the subject [44–47]. Schouten was a modern research leader. In conducting research through teamwork and in designing a research program, he was ahead of his time. Struik was one of a series of assistants with whom Schouten coauthored several articles. Schouten's zeal for his research program stemmed in large part from the need for a well-developed geometric framework within which general relativity theory and unified field theories could be studied. By the early 1920's, Schouten's work confirmed his position as a leader at the forefront of international mathematical research [43; 60]. By contrast, Schouten's style of mathematics was by no means modernist,[2] as he clung, perhaps even more strongly than Felix Klein, to the solid grounds of a geometrical interpretation of his work. Schouten's geometrically tuned direct analysis produced a totally inaccessible formalism. The results were correct and some of them even of central importance, but the packaging turned Schouten's work into unmanagable "Orgien des Formalismus," as Hermann Weyl once described it. The intemperate words "Den Mann, der dieses Buch geschrieben hat, möchte ich erdrosseln" have been attributed to Schouten himself [57, 95], but this saying probably originated in Felix Klein's circle. Considering that Schouten's mathematics was largely motivated by its potential applications to physics, one might have anticipated some reflections on what it means to apply mathematics to another field. The physicists Hertz, Boltzmann, and Ehrenfest had all pondered this theme, and although Schouten held a post as unsalaried lecturer in Leiden precisely due to the relevance of his work for theoretical physics, he stuck to the idea, much like Klein, of a fundamentally autonomous applied mathematics. Even with the advantages of hindsight, he went no further than to call the relations between mathematics and physics "interplay": their cooperation is fruitful, but progress is made in the two sciences only intermittently [42, 19]. Although Schouten did invoke such terms as "structural schema"—hinting that the notion of mathematical modeling was in the air in Delft as well—the tradition in which he and his student Struik worked developed no new notion to express a more intricate relationship between pure mathematics and its applications.

In 1922 Struik defended his thesis in Leiden. The following year he married, and from 1924–1926 he and his wife, Ruth, worked in Rome and Göttingen sup-

[2] In later years, for example, both Schouten and Struik regretted never having familiarized themselves with topology [Sch 4; Sch 5].

ported by a Rockefeller fellowship. After pondering the possibility of working on a scientific project in the Soviet Union, they opted instead for New England, and in late 1926 Struik joined Norbert Wiener on the mathematics faculty at MIT.

Schouten's wish to bring Struik back to Delft in 1934 was quite understandable, given their ongoing collaboration and the preparations they had made on their two-volume *Einführung in die neueren Methoden der Differentialgeometrie* [47]. Moreover, Struik had been lecturing on probability theory at MIT, had published on the subject [49], and had even edited the papers on probability theory delivered at a 1933 AMS meeting [50]. In view of the fact that the Netherlands generally lacked expertise in this rapidly emerging field, the country might well have benefitted from Struik's input. But this was not to be.

STRUIK'S SOCIOLOGY OF MATHEMATICS

When it came to the systematic question of how to combine socialism and mathematics, Struik eventually sought to reconcile, rather than to combine, his interests. He reached a resolution through three stages. Initially, the two spheres of interest had little to do with one another. While in the United States, Struik's interest in political matters continued unabated and politics filled every spare moment of his time. The pinnacle of his political activity in the Netherlands came in the mid 1930s, when after eight years he returned to his native country for some months. During this period he published a set of two introductory booklets for CPN training courses on historical and dialectic materialism that appeared under the pseudonym O. Verborg [64; 65]. These writings were produced during the very sabbatical leave from MIT in 1934; when the Dutch government prevented him from teaching at Delft.

The second stage in Struik's resolution of scientific and political interests came through his work in history. A strong tradition of popularizing science, particularly through historical introductions, had long been nourished in leftist political circles in the Netherlands. Marcel Minnaert, who had been Struik's fellow student in Leiden, had been very active in this domain, but the most successful figure of all was Anton Pannekoek, a socialist of Mannoury's generation who had been active in the German Social Democratic Party and whose writings on astronomy were very widely read. In a similar popular vein came the work of Lancelot Hogben, *Mathematics for the Million* [24], which appeared in a Dutch adaptation. This is only to say that a long-standing tradition of interest in the history of science was evident within leftist circles, and it was therefore not exceptional for a "socialist professional" to contribute to it. In doing so, Struik eventually went far beyond mere popularization with contributions to the history of mathematics and science that reached a high scholarly standard. Indeed, his *Concise History of Mathematics* [55] proved that it was possible to combine first-rate scholarship with a genuinely readable literary style. Struik's numerous contributions to the history of mathematics were largely undertaken as a complement to his own mathematical production, and were only rarely self-reflexive in the sense of touching on the latter. The only major exception to this was his "Outline of the History of Differential Geometry" [48]. Struik's *Concise History,* on the other hand, came about almost by accident after he was approached by the publisher, and it was written in rather short order immediately after he had completed the self-imposed and much more difficult task presented by the theme of his *Yankee Science in the Making* [54]. As with all his other historical publications, these works reveal that, for Struik, the history of mathematics represents far more than accrued knowledge collected in the form of theorems, proofs, and solutions to problems as often portrayed in standard texts. His assertion that "[o]ur mathematical conceptions were formed as the result of a long social and intellectual process." [56, 125] expresses no mere formal conclusion, but rather a firm conviction as to how mathematical ideas are produced. Far from denying that mathematics exists side by side with the arts, sciences, and technology as a central ornament of human culture, Struik has maintained that the material basis is decisive, and that throughout history the socio–economic structure has been the one invariable factor that influences the pace and direction of the development of mathematics. These conclusions hint at the third and final stage of Struik's undertaking to harmonize his mathematical and political concerns.

The notion that even science is shaped and influenced by social and economic factors would appear only "natural," one might think, within a Marxist worldview, and yet this was by no means a widely received opinion before the mid-1930's (outside the circles of the Marxist intelligentsia it still had a much longer way to go). In fact this notion received its first more elaborate Marxist treatment when Boris Hessen addressed this theme at the International Congress of the History of Science and Technology held in London in 1931. Struik gained considerable inspiration from this new approach, and one can detect shades of this even in his political writings from the 1930's (e.g., [64; 65]). These ideas also helped to inspire Struik and other Marxist scholars when in 1936 they founded the journal *Science and Society,* "a Marxian quarterly" according to its opening editorial.

