Typing Physics:
The Essential Role of Typists in Intra-Scientific Communication

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Abstract

I present a case-study of intra-scientific communication, focusing on the role of technical typists for the *Physical Review* (PR) c. 1957-1977. I argue PR became a trading zone amidst the page-charge crisis, and analyze the working networks of physicists, typists, and editors to resolve this threat to the equality of intellectual authority of qualified practitioners. Challenging the picture of typist as "automaton," I identify the skills and technical knowledge necessary to perform manuscript translation, and offer an account of the material culture of intra-scientific communication to situate the typists' epistemic role in the broader project of science. I claim this is a case of an epistemic contribution that has been instrumentalized, akin to human computers and human scanners. However, unlike these cases, the technical typists were not directly involved in the production or critique of scientific data. Rather their novel contributions occurred in the new field of mathematical typesetting that emerged from this trading zone. Thus I seek to differentiate the material culture of scientific experiments from the material culture of intra-scientific communication. I see this project as an extension of Galison's trading zone framework for the material culture of experiment, recognizing that there are many more material objects besides those of the laboratory that are created in the scientific process.

Keywords: typist, Physical Review, APS, AIP, Peter Galison, trading zone, material culture, human computers, material production, scientific knowledge, instrumentalized knowledge

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1. Introduction

Studies of the social structure of science have helped illuminate key parts of scientific epistemic practices. However, most of these studies have concentrated on the laboratory or the arenas of community receptivity. I argue that there are also interesting questions to be asked at the level of publication. In order for any scientific community to cooperatively produce scientific knowledge, there must be a method of efficiently disseminating results and ideas. Before author-prepared manuscripts were the norm, there were people involved in the translation from scientific manuscript to printed work. What epistemic role did they play? How does it differ from the material production of scientific data, performed by telescope operators, human computers and human scanners for example?

In this paper I will explore this question by studying the technical typists who worked for the journal *Physical Review* c. 1957-1977. I have a series of goals for this case study:

1. More thoroughly characterize the work performed by these typists than has hitherto been explored by clearly delineating what skills and kinds of knowledge were needed to perform manuscript transcription. Specifically, I will assess the characterization of typist as "automaton" offered by some of the source material
2. Situate the work of technical typesetting in the historical context of American Physics c. 1957-1977 and its role in the health of intra-scientific communication networks
3. Offer an analysis of the material culture of scientific publication and transcription that can make sense of the different kinds of epistemic roles played by typists

In this study, I will make extensive use of Peter Galison's trading zone analysis. In his seminal 1997 work, *Image & Logic: A Material Culture of Microphysics*, Galison offers an analysis of 20th century experimental physics, examining the production of scientific knowledge through an anthropological lens: he studies how communities of theorists, experimentalists, and engineers – each with their own distinct cultures, languages, and understandings of physics – interacted productively with each other in the process of answering a particular scientific question. The *trading zone* is the spatial and symbolic locale in which these different groups must mediate different languages, concepts, and priorities to cooperatively answer scientific questions of interest to both of them. This analysis has not yet been extended to so-called administrative areas like publication and typesetting. In part, I will spend some time delineating how the epistemic roles played by these typists are markedly different from those played by the engineers in Galison's typical examples. That being said, the trading zone remains a useful tool to describe local coordinations. I argue that this extension of the trading zone beyond its original context gives us some tools to understand the enterprise of science more broadly construed, and the roles played by actors in intermediate zones that have been integral to the progress of science and related domains of knowledge.

In Section 2, I will give more detailed background on the relevant aspects of the trading zone for the subsequent analyses. In Section 3, I will describe the historical context of physics publishing that necessitated the creation of the technical-typist. In particular, I will describe the *page-charge crisis* that emerged in response to the inability of journals like *Physical Review* to handle the growth of postwar physics research, and the effect it had on channels of intra-scientific communication. I will argue that the technical typists were single-handedly responsible for the resolution of a serious threat to the equality of intellectual authority of qualified practioners, in the language of Helen Longino [11]. Furthermore, I will argue that their work required significant knowledge of physics and math that makes characterizing them as "automata" inappropriate. Finally, I will describe the emergent trading zone that developed between typists, copy-editors, and scientists to approach the publication problem. In Section 4, I will explore how the field of mathematical typesetting grew and was shaped by the work done at *Physical Review*, and examine the typists as both sources of data and active critics in the new questions that emerged in the trading zone of Section 3. In Section 5, I will then offer an account of the material culture of intra-scientific communication. I will ultimately argue that, in these "administrative" areas of intra-scientific communication, the trading zones that emerge are intersections of scientific and non-scientific areas of expertise. As a result, the questions that emerge are of interest to the members of this zone, and not questions that will always engage in a critique of the science itself, nor will they be easy to situate beyond the zone itself. The developments and novel research produced in this zone are thus epistemically-relevant to the progress of science only by proxy, in the sense that networks of scientific communication need them to function. The new knowledge they produce does not have bearing on the content of the science – like it does for other kinds of instrumentalized knowledge – but it does require some knowledge of the science, and has bearing on the health of scientific communication networks and thus the existence of community-level objectivity.

I will be drawing from internal memos, correspondence among PR editors, hiring documents, project proposals, and committee meeting notes from *Physical Review*, *Physical Review Letters*, and the *American Institute of Physics* housed by the Niehls Bohr Archives at AIP headquarters. However, I do not believe that this analysis is exhaustive of the work performed by typists. In fact, one significant limitation of this case-study is that I do not have much primary source material from the typists themselves describing their own work. Instead I will mostly be drawing from comments made by managerial figures in the journal. As a result, likely only a fraction of the actual contributions by typists will be detailed here.

2. Galison on Trading Zones

First, we look to the notion of a *trading zone*. For Galison, Thomas Kuhn correctly identified that different subcultures often have fundamentally different languages, ontologies, and standards of significance for the objects they study. However, Galison breaks with Kuhn's incommensurability thesis[1], arguing that despite these "global differences" a "local coordination" can develop between two different subcultures when working toward a common goal. Using an anthropological lens, Galison identifies the ways in which these local coordinations proceed in "...place, exchange, and knowledge production" [10, 784] despite the, "...differences in classification, significance, and standards of demonstration..." [10, 803]. Galison primarily investigated the relations between theorists, experimentalists, and engineers. Looking to various seminal experimental efforts of modern physics, he contends even subfields cannot be treated as homogeneous communities. In fact, he argues theory change in these partially-autonomous pockets can occur asynchronously as different communities have different priorities and uses for different kinds of knowledge. Instead, we should look to the trading zones organized around

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[1] It is debatable how much Kuhn himself endorsed incommensurability, especially in his later writings. Galison's specific exploration of local coordination, however, is still interesting as a philosophical project beyond this.

collective scientific questions. [10, 782].

Trading zones are both spatial and symbolic. Firstly, a trading zone is "spatial" in that it occurs within and affects the physical locations where these local coordinations take place. In *Image and Logic*, Galison examines the layouts of physics departments and argues that many of them display a "physicalized architecture of knowledge" and model the relations between communities. The changing layouts and architectures can sometimes be used as a proxy for understanding shifting needs within the sciences.