The transition Struik made over these years is well illustrated by his quarrel with Lancelot Hogben, whose *Mathematics for the Million* had been very well received by Struik and which received a favorable review in *Science and Society.* Hogben, for his part, reacted critically to Struik's contribution [51] in the journal's first issue, associating it with other "pompous excursions into the quagmire of Prussian metaphysics." He demanded no less than a purge:

> It is disappointing to find this obsessional Germanophilia obtruding in an otherwise suggestive article [. . .]. The writer, D. J. Struik, in an exposition with most of which we might agree if he expurgated the sixteen references to Hegel by name—states that "the materialism typical of the seventeenth, eighteenth and nineteenth centuries is characterized by the contention that real explanations are always of a quantitative character." This is not merely nonsense. In Jeremy Bentham's phrase, it is nonsense on stilts. [25, 150]

In the next issue, in 1937, Struik struck back, accusing Hogben of "Hegelophobia," before going on to argue carefully that dialectical materialism represents a step beyond mere materialism. Struik countered Hogben's contention that his materialism was rubbish by insisting that the Englishman's notion of materialism was obsolete. "It is through Hegel and the dialectical materialists that we have learned to transcend this stage of materialist theory" [52, 550]. Dialectical materialism provided Struik with a new and broader view of mathematics that enabled him to relate to the cultural history of mathematical thought a broad spectrum of rational categories which Hogben refused to acknowledge had any connection with mathematics.

In 1938, soon after the founding of *Science and Society*, Robert Merton published his now classic study, *Science, Technology and Society in Seventeenth Century England* [33], and a further article for the newly launched quarterly entitled "Science and the Economy of Seventeenth-Century England" [34]. Merton's work not only opened new vistas in the history of science but also helped inspire Struik both to formulate a general program for the sociology of mathematics [53] and to undertake a major study within the context of that program, namely to explore the early development of science in America [54]. The sociology of mathematics, as presented in Struik's article [53] bearing that same title, was primarily to be understood as a new approach to the history of mathematics, an approach in which the social context can be viewed as the essential crucible for the production of mathematical knowledge. This appeal to the influence of different types of social structures in order to gain a better understanding of the prevalence of certain styles or stages of development in an intellectual discipline had, in the case of mathematics, never been made so explicitly before. If Struik did refer to Engels' *Dialektik und Natur* [17] repeatedly, and if, just as clearly, Hessen's paper of 1931 on the "Social and Economic Roots of Newton's *Principia*" [23] had broken new ground for him, it was Merton's study that provided him with the decisive clue that led him to combine sociology of science with the history of mathematics for the first time (cf. [60a]).

During the war years much of the normal mathematical research activity at MIT came to a standstill. Some of the professors were involved in research for the military; others, including Struik, carried heavy teaching duties connected with the training of military personnel. Aside from this, Struik spent much of his time pursuing an entirely new research project: to study the origins of American science in their social and economic setting, a subject that had barely been touched upon by historians before this time. Even more significantly, the dialectical-materialist approach Struik adopted toward this subject was unprecedented. He completed the manuscript in 1946, after some five years of research, and it was published in 1948 as *Yankee Science in the Making* [54], his most personal scholarly work [Sch 1; Sch 2]. Insofar as he achieved a synthesis of academic and political endeavours in his life, the results lie here. In the 1930s Struik's writings—as Verborg as well as his essays in *Science and Society*—show a somewhat formal or cerebral reception of the idea that science is influenced by social and economic factors; new ground is broken, but not very deeply. His article on "Sociology of Mathematics" in 1942 brought this approach to bear on Struik's own subject, the history of mathematics, and the examples he discusses, however briefly, are telling ones. At the same time, the article was intended to be programmatic, and *Yankee Science* exemplified how that program might be pursued. Full of cogent social analysis and vivid details, it offers a truly synthetic picture of early American science.

Dirk Struik chose to be a socialist professional, and his socialism never interfered with the content of his mathematics (although it did at times prompt others to try, occasionally successfully, to prevent him from teaching mathematics). His interest in the discipline's history may well have issued from his own political concerns, stemming first from the leftist tradition of popular historiography and, second, from the taste for history that his interest in dialectics fostered and brought about. Moreover, his approach to history of mathematics was clearly influenced by his own socialist convictions, which led him readily to accept the idea that science, at least in its pace and direction of development, was influenced by social factors. That acceptance was in turn instrumental in formulating the possibility of a sociology of mathematics, and in demonstrating the fertility of this approach in his study *Yankee Science in the Making*. The result helped spawn a new subdiscipline, sociology of mathematics, and provided new avenues of exploration for historians of science and mathematics. Thus, being a political progressive enabled Struik to become an innovator when it came to theorizing about mathematics, if not in its practice.

JAN BURGERS: PHILOSOPHY AND MATHEMATICS

Jan Burgers' professional career reveals rather little about his political preferences. One year younger than Struik, he became close friends with him while they were fellow students in Leiden. Burgers participated in political activities at that time, but he played no leading role in them; he later offered Struik his services as a translator for *De Tribune*. Four years after he had begun his studies, Burgers completed his dissertation, and even before he had defended it he was called to the newly installed chair for Aero- and Hydrodynamics at the Technische Hoogeschool in Delft. That was just shortly after Struik's arrival in Delft to serve as assistant to Schouten. Thus, in one swift move, Burgers advanced from being a student to heading a newly established research institute, and Dirk Struik saw his junior comrade transformed into a distinguished figure within the established academic hierarchy [Bu 2].

World War I had shown that aeronautics would play a decisive role in future military conflicts, and these circumstances prompted the creation of Burgers' chair in Delft along with the promise of laboratory facilities to follow, after unsuccessful pleas in 1912–1913. However, it would take another 25 years before a professorship in aviation engineering was established. For the time being, Delft restricted itself to the theoretical side of the field, and Burgers continued his work at a brisk pace. In 1924 he and his Delft colleague in applied mechanics, Cornelis Biezeno, organized an international conference on applied mechanics. This meeting turned out to be the first in a still ongoing series of international conferences. The related International Union for Theoretical and Applied Mechanics (IUTAM) was founded only after World War II, and, again, Burgers played a leading role in launching it. It was through contacts made at the 1924 conference in Delft that Dirk Struik and his wife Ruth made plans to study with Levi-Civita in Rome and with Courant in Göttingen soon thereafter. Upon their return to Delft in 1926, the

Struiks watched over Burgers' house while he visited St. Petersburg to lecture on aerodynamics at the institute of Ehrenfest's friend Joffe [29, 199; ESC 133; ESC 134; ESC 135].

Whereas Struik pursued historical interests to complement his mathematical research, Burgers' tastes ran more in the philosophical direction. He had broad intellectual interests and read a good deal of the cultural critics so popular during the interwar years, but his deepest inspiration came from Alfred North Whitehead's works, particularly his *Process and Reality* and *Science and the Modern World* [66; 67]. Burgers incorporated Whitehead's ideas into his own scientific vision which he set forth in several articles dealing with topics ranging from entropy and life, to causality, and the characteristic traits of modern Western science [7; 14]. He personally considered his book, *Ervaring en conceptie* [11], later translated as *Experience and Conceptual Activity* [12], one of his major accomplishments and was very disappointed when it went practically unnoticed.

Through his widespread international contacts during the 1930's, Burgers was well aware of contemporary opinion with regard to the role and function of science in society. In the United Kingdom in particular, scientists such as Julian Huxley and J. G. Crowther had expressed arguments in favor of directing science so as to benefit society as a whole. In 1937 the International Council of Scientific Unions, a body linking most of the national academies of science, set up the Committee for Science and its Social Relations. The Dutch chemist H. R. Kruyt acted as vice president of the International Council from 1937 to 1945. Through the Dutch Academy of Science, Kruyt and Burgers proposed that the Council appoint a committee to coordinate work in relation to the social responsibilities of science and scientists. Such a committee was installed in 1937, but its assignment was reduced to the task of surveying current research activities [37, 461]. These events, it should be noted, ran parallel to those that led to the founding of the journal *Science and Society* and reflected, in large part, similar social concerns, but they were clearly much closer to the mainstream of science.

Burgers was very active in this Committee for Science and its Social Relations. He was also a visible spokesman within the Dutch scientific community when the debates over the proper role of scientific research really heated up just before the outbreak of World War II. Along with a group of concerned scientists that included Jan Tinbergen, Burgers took the initiative in establishing an institute for the study of the implications of science for the development of social relations in the Netherlands [6].

The war prevented the founding of such an institute, but parallel events did propel this idea one step further. The year 1940 saw the founding of ISONEVO, an institute for social research on the Dutch population (social demographics), and in 1942 a survey of scientific activity in the Netherlands was in fact conducted for the first time. With the help of these prior developments, by 1945 the time was ripe to found scientific, rather than technological, research institutes by means of a framework that preceded the present-day Dutch National Science Foundation (ZWO). Also after the war, the same social concern of scientists led to the rise of the "Science and Society movement" in the Netherlands, although links to the international journal with this title appear to have been few, if any (see [35; 1]).

One cannot really assert that Jan Burgers sought to resolve, much less integrate, socialism and science in a manner similar to the way Dirk Struik approached this problem. Burgers' social conscience had led him to participate in political activity during his student years and, again, inspired his efforts to heighten social awareness among scientists in the 1930's. His reflections on the role of science in society led to innovation in the practice of science. In the Netherlands such innovations, involving systematic research and its organisation, took place after World War II. Burgers had already been a research leader, much in the style of Schouten, during the interwar years, and after 1945 he was active both locally and internationally in organizing modern scientific research. In 1955, at the age of 60, Burgers showed few signs of slowing down, and to the amazement of his friends and colleagues he accepted the challenge of setting up a new research institute in Maryland, which he directed for another 10 years.

BURGERS AND MATHEMATICAL MODELS

The central topic of Burgers' research was the statistical theory of turbulent motion, a topic remarkably close to the subject of Ehrenfest's dissertation, but without a direct connection to it. A leading scholar in the field with regular publications in *Zeitschrift für Angewandte Mathematik und Mechanik* (*ZAMM*) and a standard text coauthored with Theodor von Kármán in Durand's *Aerodynamic Theory,* Burgers took a theoretical, scientific approach to the subject, as opposed to the looser, engineering-oriented style that dominated earlier research in aviation engineering.[3]

Burgers emphasized his scientific orientation and distinguished his own work from that of other researchers by the ambition to establish "an absolute theory." This meant that he was not content merely to describe how turbulence evolves; he hoped to find a theory that could explain how it originates. Conscious that he did not have the latter in hand, Burgers presented, in a sequence of articles written between 1939 and 1948, first "mathematical examples" and later "mathematical models" illustrating the theory of turbulent motion [13]. The very titles of the articles reveal the emerging new role of mathematics: "Mathematical Examples Illustrating Relations Occurring in the Theory of Turbulent Fluid Motion" [3]; "Application of a Model System to Illustrate Some Points of the Statistical Theory of Free Turbulence" [4]; "On the Application of Statistical Mechanics to the Theory of Turbulent Fluid Motion.—A Hypothesis Which Can Serve as a Basis for a Statistical Treatment of Some Mathematical Model Systems" [5]; "A Mathematical Model Illustrating the Theory of Turbulence" [8]; "A Model for One-

[3] It is worth noting in this regard that the new style came into vogue with the founding of the Gesellschaft für Angewandte Mathematik und Mechanik (GAMM) in 1922, one year after the ZAMM; the GAMM was subtitled "Ingenieurwissenschaftliche Vereinigung," thereby stressing its "scientific" orientation.

Dimensional Compressible Turbulence with Two Sets of Characteristics'' [9]. Burgers was very precise in his wordings, and consciously employed the phrase ''mathematical model for'' rather than the usual ''mathematical model of'' in these writings. For Burgers, a mathematical model was the expression in mathematical ''matter'' of what one holds to be true of some subject; typically an axiom system for a theory in physics was expressed in mathematics, thus producing a mathematical model for the physical insight concerned.