Additionally, a trading zone is the "symbolic," sometimes ephemeral, arena in which different practitioners collaborate, necessitating the creation of "pidgin" or "creole" contact languages between them [10, 783]. These languages arise when two groups need to share intellectual and material resources foreign to each other. One way this can happen is that one group withholds its full language, either, "...to preserve cultural identity, or because its members believe that their social inferiors could not learn such a complex structure" [10, 832]. These contact languages help, "...localize symbolic systems for the purposes of coordinating them at the margins" [10, 833]. Operationalized contact languages are not, however, simple or automatic. In Galison's words,

> Superficially, the handing of charts, tubes, and circuit boards back and forth across various interexperimental cultural divides might look like a case of worlds crossing without meeting. This description, however, would do violence to the expressed experience of the participants. They are not without resources to communicate, but the communication takes place piecemeal, not in a global translation of cultures, and not through the establishment of a universal language based on sense-data. (838)

Galison is interested in the local exchange and negotiations that can occur between different subcultures. In particular, Galison locates these zones through instruments, and other material objects of the laboratory [10, 5]. Derived from work in cultural anthropology, Galison uses the term "material culture" to examine how scientific instruments and those who use them are intertwined. In particular, he writes,

> I am after the material culture of the laboratory as the 'image' of the designer. At the same time, I am after the reciprocal; the experimenters themselves - their relations and their practices - as the image of the machine at which they work. Imaging works both ways. [10, xviii]

The co-constituitive nature of this relationship is an extremely useful paradigm for analyzing experimental physics, and paired with the trading zone, allows us insight into a complex network of relationships. In the partially autonomous pockets that emerge in the production and use of these material objects, we come to understand how these material objects are "...dense with meaning, not only laden with their direct functions, but also embodying strategies of demonstration, work relationships in the laboratory, and material and symbolic connections to the outside cultures in which these machines have roots..." [10, 2]. This emphasis on the meaning baked into the material is paramount for me, but I apply it in a very different context than Galison. In particular, I will extend his framework to more "administrative" areas, where the common goal is not a particular scientific experiment, but rather the efficient publication of scientific manuscripts.

Within the material culture of scientific publication, I am interested in the production of all physical objects necessary to document and communicate scientific results. I take this concept to be distinct from the material culture of experiment. For example – though a fruitful subject for a philosophical analysis of instrumentalized knowledge – notes taken by an assistant during a scientific experiment would belong to the material culture of scientific experiment, not the material culture of publication.[2] I separate these two concepts in order to make sense of the different epistemic roles played by groups like the typists as opposed to scientific assistants. I will elaborate on this substantially in Section 5.

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[2] The implication here is not that the assistant does not have scientific knowledge. Rather I am interested in these two different stages of the scientific process, where one group is concerned with the handling of pre-processed scientific results, and the other is an active part of the processing of scientific data into scientific results. Undoubtedly there will be cases where these roles overlap, but that is not the subject of this study.

3. Birth of the Technical Typist

In this section I will review the context of the page-charge crisis and how it was viewed as threat to the community-level objectivity of scientific research. I will explain how the crisis was resolved through an emergent trading zone between typists and physicists. In doing so, I will catalog the typists' skills and assess the characterization of typist as automaton. Most importantly, I will describe the cooperative experiments conducted with Bell Labs and the epistemic roles of the typists in novel mathematical typesetting research. In this section, the reader will become familiar with the features of comparison that will be discussed in Section 4 to understand the epistemic roles of the typists in the broader context of science.

3.1. The Page-Charge Crisis

In the 1950s-60s, American physics experienced a boom of post-war research in a variety of specialized subfields [5]. The publication lull of the 1940s was following by a tripling of articles published in 1956 compared to the pre-war 1930s period. Joseph Martin attributes this boom to, "...an abundance of research funding...The population of credentialed physicists was ballooning, and they had ready access to turn their labors into papers. The *Physical Review* was unprepared for the deluge that the confluence of these factors caused." [12, 80]. This was a significant financial crisis for the journal.

The biggest financial bottleneck occurred at the level of manuscript transcription. Prior to 1959, PR contracted out all publishing operations to a few publishing companies (Lancaster Press, Weber & Stevens, Canterbury Press, and Palm & Oliver)[6]. These companies used linotype composition, and "...expensive hot metal or monotype print shops" [8]. According to the AIP Style Manual of 1959 (the institute that published *The Physical Review* among other journals), the whole process can be broken down as follows:

1. Authors submit typed manuscripts with handwritten equations to PR, who send copies to anonymous referees
2. After approval by the referees, the author's manuscript is sent to the Publication Office: "...the manuscript leaves the hands of people who understand its content, but may not know how to print it, and goes into the hands of people who may not know what the article means but can prepare it for publication." [4, 33, Style Manual]

3. The publication office adds marginalia to the manuscript so that "...the typesetter's task will be as easy as possible" [4, 33, Style Manual]
4. The manuscript is sent to the printing plant, which will employ one of the following techniques: Linotype Composition or Monotype Composition in which a typist employed by the publishing company types the marked-up manuscript into the PR format
5. The printer makes "galley-proofs," or first draft prints of these articles, which are then sent to the authors for corrections
6. The corrected galley proofs are sent back to the editorial staff, who make any authorial corrections
7. Repeat steps 4-6 until the authors are satisfied
8. The final proof is then sent to the printer to be mass-produced

This process was especially costly because it required a host of special characters not standard for these publication houses – causing delays and rising costs as research expanded and new symbols were needed to keep pace with the field [8]. Furthermore, the typists at Lancaster Press were generically trained, often not familiar with complex mathematical language, and employed physically far-away from the editorial office so questions could not easily be addressed.

PR editorial decided to put a temporary bandage on the financial problems of the journal by raising the page charge – i.e. the cost per page that a physicist's home institution was required to pay for publication of those results [5]. However, many poorer institutions were unable to afford this new rate, and continued to submit articles without paying the new charge, against PR policy. To deter this behavior, PR then implemented a policy of delaying publication of articles if institutions did not honor their back-log of page charges [6]. The solution incited uproar among physicists, both internal to the operation and external to the journal [6]. One professor of physics at Carnegie Mellon wrote to PR:

> A scholarly journal is, by definition, I believe, one in which all decisions concerning publication are based strictly on the merit of the article...A journal which treats articles differently depending on the affluence of the writer or his backers can no longer be considered an independent scholarly journal but rather some kind of advertising medium

Interestingly, this crisis inspired a conversation among physicists regarding the integrity of their publishing mechanisms. In a PRL editorial on the crisis in response to the uproar, editor Samuel Goudsmit wrote,

> We do not understand the logic of withholding page charges. Does it mean that that institutions openly admit that their work does not merit the expense of publication, except as wasteful preprints, a format entirely suited for filling in trash baskets? We, on the other hand, strongly believe that research is not complete until it is properly published...The page charge system leaves the control of the journals in the hands of the community of research scientists, where it belongs [4]

Even though informal circulation networks among scientific peers still existed, responses like these reflect just how much the community depended on journal publication, echoing Goudsmit's sentiment here, that, "...research is not complete until it is properly published." In this financial crisis, the centrality of scientific communication became a public conversation, and recognized as the final step in scientific research. In this sense, I find Helen Longino's notion of community-level objectivity an appropriate framing. For Longino, objectivity arises from scientific inquiry specifically because it is inherently a social enterprise, rather than an individual one [11, 67]. This criterion arises because, "...scientific knowledge is not produced by collecting the products of such imagined individuals into one whole. It is produced through the process of critical emendation and modification of those individual products by the rest of the scientific community"[11, 68]. To achieve that critical discourse, one of Longino's necessary criteria is the equality of intellectual authority of qualified practitioners. The page-charge crisis clearly put this criterion at risk, and practicing physicists were quick to protest it.