In his retrospective 1955 valedictory lecture, Burgers summarized this approach as follows:

> Along different lines a lot has been reached which I, with my model, could not. But what has not been reached is, so to speak, an ''absolute theory,'' which parting from fundamental data leads to the true force of turbulence in its various aspects. The theory of so-called ''isotropic homogeneous turbulence'' may to some extent show how a given turbulence evolves, but it makes use of a hypothetical formula, which leaves many questions unanswered. I believe I may say that with my simplified model I am able to attain more principal results. [10, 15]

Here the echo of Paul Ehrenfest's position was only slightly dampened. During the early 20th century, theoretical physics went through its most dramatic passage and Ehrenfest had been at the very heart of it [29, xv]. The struggle to create the concepts of 20th-century physics involved more than physical insight per se, it also involved a major effort to interpret the status of scientific concepts. This entailed a profound reassessment of the nature of the contributions which mathematics could offer to physics, and to science in general. This latter aspect is most characteristic of the views of Ehrenfest, whose influence on Burgers was particularly strong.

While many physicists preferred to approach the ontological problems raised by physical theories from the comfortable position offered by positivism, Ehrenfest avoided such easy solutions. In fact, already in his Vienna doctoral dissertation, written in 1904 under the supervision of Ludwig Boltzmann, he adopted the approach of Heinrich Hertz's *Principles of Mechanics Presented in a New Form* [22] to treat problems of theoretical aerodynamics through an advanced use of classical mechanics. Ehrenfest's teachings eventually enabled Burgers, and later Tinbergen, to draw upon Hertzian views in setting forth their own respective notions of a mathematical model.

The connection between Burgers' thinking and Ehrenfest's views can perhaps be seen most clearly by referring to the famous survey article written in 1911 by Paul Ehrenfest and his wife Tatyana on the conceptual foundations of the statistical view of mechanics for the *Encyclopädie der mathematischen Wissenschaften* [16]. In this study they took a firm stance in favor of physical insight, opposing Mach's positivism and Gibbs' pragmatism in the very domain of physics where the idea of scientific truth had gone furthest adrift. Since the 1850's thermodynamics had been based on a kinetic theory of gases. The crude analogy of bouncing billiard balls had shaken the classical Laplacean ideal of physical truth, a kind of truth which was considered to be confirmed by, or even embodied in, the mathematics applied to it. Maxwell's formulation of the theory of electromagnetism dealt a further blow to the mechanical worldview, and led Ernst Mach to conclude that all theorizing in physics was purely metaphorical. J. Willard Gibbs went even further than Mach in advocating a pragmatic position ("as long as the theory works to derive the main results") or even a pragmatist view ("the truth of the theory is in its working") with regard to the ontological status of the statistical theory of gases. In his *Elementary Principles in Statistical Mechanics* of 1902 Gibbs wrote:

> Difficulties of this kind have deterred the author from attempting to explain the mysteries of nature and have forced him to be contented with the more modest aim of deducing some of the more obvious propositions relating to the statistical branch of mechanics. Here, there can be no mistake in regard to the agreement of the hypotheses with the facts of nature, for nothing is assumed in that respect [19, x].

In their *Encyclopädie* article, the Ehrenfests reacted to this position with little-disguised disgust: "Die kinetische 'Erklärungen' werden zu Abbildungen und dementsprechend jene beiden Gruppen von 'Hypothesen' zu willkürlichen Festsetzungen über den Aufbau des abbildenden Schemas" [16, 52]. Explanations turn into pictures and hypotheses into arbitrary statements. Clearly, Ehrenfest stuck to the search for a deeper truth and rejected Gibbs' "modesty." In the tradition of Helmholtz, Hertz, and Boltzmann he put physical insight in the first place; the role of mathematics was then to provide the appropriate images for expressing such insights. The term image, "Bild," had been introduced by Hertz.

Such was the situation concerning the relation of mathematics and physics in the early twentieth century.[4] The idea of a truth-conveying applied mathematics had come under severe criticism, but no clear new notion had been developed to replace it, although Hertz's notion of a "Bild" clearly offered one promising direction in which one might look. Burgers showed respect for the technical achievements attained by researchers who pursued more pragmatic approaches, but when it came to matters of real scientific insight he was just as reluctant to invoke ad hoc hypotheses as Ehrenfest had been. In the same vein, Burgers held on to the search for a deeper truth in his studies of the statistical theory of turbulence, calling his results "models" or "examples" because they were simplified and provisional expressions of insight.

What at first would appear as a conservative position in the evolution of scientific research, holding on to the search for truth against relativism, proved to be an intellectually fruitful position for formulating a way in which the older style of "applied mathematics" could be superseded. Burgers' notion of mathematical

[4] There is an awkward connection between the debates in the 1900's over relativism in science and relativism in socialist ideology. Boltzmann, like Ehrenfest later, took the anti-relativist position against Mach and his writings on analogy. Lenin in his *Materialism and Empirio-criticism* of 1908 sided with Boltzmann against Mach and the epistomological relativism of the "Machists." They had made "matter disappear" [31, Chap. V-2], which was the gravest sin in the eyes of the materialist. The Austrian social democrats were judged to be contaminated with Machian thought and, as Austro-Marxists, suffered condemnation within the communist movement long afterward.

modeling hinted that the former ideal of applications relating mathematics and physical theory had become untenable, while at the same time it silently echoed that ideal. Schouten and Struik had been working in a field in which the classical style of applying mathematics to empirical sciences still held up in some ways. Struik did reflect upon the relations between mathematics and technology and science in his history and sociology, but he never drew on these reflections in his own mathematical work. Unlike Burgers and Tinbergen, or Wiener and von Neumann, he stayed within domains of mathematics where applications predominantly were done in the classical style. The fast-breaking developments in Burgers' field, more closely related to technology, forced him to look for a new paradigm for making mathematics useful, and the direction he took, by coining the notion of mathematical model, betrayed the lasting influence of Ehrenfest's thinking.

JAN TINBERGEN: THE NEW FACE OF SCIENTIFIC SOCIALISM

Jan Tinbergen enrolled as a student at the University of Leiden well after Struik and Burgers had left for Delft. Of the three, he alone managed to avoid the choice between socialist professional and professional socialist. In his dissertation he expressed his gratitude to Paul and Tatyana Ehrenfest for pointing out a route that enabled him to combine scientific work with political ambitions. In 1921, when he began his studies, social democracy and communism had grown so far apart that they no longer presented parts of a single political movement. Virtually no common ground remained in youth movements, debating clubs, and the like, so that Tinbergen and his fellow students found themselves busy launching fresh organizations. These initiatives were taken without reference to the earlier efforts of Dutch social democrats. Tinbergen helped to found a club for social democratic students—just as Struik had done ten years before—as well as a student journal, *Kentering* (or *Turn*), that was launched on a national scale. Together with Hein Vos, a Delft engineering student, and others, Tinbergen also organized a socialist study group that focused on economic issues. Its participants, however, took a far more pragmatic line of thought than had their socialist brethren from the pre-1920's era. They made a clean break with the past, and essentially acknowledged no predecessors. Jan Tinbergen never met Dirk Struik and only years later did he come to know Jan Burgers.

Tinbergen belonged to a new generation of Social Democrats. Although the SDAP promoted major plans for the socialization and national organization of production in 1920 and 1923, the younger party members largely steered away from divisive debates over economic determinism and the socialization of the means of production. Scientific socialism was, for them, seemingly taboo, although in fact this younger generation was intent on redefining it in their own terms. They must have been keenly aware of the paradoxes that had plagued social democracy in the past and how these had resulted in an unproductive fragmentation of the movement. The shadow of "Troelstra's mistake" from 1918 hung over them although it was hardly ever mentioned, and the failure of the first generation was something that this "third generation" of Dutch Social Democrats wanted to avoid at all cost. Not that every detail was consciously conceived with this in mind, but those writing in *Kentering* who dared to address such themes as the necessity of the advent of socialism would, usually in the next issue, be sternly repudiated and identified with the failed older generation.

During the 1920's, two mutually interdependent currents emerged within social democracy, cultural socialism and socialism of planning. Cultural socialism stressed a vision of socialism as a superior way of life: purer, friendlier, and characterized by its strongly felt solidarity. At the extreme end of its spectrum were the religious socialists. Planned socialism, on the other hand, proposed technical measures that could bring about full employment and a more equitable income distribution. At the extreme of this second current were those who, like Tinbergen, proposed the use of statistics and mathematics in the service of socialist ideals. Thus, from this perspective, it might appear that Tinbergen was situated at the technocratic fringe of the social-democratic movement. His position, however, was anything but marginal, and his ideologically moderate views and politically constructive position gained dominance in the party in the 1930's.

A clear idea of Tinbergen's motivation can be found in a series of articles, among his very first, published in the socialist newspaper *Het Volk*. In them he reported on the situation of the unemployed poor in Leiden who had been struck by the 1920–1922 economic depression. These reports culminated with an emotional appeal to put a stop to this waste of human talent.

TINBERGEN'S SUCCESSFUL FAILURE

In the meantime, Jan Tinbergen studied physics with Ehrenfest, although he felt deeply that he should direct himself toward more socially constructive goals. Struik's problem had come to be his as well. As one of the first conscientious objectors to military service in the Netherlands—the law recognizing this status had been passed in 1923—he served his country by working at the Central Bureau of Statistics (CBS). There, he found abundant empirical material to support his, till then, far more abstract concerns with economics. As a result, he engaged in research on business cycles.

In 1929 Tinbergen completed his thesis work under the supervision of Ehrenfest. Essentially mathematical in nature, it concerned problems of minimization and included two appendices, one concerned with physics and the other with economics, that provided examples rather than applications of the mathematical structures treated in the main text [61]. This work signals his first serious attempt, as yet unrealized, to forge a successful combination of mathematical techniques that would serve socialist ideals.

Jan Tinbergen remained active in the Social Democratic Labour Party, and precisely as a socialist professional he became a professional socialist. Seeking to develop mathematical economics in the tradition of Walras and Pareto, and drawing on Ehrenfest's conceptions in mathematical physics, he pursued an "absolute theory" of economics. Just like Burgers', his zeal revealed the decisive influence of Paul Ehrenfest, but even more striking than in Burgers' case the resulting "failure" proved to be extremely fruitful. As it turned out, the transfer of physical theorizing to economics could not work [2], but along the way Tinbergen gained deep insights into the phenomenon of business cycles that helped ground the new science of econometrics.

In 1933 Tinbergen was appointed to a chair in "statistical analysis" at the Rotterdam School of Economics, and the following year he became a member of the board of trustees of the newly founded scientific bureau of SDAP. Along with his friend Hein Vos, the bureau's director, he coauthored the "Plan van de Arbeid" in 1935, which stood firm for the next decade as a symbol of the moderate and constructive position of the SDAP. This Dutch labor plan differed from its Russian and Belgian predecessors in that it was scientifically based, i.e., based on the principles of scientific economic rationality. The assumption that these principles of economic rationality might really be made to work was substantiated by Tinbergen one year afterward in an academic debate on the possibilities of active economic policy. In his contribution to the debate Tinbergen projected a "quantitative stylizing of the Dutch economy" to isolate the important factors and their effects by means of a set of definitions and equations. This "model" of the Dutch economy, as he called it (written with quotation marks at first), would allow one to throw some data into the "mathematical machinery" which would then predict the results [62, 68, 92]. This work marked a major turning point in the process in which classical applied mathematics gave way to mathematical modeling. This new style of putting mathematical thought to use resulted from—Struik was quite right here—a long intellectual and social process. Tinbergen's work was eventually recognized as the first ever macroeconomic model, an achievement for which he was awarded the Nobel Prize for Economics in 1969, along with the Norwegian Ragnar Frisch. The fulfillment in 1936 of his earlier aspirations signaled the full integration of Tinbergen's dual roles of socialist professional and professional socialist. The process continued with, among other things, his scientific work for the League of Nations in the late 1930's and his assumption in 1945 of the directorship of the Central Planning Bureau, a post to which he was called by Hein Vos, Holland's first Minister of Trade and Industry after World War II.