These threats to the equality of intellectual authority led Goudsmit to propose a dramatic change to publishing operations: *PR* would begin in-house typewriter composition and sub-divide into smaller journals based on subfield. The publication houses would still be needed for mass-production, but the first transcription of the manuscript would be performed internally by hand-selected "technical typists."

3.2. A Solution: In-House Typewriter Composition

Jumping ahead in the timeline, we know this decision was successful. An internal AIP memo in 1971 to Goudsmit calls the "experiment" of moving one journal PR-C to in-house typewriter composition a success [4]. In particular, the memo highlighted, "It was demonstrated that PR-C could be produced on time, for less money, with good quality, and with less time between acceptance and publication" [4]. Furthermore, effective June 1971, the following memo was published in PR:

> The economies resulting from the transfer of the Physical Review from monotype composition to typewriter composition have made it possible to reduce the publication charge of all sections of the Physical Review...the switch to typewriter composition has also resulted in a reduction of the time lag between date of acceptance and date of publication [4]

Why was this switch so effective? I will explore this dramatic change in operations as an emergent trading zone between technical typists, copy-editors, and physicists. Typists and copy-editors have not been studied in modern scholarship of the social dimensions of scientific knowledge. This oversight is perhaps due in part to the source material, which repeatedly characterizes the typists as "automatons." For example, the *AIP Style Manual* of 1959 describes:

> The importance of legible, precise, and carefully aligned mathematical copy cannot be overemphasized. The author should always keep in mind that those who have the responsibility of converting his manuscript to a printed version will reproduce what they *see*, not what the author *knows*. The compositor is neither a mathematician nor a physicist. He should be regarded virtually as an automaton who sets type directly from copy and who cannot be expected to apply editorial judgement [4, Style Manual]

In Section 3.4, I will argue that this characterization is both 1) inappropriate to the skills required of a technical typist, and 2) can nonetheless be made sense of in context. Characterizations like this one may strike the reader as an indicator of a case of epistemic injustice via instrumentalized knowledge: the epistemic contributions to science of a particular group have been characterized as automatic, or devoid of skill, and thus missing from the scientific story. After I explain what has gone wrong with this characterization in Section 3.4, I will assess the suitability of the instrumentalization lens.

3.3. Typing Trading Zone

In a trading zone, groups with different skill-sets need to exchange knowledge to cooperatively solve a difficult problem. In this exchange, contact languages are established to mediate the different meanings ascribed to the same object. In this section, I will explore how typists, copy-editors, editors, and physicists were able to efficiently process manuscripts while ascribing different meaning to these objects. I will catalog the technical work performed by the typists (and to a lesser extent, the copy-editors). In doing so, I will explore some of those contact languages, and assess how much typists and copy-editors needed to engage with the phyics in order to transcribe it. [3]

3.3.1. Experience with Mathematics and Physics

PR editoral was intentionally selective with the hiring of typists and proofreaders in this critical period. The following excerpt comes from H. William Koch, the executive director of AIP, to editor Sam Goudsmit regarding the publication backlog situation,

> To operate this production system we plan to hire 3-6 fulltime recent college graduates and 14-20 part-time college students. All of them will have to have some college-level background in math or science and good basic typing skills. They will be trained successively in all phases of the work: copy-editing, typing, proofreading, and paste-up. By using college students we expect to greatly decrease training time and cost, and decrease the amount of unnecessary copy-editing and time spent on correcting, and increase quality through more effective communication. Using them part-time gives us access to this potential labor pool in the first

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[3] In the source material, I find numerous other kinds of technical skills that helped to resolve the page charge crisis (some typists took on editorial roles, joining PR editor George Trigg in the "closing of the book ritual", some typists trained other typists for more mathematically dense journals, some typists were praised for their ability to communicate with physicsts, and more). Some of these other skills fall outside the scope of what I hope to argue in this paper, but I am happy to discuss further via email correspondence if my reader is interested.

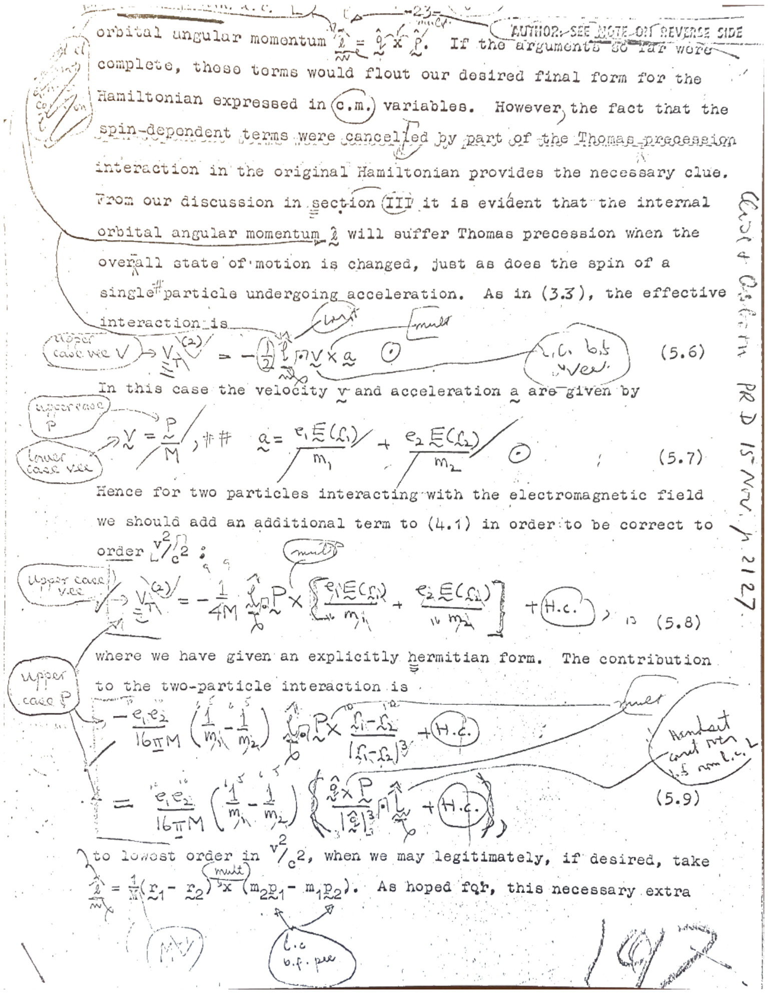
> place, but also will serve to keep productivity high by reducing the boredom factor. There will be 2 shifts. [3]

In this internal memo, Koch emphasizes the choice of college students with math and science training for the new production crew. Hiring based on familiarity with math and science marks a significant departure from the previous contracts with typists from publication houses. In this case, it is specifically those typists with knowledge of the field who are the biggest asset to PR and the managing organization, the American Insitute of Physics (AIP), in resolving their publication backlog – both to cut down on copy-editing mistakes but also to make the lines of communication with different groups more fluid.