Within the context of this essay, the most important aspect is that Tinbergen's integration in 1936 was achieved through a new paradigm for the role of mathematics. Again, the urge to combine science and socialism proved an innovative force for the pursuit of scientific problems. Even more striking is the fact that, just like Burgers, and on quite similar grounds, Tinbergen developed the very same notion of a mathematical model. The notion of mathematical modeling rapidly spread after it was suggested by Burgers, Tinbergen, and a few others. It not only conceptually superseded the notion of applied mathematics, but replaced it in many domains.

In the evolution of Tinbergen's work the idea of "scientific socialism" was turned inside out to mean pursuing socialist goals by means of the scientific method, rather than the original claims made by Kautsky and Bernstein in the 1890's that socialism was itself scientific. There was nothing novel about employing scientific methods as a means for achieving socialist goals. The novelty came with the gradual identification, not only by Tinbergen and not only in the context of socialism, of scientific method and mathematical modeling. The other novel element, the point that really reversed the idea of scientific socialism, concerned the establishment of goals by scientific methods. Tinbergen took up the very term "scientific socialism," the original tenor of which his generation of Social Democrats had so derisively dismissed, and gradually loaded it with a diametrically opposite meaning. The original idea held that the theory of socialism, and in particular the progression of social relations towards a socialized mode of production, was scientific, and hence had to be valid by necessity. Tinbergen, for his part, proposed instead a "mature socialism," that was scientific in a totally different sense.

The science of welfare economics, he explained, provides us with the conditions that must be fulfilled in order to maximize social welfare, but the real problem is to "interpret these conditions in terms of the institutions which together will enable these conditions to be materialized. This group of institutions may also be called the optimum social order or regime and this I take to be identical with the mature socialist order" [63, 11]. In short: what produces the scientifically optimal social order is taken to be socialist. Unless one holds socialism to be a scientism in the first place, Tinbergen's was a new definition of socialism. Thus the successful combination of mathematics and socialism changed both. Mathematical practice was enriched with mathematical modeling. Socialism, in particular scientific socialism, did not mean the same thing anymore after it had become rationalized by scientific method.

CONCLUSIONS

Starting from similar backgrounds, scientific training, and socialist aspirations, Dirk Struik, Jan Burgers, and Jan Tinbergen each found their own distinctive ways to combine their interests in mathematics and politics. The desire for integration did have an impact, but this varied markedly depending on the route chosen. In Struik's case, politics and mathematics had little to do with one another on a practical level, but the former had a very decisive impact on his work in the history of science and mathematics. As the most clear-cut examples of this, one can point to his program for a sociology of mathematics and the part this played in his conception of *Yankee Science in the Making*. Burgers took a lower political profile, and through a broader notion of social consciousness stimulated the awareness of social responsibility among scientists. His efforts had a major impact on the style and organization of science in the Netherlands after World War II. Tinbergen, who enjoyed success in both politics and science early in his career, exploited an almost natural opportunity to integrate the two. His career was based on a choice rather than a dilemma, and his work exerted a major impact on both economics and on mathematics. As econometrics grew, it helped to promote a new paradigm for making mathematics useful, mathematical modeling. Thus, with all three men, social and scientific concerns went hand in hand and the former proved to be a powerful innovative force for the latter.

Struik, whose approach to mathematics changed the least of the three, had the most radical view on the dependence of mathematics upon cultural and social factors. Tinbergen's mathematics, on the other hand, changed dramatically under the influence of intellectual and social developments. Curiously, it was not Struik's own, but Tinbergen's style of mathematics that revealed the fertility of the sociological point of view. Mathematical modeling was the result of both internal reflections and external influence on the practice of mathematics. Further research will show [1] that, in turn, this form of serviceable mathematics helped create further rationality both in industrial production and in culture. From Struik via Burgers to Tinbergen, the idea of putting mathematics to use evolved from classical applied mathematics to be reformed and revitalized in the face of technological challenges and to emerge in the mid-twentieth century as the modern notion of mathematical modeling.

REFERENCES

Unpublished Sources

AW. Technische Hoogeschool te Delft, Archief Afdeeling Algemeene Wetenschappen. Minutes of the meeting of professors: [AW 1] 19 IX 1934; [AW 2] 9 XI 1934. Delft University of Technology, Central Archives.

Bu. Correspondence of Jan M. Burgers and Dirk J. Struik: [Bu 1] DJS to JMB, 4 VIII 1918; [Bu 2] DJS to JMB, 22 VII 1919; [Bu 3] DJS to JMB 25 VIII 1925; [Bu 4] DJS to JMB 28 VIII 1925; [Bu 5] DJS to JMB 18 VIII 1926; [Bu 6] Ruth Struik to JMB 5 VII 1927; [Bu 7] DJS to JMB 6 VII 1927. Burgers Archives, Laboratory for Aero- and Hydrodynamics, Delft University of Technology.

ESC. Ehrenfest Scientific Correspondence, including Dirk J. Struik, Jan Tinbergen, and Jan M. Burgers: [ESC 133] Paul Ehrenfest to Jan M. Burgers, 2 XI 1928; [ESC 134] JMB to PE, 2 XI 1928; [ESC 135] JMB to PE, 4 XI 1928; [ESC 373] Jan Tinbergen to PE, 13 IV 1928. Ehrenfest Archives, Museum Boerhaave, Leiden.

Sch. Correspondence of Jan A. Schouten: [Sch 1] D. J. Struik to J. A. Schouten, 15 VIII 1945; [Sch 2] DJS to JAS, 5 IV 1947; [Sch 3] DJS to JAS, 18 V 1947; [Sch 4] DJS to JAS, 30 XII 1950; [Sch 5] JAS to DJS, 14 I 1951. Library of the Centre for Mathematics and Computer Science (CWI), Archives Wiskundig Genootschap, Amsterdam.

Str. Dirk Struik, 'Leiden', Chaps. V and VI from unpublished autobiographical manuscript, ca. 1970.

Tin. Jan Tinbergen: [Tin 1] newspaper interview *NRC-Handelsblad* 10 XI 1987; [Tin 2] personal communication to the author, 22 IX 1987.

Wae. B. L. Van der Waerden, personal communication to the author, 15 XI 1985.