To understand why familiarity with mathematics was an asset, I now turn to the submission instructions given to authors. These instructions from PR give us insight into how physicists had to engage in a contact language understandable to the technical typists. From a standard issue of *Physical Review* in 1969, the following instructions are given:

> Notation should be chosen so as to be clear, compact, and consistent with standard usage. The prime requisite is that the copy be as clear as possible to the typesetter who is neither a physicist nor a mathematician. To this end a certain amount of editorial copymarking is necessary. All unusual symbols should be identified the first time they are used, and at subsequent times when confusion might arise. Boldface symbols should be marked by a wiggly black underline always. Hand-written symbols should be identified as capital or lower case. Handwritten Greek symbols should be identified in the margin the first time and underscored in red later if confusion is possible. (This is particularly important for those symbols such as χ or κ; for for capital Σ and Π which can be confused with the summation or product symbols, themselves oversize special characters). German script, or sans-serif letters should be identified the first time in the margin and later underscored in green if they may be confused with other letters. Unusual symbols, even if available should not be used unless absolutely necessary [13]

Authors were given explicit instruction for how to restructure their mathematical expressions such that they could be readable by a technical typist,



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orbital angular momentum $\ell = \hat{\rho} \times \hat{p}$. If the arguments so far were complete, these terms would flout our desired final form for the Hamiltonian expressed in c.m. variables. However, the fact that the spin-dependent terms were cancelled by part of the Thomas precession interaction in the original Hamiltonian provides the necessary clue. From our discussion in section III it is evident that the internal orbital angular momentum ℓ will suffer Thomas precession when the overall state of motion is changed, just as does the spin of a single particle undergoing acceleration. As in (3.3), the effective interaction is

$$V_T^{(2)} = -\frac{1}{2}\,\ell\cdot v\times a \qquad (5.6)$$

In this case the velocity v and acceleration a are given by

$$v = \frac{P}{M}, \quad a = \frac{e_1 E(r_1)}{m_1} + \frac{e_2 E(r_2)}{m_2} \qquad (5.7)$$

Hence for two particles interacting with the electromagnetic field we should add an additional term to (4.1) in order to be correct to order v^2/c^2:

$$V_T^{(2)} = -\frac{1}{4M}\,\ell\cdot P\times\left[\frac{e_1 E(r_1)}{m_1} + \frac{e_2 E(r_2)}{m_2}\right] + \text{H.c.}, \qquad (5.8)$$

where we have given an explicitly hermitian form. The contribution to the two-particle interaction is

$$-\frac{e_1 e_2}{16\pi M}\left(\frac{1}{m_1}-\frac{1}{m_2}\right)\ell\cdot P\times\frac{r_1-r_2}{|r_1-r_2|^3} + \text{H.c.}$$

$$= \frac{e_1 e_2}{16\pi M}\left(\frac{1}{m_1}-\frac{1}{m_2}\right)\left\{\frac{\hat{\rho}\times P}{|\rho|^3}\cdot\ell + \text{H.c.}\right\}, \qquad (5.9)$$

to lowest order in v^2/c^2, when we may legitimately, if desired, take $\ell = \frac{1}{M}(r_1 - r_2)\times(m_2 p_1 - m_1 p_2)$. As hoped for, this necessary extra

Figure 1: Example marked-up manuscript [4]

"...who is neither a physicist nor a mathematician." This contact-language involved color-coding, marginal notes to the typist, a reduction of the symbolic language, and some internal codes like the "wiggly black line" meant to indicate boldface. See Figure 1 for an example of such a marked-up manuscript. Typists would translate the marginalia (e.g. a squiggly black line) in the equations into the corresponding typewriter keys, sometimes physically altering out their typewriter keys if a special character was needed. Former editor George Trigg describes the situation,

> The solution to the problem was proposed by Simon Pasternack, then Editor of the Physical Review, who noted that if one key on a typewriter is held against the plate and struck from behind by another key, it is the type bar that is struck that makes the impression...Each typist was provided with a rack in which the arms were kept. The typists became quite deft at hanging the bars in place. ([8]).

In summary, the typist would receive a manuscript with handwritten equations, type up the text, and when arriving at a mathematical expression, translate between the marked-up handwritten expressions and their rack of special characters, and finally alter the typewriter itself to make the appropriate impression. The whole process would be repeated with revisions if authors had additional edits after receiving the galley-proofs.

As this trading zone continued to develop, typists would encounter obstacles and report back to head-editorial as they were able to resolve them. For example, technical typist Barbara Weissman writes to AIP staff member Milo Dowden in 1969 with the following report [4]:

> In order to judge the improvements in AIP handling of The Physical Review issue No. 1...please note the following points
>
> 1) Figures: the size of figures prior to AIP handling was arbitrarily based on column width. We adapted the formula used on Phys. Rev. issues 2-5 and found that the sizing was too small. Therefore we increased our formula by a correction factor of 10...
> 3) The breaking of equations at mathematically correct breaking points is significantly more consistent...
> 6) Paste-up procedures have steadily improved. Areas to note specifically:
>   a) Equation numbers are aligned.
>   b) Spacing is more equalized between equations
>   c) There are fewer razor cut letters
>   d) Type lines are straighter.
>   e) Margins are better aligned...

From this rare document written by a typist, we get a glimpse into what kinds of information she would have had access to and the kinds of obstacles typists were dynamically solving. In particular, Weismann reports on how equation typesetting is improving (i.e. the effective and accurate communication of scientific ideas) due to changes in typesetting (i.e. where to place equation line breaks) informed by her technical expertise of where the "mathematically correct" line breaks should occur. Furthermore, she discusses corrections factors being made to internal figure placement formulas, as well as spacing and margin details. All of these factors are extremely relevant to both parties in the trading zone, but the mechanics would have been unknown to the physicists acting as journal editors like Koch and Mentzner. Weismann's ability to accurately assess and report the editorial handling of mathematics is contingent on her knowledge of mathematics and typesetting, and indispensable to the physicists she interfaces with.

So far, these skills have straddled the boundary between content and formatting. However, there are a few documented cases of mathematical mistakes purely in the content of scientific articles that were caught by copy-editors. In the AIP Publication Division Records, there are numerous letters from authors to the AIP publishing office praising the skills of the copy-editors in catching mistakes and ambiguities in manuscript equations [4]. For example, one letter from R.P Hurst in 1971 writes:

> This is just a note to convey our thanks to whoever [sic.] prepared the enclosed manuscript for the printer. He did a truly outstanding job. To be specific, I could mention the errors he found in Eqs. 36 and 38, and the ambiguity he found in Eq. 9...The job done on this paper was much more expert than usual [4]

Unlike typists, copy-editors were hired from graduate physics programs and were primarily male, compared to the primarily female technical typists [4]. Copy-editors were significantly involved with the content of the manuscripts, even after input from referees and editors. In particular, their job was to look for possible content-error issues and add additional marginalia to the manuscripts to make the job of the technical typists easier. A visualization of the workflow is represented in Figure 2. Although vital to material production, I have not focused this analysis on the copy-editors, particularly because this population remained largely the same throughout the page-charge crisis.

That being said, the differences in responsibilities between typists and copy-editors was often a distinction without a difference. As Ken Mentzer writes in an AIP memo to the PR editors, “In the case of PRL the proofreading is mostly done by the typists; in the case of APL by the copy-editors” ([4]). Disambiguating the duties of a copy-editor vs. a typist may go beyond the scope of the archival material I have access to. Due to this overlap of roles, it would not be inconceivable that typists were also able to catch mathematical errors like the Hurst example, though I will defer a definitive claim on this front.

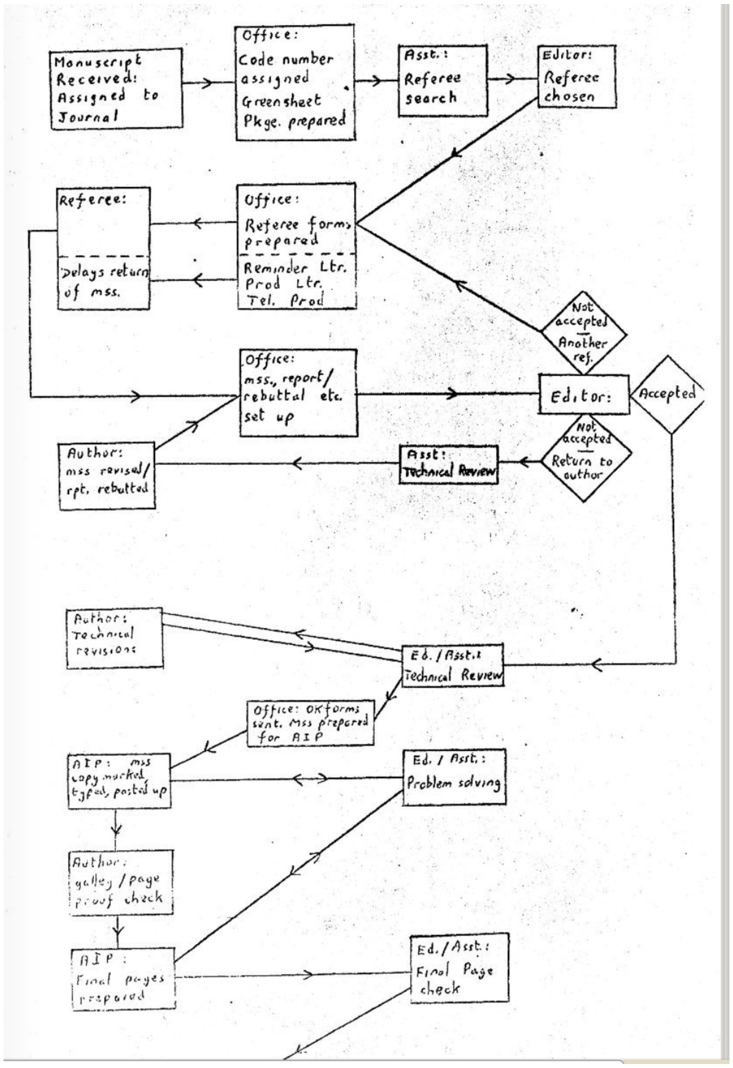


Figure 2: AIP editing network. After the submitted manuscripts undergo significant technical review from referrees and editors, in the AIP, the stage of copy-marking, typing, and paste-up involves a double-headed arrow with the ambiguous label "Ed./Asst: problem solving." This figure is a good representation of the ambiguous job responsibilities held by typists and copy-markers, as well as specialized knowledge needed to interface with the editorial team to solve technical issues as they arose

Due to their multitude of roles, the typists could not simply haven been transcribing mathematical equations with no sense of their meaning. If my reader is not yet convinced, I will now describe the case of computer-assisted typesetting, this claim is even clearer.

3.3.2. Computer-Assisted Typesetting

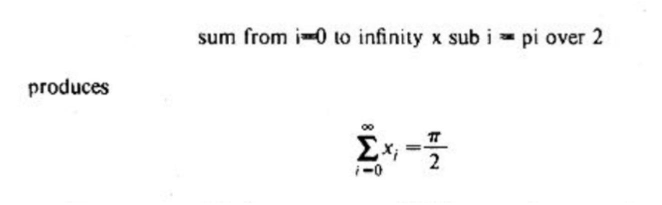
In 1970, Goudsmit and Trigg began preparing PR for yet another major transition: computer-assisted in-house typewriter composition. In this section, I will describe how this changed the typesetting job. I will conclude by returning to assess to characterization of typist as automaton.

In a three-phase proposal to introduce computers to PR and PRL, editor of PR-D, Peter Adams, proposed to introduce a computer-based referee submission database and transition from typewriter composition to UNIX computer-assisted typewriting. Typists were now trained for photocomposition, where they translated manuscripts and mathematics into a UNIX-based coding language (similar to LATEX). This new language represents yet another contact language developed in a trading zone. The reader should note that mathematical typesetting, and specifically computerized mathematical typesetting, was a completely uncharted endeavor. I will return to this significance of that observation in Section 4.

Produced by Bell Laboratories, this language was an attempt to digitize the special-character IBM typewriters. As such, it is one of the most explicit documents I have on how a local coordination between typists, physicists, and now typesetting programmers, was negotiated. In the documentation for the UNIX language, B. W. Kernughan and L. L. Cherry write,

> The language has been designed to be easy to learn and to use by people (for example, secretaries and mathematical typists) who know neither mathematics nor typesetting [7]

The characterization of typists as people who "know neither mathematics nor typesetting" reflects the tension of recognizing the typists as both skilled and unskilled workers. As a contact language, we can analyze this as an instance of one community withholding its full language, “...because its members believe that their social inferiors could not learn such a complex structure” [10, 832]. We can make sense of that tension in this document by noting that Bell Labs is attempting to sell PR its programming language. Therefore it makes sense that they describe it as usable by someone with no knowledge of the subject matter. That being said, a cursory look through some of the details of the documentation reveal a slightly different story. See Figure 5 for an example piece of UNIX input.