Published Sources

1. Gerard Alberts, *Jaren van berekening; toepassingsgerichte initiatieven in de Nederlandse wiskunde-beoefening 1945–1960*, Amsterdam: CWI, (in press).
2. Marcel Boumans, *A Case of Limited Physics Transfer: Jan Tinbergen's Resources for Reshaping Economics*, Amsterdam: Thesis Publishers (Tinbergen Institute Research Series **38**), 1992.
3. J. M. Burgers, Mathematical Examples Illustrating Relations Occurring in the Theory of Turbulent Fluid Motion, *Verhandeling KNAW Eerste Sectie* **17**, No. 2 (1939), 1–53.
4. J. M. Burgers, Application of a Model System to Illustrate Some Points of the Statistical Theory of Free Turbulence, *Proceedings KNAW* **43** (1940), 2–12.

5. J. M. Burgers, On the Application of Statistical Mechanics to the Theory of Turbulent Fluid Motion: A Hypothesis Which Can Serve as a Basis for a Statistical Treatment of Some Mathematical Model Systems, *Proceedings KNAW* **43** (1940), 936–945; 1153–1159.
6. J. M. Burgers, De betekenis van de wetenschap voor de ontwikkeling der maatschappij, *Het Kouter* (maart 1940), 91–101.
7. J. M. Burgers, Trekken van moderne westerse wetenschap, *Mededelingen Nederlandsche Akademie van Wetenschappen, Afdeeling Letterkunde, Nieuwe Reeks* **7,** No. 5 (1944).
8. J. M. Burgers, A Mathematical Model Illustrating the Theory of Turbulence, *Advances in Applied Mechanics* **1** (1948), 171–199.
9. J. M. Burgers, A Model for One-Dimensional Compressible Turbulence with Two Sets of Characteristics, *Proceedings KNAW* **B58** (1955), 1–18.
10. J. M. Burgers, *Terugblik op de hydrodynamica* (valedictory lecture), Delft: 1955.
11. J. M. Burgers, *Ervaring en conceptie,* Arnhem: Van Loghum Slaterus, 1956, translated as [12].
12. J. M. Burgers, *Experience and Conceptual Activity,* Cambridge, MA: MIT Press, 1965.
13. J. M. Burgers, *The Nonlinear Diffusion Equation,* Dordrecht: Reidel, 1974.
14. J. M. Burgers, Causality and Anticipation, *Science* **189** (July 18, 1975), 194–198.
15. P. J. L. Daams, *Vreemde woordentolk voor de arbeidersbeweging.* Amsterdam: Pegasus, 1935.
16. P. and T. Ehrenfest, Begriffliche Grundlagen der statistischen Auffassung in der Mechanik, *Encyklopädie der Mathematischen Wissenschaften mit Einschluss ihrer Anwendungen,* Hrsg. Walther Dyck *et al.*, Leipzig/Berlin: Teubner, 1898–1935, Band IV *Mechanik,* in 4 Teilbänden Hrsg. von F. Klein und C. H. Mueller. IV.32 (IV-4 Heft 6). [This paper appeared Dec. 12, 1911].
17. Friedrich Engels, *Dialektik der Natur,* 1895. Reprint ed., Frankfurt: Marx-Engels Archiv, 1937. Transl. C. Dutt, *Dialectics of Nature,* New York: International Publishers, 1910.
18. *For Dirk Struik: Scientific, Historical and Political Essays in Honor of Dirk J. Struik,* eds. R. S. Cohen, J. J. Stachel and M. W. Wartofsky, Dordrecht/Boston; Reidel (Boston Studies in the Philosophy of Science, Vol. XV), 1974.
19. J. Willard Gibbs, *Elementary Principles in Statistical Mechanics; Developed with Especial Reference to the Rational Foundation of Thermodynamics,* New York: Scribner's/London: Edward Arnold, 1902. [Yale Bicentennial Publications]
20. Ger Harmsen, *Blauwe en rode jeugd; Ontstaan, ontwikkeling en teruggang van de Nederlandse jeugdbeweging tussen 1858 en 1940,* Assen: Van Gorcum, 1961. [Reprint ed., Nijmegen: SUN, 1971]
21. Ger Harmsen, *Nederlands kommunisme; Gebundelde opstellen,* Nijmegen: SUN, 1982.
22. Heinrich Hertz, *Die Prinzipien der Mechanik in neuem Zusammenhang dargestellt,* Hrsg. von Ph. Leonard; mit einem Vorworte von H. von Helmholtz, Leipzig: J. A. Barth, 1894. Translation: Heinrich Hertz, *Principles of Mechanics Presented in a New Form,* transl. D. E. Jones and J. T. Walley, New York: Dover, 1956.
23. Boris Hessen, The Social and Economic Roots of Newton's *Principia,* in *Science at the Cross Roads; Papers Presented at the International Congress of the History of Science and Technology Held in London 1931 by the Delegates of the U.S.S.R.*, London: Kniga, 1933; reprint ed., London: Frank Cass, 1972, pp. 151–192.
24. Lancelot Hogben, *Mathematics for the Million,* London: Allen & Unwin, 1936.
25. Lancelot Hogben, Our Social Heritage, *Science and Society* **1** (1936–1937), 137–151.
26. *Honderd jaar sociaal-democratie in Nederland 1894–1994,* Eds. M. Brinkman, M. de Keizer, and M. van Rossem, Amsterdam: Bert Bakker/WBS, 1994.
27. A. A. de Jonge, *Het communisme in Nederland. Geschiedenis van een politieke partij,* The Hague, 1972.

28. Felix Klein, *Vorlesungen über die Entwicklung der Mathematik im 19. Jahrhundert,* Vol. II, Berlin: Springer, 1927.

29. Martin, J. Klein, *Paul Ehrenfest, The Making of a Theoretical Physicist,* Amsterdam: North-Holland, 1970.

30. E. H. Kossmann, *The Low Countries 1780–1940,* Oxford: Oxford Univ. Press, 1978.

31. V. I. Lenin, *Materialism and Empirio-criticism,* Moscow: Zweno, 1908; reprint ed. in *Works,* Vol. 18.

32. G. Mannoury, *Mathesis en Mystiek, een signifiese studie van kommunistics standpunt,* Amsterdam: Mij. voor goede en goedkoope lectuur, 1924; reprint ed., Utrecht: Kohn, Scheltema Holkema, 1978.

33. Robert K. Merton, *Science, Technology and Society in Seventeenth Century England, Osiris,* **IV,** No. 2 (1938); reprint ed., New York: Harper and Row, 1970.

34. Robert K. Merton, Science and the Economy of Seventeenth Century England, *Science and Society* **3** (1939), 3–27.

35. Leo Molenaar, *"We kunnen het niet langer aan de politici overlaten"; De geschicdenis van het Verbond van Wetenschappelijke Onderzoekers 1946–1980* (diss. UvA), Delft: Elmar, 1994.

36. Dale Riepe, Dirk Struik and the Sociology of Science, in [18, 581–592].

37. Arie Rip and Egbert Boeker, Scientists and Social Responsibility in the Netherlands, *Social Studies of Science* **5** (1975), 457–484.

38. David E. Rowe, Interview with Dirk Jan Struik, *The Mathematical Intelligencer* **11,** No. 1 (1989), 14–26.

39. A. J. C. Rüter, *De spoorwegstakingen van 1903. Een spiegel der arbeidersbeweging in Nederland,* 1935; reprint ed., Nijmegen: SUN-reprint, 1978.

40. M. P. C. M. van Schendelen *et al., Consociationalism, Pillarization and Conflict-Management in the Low Countries,* ed. M. P. C. M. van Schendelen, special issue of *Acta Politica* **19** (Jan. 1984).

41. J. A. Schouten, *Grundlagen der Vektor- und Affinoranalysis,* with an Introduction by Felix Klein, Leipzig: Teubner, 1914.

42. J. A. Schouten, *Over de wisselwerking tussen wiskunde en physica in de laatste 40 jaren* (Inaugural Address, Amsterdam), Groningen: Noordhoff, 1949. Also reprinted in [43].

43. *Schouten beschouwd,* eds. B. Dijkhuis and H. A. Lauwerier (collection of essays by and on J. A. Schouten), Amsterdam: Stichting Mathematisch Centrum, 1994.

44. J. A. Schouten and D. J. Struik, On n-Tuple Orthogonal Systems of $(n - 1)$-Dimensional Manifolds in a General Manifold of n Dimensions, *Proceedings Koninklijke Akademie van Wetenschappen* **22** (1919), 596–605.

45. J. A. Schouten and D. J. Struik, On Some Properties of General Manifolds Relating to Einstein's Theory of Gravitation, *American Journal of Mathematics* **43** (1921), 213–216.

46. J. A. Schouten and D. J. Struik, *Einführung in die neueren Methoden der Differentialgeometrie,* Groningen: Noordhoff, 1924.

47. J. A. Schouten and D. J. Struik, *Einführung in die neueren Methoden der Differentialgeometrie,* 2 vols. (Vol. I by J. A. Schouten, Vol. II by D. J. Struik), Groningen: Noordhoff, 1935/1938.

48. Dirk J. Struik, Outline of the History of Differential Geometry, I, II, *Isis* **19** (1933), 92–120, and **20** (1933), 161–191.

49. Dirk J. Struik, On the Foundations of the Theory of Probability, *Philosophy of Science* **1** (1934), 50–67.

50. Dirk J. Struik, Five Papers on Probability, *Journal of Mathematics and Physics* **14,** No. 1 (March 1935), 1–3.

51. Dirk J. Struik, Concerning Mathematics, *Science and Society* **1** (1936/1937), 81–101.

52. Dirk J. Struik, A Reply to Professor Hogben, *Science and Society* **1** (1936/1937), 545–550.

53. Dirk J. Struik, On the Sociology of Mathematics, *Science and Society* **6** (1942), 58–70.

54. Dirk J. Struik, *Yankee Science in the Making*, Boston: Little, Brown, 1948.

55. Dirk J. Struik, *A Concise History of Mathematics*, New York: Dover, 1948.

56. Dirk J. Struik, Mathematics, in *Philosophy for the Future: The Quest of Modern Materialism*, eds. Roy Wood Sellars, V. J. Gill, and Marvin Farber, New York: Macmillan Co., 1949, pp. 125–152.

57. Dirk J. Struik, Levensbericht van Jan Arnoldus Schouten (28 augustus 1883–20 januari 1971) *Jaarboek Nederlandsche Akademie van Wetenschappen* (1971), 94–100. Also reprinted in [43].

58. Dirk J. Struik, A Letter form Dirk Struik, in [18, XIII–XVIII].

59. Dirk J. Struik, Mijn socialistische jaren in Nederland; Herinneringen nit 1914–1924, *Jaarboek voor de geschiedenis van socialisme en arbeidersbeweging in Nederland* 1977, ed. Jac Giele *et al.*, Nijmegen: SUN, 1977, 191–246. [The English wordings of citations from this publication have, where possible, been taken from the original [Str]]

60. Dirk J. Struik, Schouten, Levi-Civita, and the Emergence of Tensor Calculus, in *The History of Modern Mathematics*, 2 Vols., eds. David E. Rowe and John McCleary, Boston: Academic Press, 1989, 2:99–105.

61a. Dirk J. Struik, Further Thoughts on Merton in Context, *Science in Context* **8,** No. 1 (1989), 277–238.

61. J. Tinbergen, *Minimumproblemen in de natuurkunde en de ekonomie* (Ph.D. Leiden), Amsterdam: H. J. Paris, 1929.

62. J. Tinbergen, Kan hier te lande, al dan niet na Overheidsingrijpen, een verbetering van de conjunctuur intreden, ook zonder verbetering van onze exportpositie?, *Prae-adviezen voor de Vereeniging voor de Staathuishoud-kunde en de Statistiek*, 's Gravenhage: Martinus Nijhoff, 1936, 62–108.

63. Jan Tinbergen, *Some Thoughts on Mature Socialism*, New Delhi: Jawaharlal Nehru Memorial Fund, 1970.

64. O. Verborg (= D. J. Struik), *Het historisch materialisme*, Amsterdam: Pegasus, 1935.

65. O. Verborg (= D. J. Struik), *De wereldbeschouwing van het communisme: Het dialektisch materialisme*, Amsterdam: Pegasus, 1935.

66. A. N. Whitehead, *Process and Reality*, Cambridge, 1929.

67. A. N. Whitehead, *Science and the Modern World*, Cambridge, 1933.