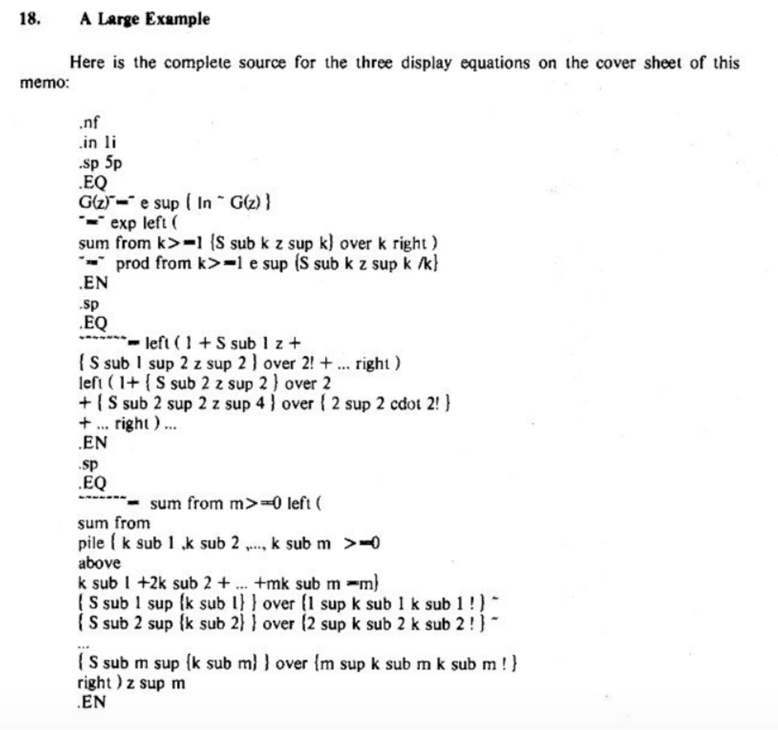
```
sum from i=0 to infinity x sub i = pi over 2
```

produces

$$\sum_{i=0}^{\infty} x_i = \frac{\pi}{2}$$

Figure 3: example UNIX input

The phototypesetting system is a far cry from the inscription-based procedures of typewriter composition. Instead of matching-up a handwritten symbol with a special character key on a typewriter, typists now inputs a text-based command describing *what the symbol means.* In Figure 8, for the simple example of typesetting a summation, the typist would need to have some sense of the bounds of a sum to be able to translate it into the typesetting language.



18. A Large Example

Here is the complete source for the three display equations on the cover sheet of this memo:

```
.nf
.in 1i
.sp 5p
.EQ
G(z)~=~ e sup { ln ~ G(z) }
~=~ exp left (
sum from k>=1 {S sub k z sup k} over k right )
~=~  prod from k>=1 e sup {S sub k z sup k /k}
.EN
.sp
.EQ
~~~~~~~= left ( 1 + S sub 1 z +
{ S sub 1 sup 2 z sup 2 } over 2! + ... right )
left ( 1+ { S sub 2 z sup 2 } over 2
+ { S sub 2 sup 2 z sup 4 } over { 2 sup 2 cdot 2! }
+ ... right ) ...
.EN
.sp
.EQ
~~~~~~~=  sum from m>=0 left (
sum from
pile { k sub 1 ,k sub 2 ,..., k sub m  >=0
above
k sub 1 +2k sub 2 + ... +mk sub m =m}
{ S sub 1 sup {k sub 1} } over {1 sup k sub 1 k sub 1 ! } ~
{ S sub 2 sup {k sub 2} } over {2 sup k sub 2 k sub 2 ! } ~
...
{ S sub m sup {k sub m} } over {m sup k sub m k sub m ! }
right ) z sup m
.EN
```

Figure 4: example UNIX input for long-form equations

The UNIX system also allowed the user to define functions. As described by Kernughan and Cherry, "This lets the user go far toward tailoring the language to his own specifications" [7]. This move from translation to generative ability makes room for typists to manipulate these environments in the case of repeated expressions – a useful, complex feature that likely contributed toward the widespread adoption of the language. Bell Labs themselves tested out the language on a user group of secretaries and mathematical typists who reacted to the system with remarks like, "...'it looks easy, much easier that what we have to do now.' The one math typist who now uses it on a regular basis is an enthusiastic convert" [7]. I will return to the importance of typist feedback in Section 4 in detail.

One might worry that this change was so drastic that the technical typists from the pre-computer era would not have been qualified. In fact, in the 1974 proposed budget, despite the relatively dramatic change in operations, no new typing staff were hired [7]. This was actually an intentional choice by Adams, who noted in the initial 1971 proposal, "Unless circumstances require a crash program, we shall attempt to prepare our editoral management programs with our present staff, rather than hire and train new personnel" (50 [7]). The continuity of staff reflects: 1) that the typists had some sense of the meaning of the mathematical expressions even before the UNIX era, and 2) that editorial was aware of the specialized knowledge they had been acquiring throughout the previous decade. One characteristic of trading zones is that sometimes the work done within them can be difficult to describe outside the zone. In this case, novel strategies in mathematical typesetting had been developing among typists for many years, hiring new personnel (however technically advanced) was just not needed.

In sections 3.3.1-3.3.2, I have outlined what evidence we have for how typists engaged with the technical material they were transcribing.

3.4. Against Typist as Automaton

Having argued against the idea that typists were "merely" transcribing what they saw, I will now explain why the source material repeatedly characterizes them as skill-less or robotic.

Most of the documentation that endorses typists as *skilled* workers comes from managing editors within the publication operation who worked closely with the typists: Trigg, Goudsmit, Pasternack, and Adams. By contrast, most of the characterizations of typists as *unskilled* automatons come from style manuals and instructional manuals, removed from the typists themselves and often making assumptions about their authority and knowledge. The UNIX manual was selling a software package to AIP and wanted to portray itself as usable by *anyone*. The AIP style manual was encouraging authors to err on the side of clarity in their manuscript submissions, as the AIP editors knew that illegible and imprecise notation could drastically slow down the publication process. Thus it makes sense that their description of the typist would be flat – they are not describing publication operations in their full complexity for posterity, they are speaking to members outside the trading zone, and each have motives to make the typists seem like mere machines.

Outside of the trading zone, the work of the typists and proof-readers is hard to situate. Their knowledge emerges in this particular instance of local coordination, one that is ephemeral but significant to a specific time period where this work is indispensable. Just like in a typical scientific trading zone, Galison notes how the discourses worked out in these places can develop lives of their own, and become quite distinct from the two subcultures from which they emerged [10]. Those who were also involved in those local coordinations (like Trigg and Goudsmit) are versed in the contact languages and understand the role the typists are playing. In their dual roles, they see the production first-hand, as well as the consequences of inefficient production on intra-scientific communication networks. As a result, the recognition of the significance of that work only makes sense to someone has been initiated into the trading zone. The UNIX and AIP Style Manual writers were not among the initiates.

In sections 3.3.1-3.3.2, I showed that the typists were:

- hired from math and physics backgrounds,
- fluent in a contact language with physicists to encode preferred typesetting for manuscript equations
- actively problem-solving questions about mathematical typesetting as it pertained to mathematically-correct break points and formatting,
- engaged in the responsibilities of copy-editing (at least at PR-C), which may have involved correcting mathematical consistency errors in submitted manuscripts
- fluent in a configurable, code-based text-editing language where they had to describe the meaning of the mathematical symbols they were typesetting

At this point, it becomes untenable to maintain that the typists did not have any understanding of what they were typing. I am not claiming that typists understood the scientific ideas behind the submitted manuscripts. Rather, I want to emphasize the interpretive, translational work they did in transcribing these manuscripts, and identify what kinds of technical knowledge were necessary to do so effectively. Taken together, I argue that the characterization of typist as “automaton” is highly inappropriate to the multitude of technical roles they had.

4. Technical Typist as Experiment and Experimenter

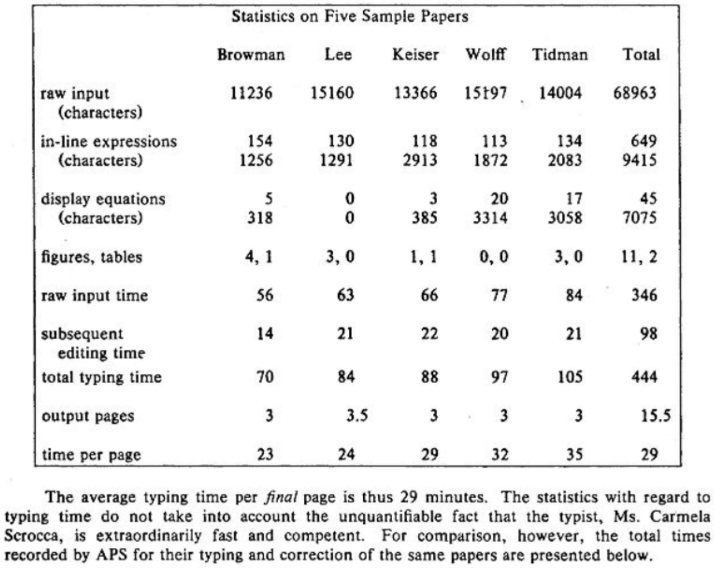
Having outlined the argument against typist as automaton, I will now discuss how typists took on active roles in knowledge production as this trading zone expanded to Bell Labs and tackled unresolved issues in mathematical typesetting writ large.

As previously mentioned, one of the major parties interested in developments in mathematical typesetting was Bell Laboratories. In particular, Samuel Morgan, the Director of the Computing Science Research Center at Bell Labs reached out to the associate director of the AIP in August 1975 to follow-up on an earlier conversation between AIP, APS, and BL personnel regarding collective interest in, "...the use of computerized typesetting for mathematical journals" [7]. Morgan's group had been developing UNIX, and was interested in how a UNIX text-editor would fare in a mathematical context, as no other mathematical typesetting software existed at the time. In this uncharted territory for both groups, Morgan proposed to conduct a...

> ...cooperative experiment in which a full-time typist would undertake to photocompose Physical Review articles from Bell Laboratories under our system. We think we could learn a good deal from such an experiment that would be of use in our further research on computerized document preparation, and the experiment should also give you a good idea whether a system like ours could save money in a large mathematical publishing operation such as yours. ([7] 137)

This cooperative experiment offered both parties something relevant to their work: for Bell Labs, they could conduct rigorous tests of UNIX mathematical type-setting, and for PR, they would get a free test-run of an alternative form of typesetting that could possibly save them money as submission rates continued to rise. The language of an "experiment" is extremely apt to the trading zone analysis: extending the zone to include Bell Labs and those interested in mathematical typesetting, new research questions emerged that could be tested, and in fact required collaboration of scientific and non-scientific expertise.

This experiment was successfully conducted and a research report written up to describe the findings by Bell Lab's employee M. E. Leske [7]. PR sent Bell Lab's three copy-edited manuscripts, one of which was from PR-D and contained significantly complicated mathematics. A Bell Labs typist, Carmela Serocca, trained on the typesetting language, was timed to estimate speed and efficiency of the system. Typists, who up until this point had been active, skilled processors of scientific knowledge, were now examined as objects of inquiry, or sources of data meant to inform research in computing. The report acknowledges, "We must thank Ms. Serocca, whose typing is the basis of this research" [7]. In Figure 5, the data from said report is detailed. The report repeatedly acknowledges Serocca's typing skills as a source of possible systematic over-estimation of typing rates.



Statistics on Five Sample Papers

	Browman	Lee	Keiser	Wolff	Tidman	Total
raw input (characters)	11236	15160	13366	15197	14004	68963
in-line expressions	154	130	118	113	134	649
(characters)	1256	1291	2913	1872	2083	9415
display equations	5	0	3	20	17	45
(characters)	318	0	385	3314	3058	7075
figures, tables	4, 1	3, 0	1, 1	0, 0	3, 0	11, 2
raw input time	56	63	66	77	84	346
subsequent editing time	14	21	22	20	21	98
total typing time	70	84	88	97	105	444
output pages	3	3.5	3	3	3	15.5
time per page	23	24	29	32	35	29

The average typing time per *final* page is thus 29 minutes. The statistics with regard to typing time do not take into account the unquantifiable fact that the typist, Ms. Carmela Scrocca, is extraordinarily fast and competent. For comparison, however, the total times recorded by APS for their typing and correction of the same papers are presented below.

Figure 5: Bell Labs Serocca Data

The UNIX language used by Serocca was actually composed with input from Bell Lab's typists. As the reader may remember, the corresponding user manual by Kernughan and Cherry for this language describes how Bell Labs developed the language with feedback from a user group of secretaries and mathematical typists who reacted to the system with remarks like,

> It botches the following things, why don't you fix them?...You really need the following features...'it looks easy, much easier that what we have to do now.' [7]
>
> By popular demand, matrices have arrived (at great expense to management, I might add) [7].

Typists were using this language, and requesting new functionalities (i.e. matrices). Some of the conventions from these developments would even be recognizable to readers of this article familiar with LATEX, in particular the use of “$$” to indicate inline mathematical expressions. As both the users and critics of the UNIX-based typesetting language, the Bell Labs technical typists became active epistemic members of a trading zone interested in solving the problem of mathematical typesetting. The request and implementation of matrix typesetting is a prime example of such an intersection. This feedback loop was enabled by the knowledge of both typesetting and mathematics that made the technical typists particularly good at their jobs. Additionally, in the Leske report, we get insight into how typist and machine were working together to typeset a manuscript, and where the limits of the real automaton actually were. For example, Leske recounts,

> The sequence of operations performed by the typist for a paper are essentially this
>
> (a) original input of the paper (including a limited amout of “on-the-fly” correction of errors)
>
> (b) rudimentary check of spelling, legality of equations and formatting commands (done by machine)
>
> (c) fix any errors found
>
> (d) print a draft version on the typesetter
>
> (e) proofread draft
>
> (f) cycle through (c), (d), and (e) until the paper is in a satisfactory state

There are many instances in which “handwork” by the typist becomes necessary - i.e. in steps (a), (c), and (e) for example - that make the intermediate knowledge of the typist an integral part of typesetting even when computerized.

The UNIX system was not immediately adopted by PR. Instead, the head editorial decided to conduct additional internal tests with PR typists to cross-examine the Bell Labs results. In an internal review from 1975 reporting on the progress of Phase III proposed by Adams, an anonymous report describes,

> The project has been underway for about eight months, during which time all personnel have had to learn all about UNIX and photocomposition essentially from scratch. Nevertheless, very few papers selected for production by photocomposition were not successfully completed on schedule – a strong indication of the underlying strength of the publication method...the manuscript input language is well designed and easy to learn. A good technical typist can become proficient in this form of input after 40 hours of training [7, 116]

This report would have been shared with Bell Labs and helped inform the development of UNIX.

In this section, I have examined how the expertise of technical typists in the trading zone at *Physical Review* became relevant to new emergent questions distinct from the original purpose of the zone. In particular, the problems of mathematical typesetting generated new questions that required new experiments to address. In these experiments, typists and their specialized intersectional knowledge, were both sources of data, and active critics in the development of new computerized techniques to address those problems. In fact, in response to a 1976 proposal for new editorial computers, the PR/PRL Funding Committee noted:

> We are aware that PR/PRL has pioneered in and acquired a body of experience in the use of the computer in editorial operations extending back over a number of years [7]

Given the novel research developments of the typists and Bell Labs, it is no wonder that AIP memos recognize PR as a “pioneer” in the field of computerized typesetting.

In this section, I described how the typists took on active epistemic roles in experiments of mathematical typesetting conducted with Bell Labs, both as objects of experiment and experimenters themselves. I will now discuss how to understand the epistemic roles of the typists as compared with other cases of instrumentalized knowledge production.

5. An Account of the Material Culture of Scientific Publishing

When assessing this case-study for larger philosophical import, I will consider how it differs from similar parallels one might be tempted to draw. As discussed in the introduction, there are a multitude of case studies now being explored regarding the ways in which scientific workers, particularly women, have been "instrumentalized" by scientific discourse. This language in particular comes from Ana-Maria Creţu's "Human Computers as Instruments." In this preprint, Creţu analyzes the Harvard Human Computers at Harvard College Observatory and the Bristol Scanners at the Bristol Nuclear Research Group [9]. By "instrumentalization," Creţu means that these scientific workers were treated as instruments. In doing so, we distort the historical picture and discredit certain methods and types of knowledge, all of which can stunt scientific progress [9]. Similarly, Eun-Joo Ahn has explored the Mt. Wilson observatory telescope assistants who were actively involved in stellar astrophysics research by making and analyzing photographic plate renderings of the Sun – women whose names are rarely cited and whose work was deemed automatic [2]. Finally, Galison himself discusses the human scanners employed by Cecil Powell's Bristol Laboratory who were tasked with identifying particle tracks on emulsion films corresponding to particle decay events – Galison explores the quasi-scientific authorship granted to these scanners and how denying scanners knowledge was an important methodological practice to protect against confirmation bias [10, 33,200].

These historical episodes bear a few marked similarities to the typists:

1. They performed skilled work that required some knowledge of math and/or physics
2. Their work was considered automatic or devoid of critical thinking skills that later scholarship has then questioned
3. Their work was necessary to the progress of science but often repetitive and tedious

However, there are also some important dissimilarities:

1. The typists at PR were not involved in the creation of scientific data for physics
2. The typists at PR were not engaged in critique of the science itself that shaped the content of the conclusions reached by the physics papers

3. The scanners and telescope operators were not engaged in work that resolved a crisis of scientific communication

Despite these dissimilarities, the case of the typists is also not so distant from the content of physics that it could be called custodial or purely administrative, as compared to say the postal workers who delivered the copies of PR to academic institutions or the secretaries who worked for physics departments to organize conference logistics. These alternative forms of labor are clearly necessary for the functioning of physics, but do not require a familiarity with math or basic physics, nor an exchange of expertise with physicists to produce new knowledge.[4].

As a result, we need a different framework to describe the *material culture of scientific publication* that can account for the labor of the typists on this spectrum of instrumentalized knowledge. I offer the following framework.

5.1. The Material Culture of Intra-Scientific Communication

Galison is primarily interested in the material culture of the laboratory – the objects that reflect and shape epistemic practices are scientific instruments, technical manuals, laboratory floorplans, and more. All of these objects are related to the production of data in experiment. Thus, the trading zones that emerge around these objects form between different groups involved in experiment (physicists, engineers, etc.). In this analysis, I have been concerned with the material culture of *intra-scientific communication*, specifically publishing. In this sense, I have extended Galison's framework beyond its initial scope in order to more appropriately characterize how the typists were engaging with technical knowledge. This distinction between a material culture of *experiment* and one of *publication* allows us to identify what epistemic roles the typists had – given that the scientific results they were transcribing had already been processed into a semi-final form. In particular, epistemic agents in the material culture of scientific publishing will not engage in a critique of the science itself. They will, however, need some knowledge of the content in order to handle it directly.

---

[4] I do not mean to establish a hierarchy here, rather my point is that these other groups are not engaging with the physics in a way that creates a trading zone between the fields. The typists are one example of a zone between scientific and non-scientific traditions

A characteristic feature of this framework is that there will be emergent trading zones between areas of *scientific* and *non-scientific* expertise that can produce new research questions specific to that zone. In this sense, I use the trading zone terminology intentionally, specifically to indicate the capacity for new research questions. Treating this area as a trading zone allowed us to be sensitive to the centrality of typists to the new mathematical typesetting languages developed at Bell Labs. Although the technical typists were not active critics of the content of the physics manuscripts they transcribed, their specialized knowledge in this boundary was sufficiently novel and deep to enable them to be both sources of data and active critics in the "experiments" in UNIX that ensued. These experiments sought to address technical obstacles that emerged in the material realm of publication - namely, mathematical typesetting - and progressed asynchronously from parent fields; this intersection of scientific and non-scientific knowledge created new questions interesting to those involved in the trading zone, and answerable only by those literate in its contact languages. In the case of the technical typists, those new questions of UNIX were necessary to the smooth functioning of the field of physics as a whole, but only by proxy.

Furthermore, agents involved in material production are able to generate new questions in the trading zone specifically because of the successful local coordination they engaged in, and the technical skills they developped as a result. For example, the typists in this case were only interesting to the Bell Labs UNIX Research team because they had knowledge of mathematics, physics, and typesetting. Without that intersection of knowledge, their feedback would have been irrelevant to Bell Labs. Technical knowledge from material production requires a partial initiation into the parent fields from which this zone emerges. It is usually this knowledge and the epistemic norms that arise from it that can be instrumentalized by scientific discourse.

We should not treat the typists as epistemic agents with regards to the scientific results they were processing. By contrast, those who were involved in the production of scientific data (i.e. human computers, scanners, telescope operators) should be treated as scientific epistemic agents, able to generate new research questions within their scientific parent field. My point in differentiating the two is that we do not need to require agents to produce scientific data in order to recognize their role in the scientific project, the technical knowledge they needed to engage with the science, and their capacity to produce new research questions in a scientific–non-scientific emergent trading zone. My intention with this study is not to create a hierarchy of contributions to physics, but rather to locate the role of transcription and translation of scientific manuscripts in the scientific process writ large.

6. Conclusion

I have offered an analysis of the epistemic contributions of technical typists for *Physical Review* and their role in maintaining intra-scientific communication networks. In particular, I have argued that what had been considered "administrative" or automatic work can be reanalyzed as an instance of complex technical knowledge emerging in a trading zone between typographical knowledge and knowledge of physics. In this trading zone, I analyzed the contact languages developed between typists, physicists, editors, and copy-editors to collaboratively communicate in the production of scientific articles. As initiates in this trading zone, I argued that the typists became indispensable to the publishing operation. More specifically, I identified a particular crisis in the equality of intellectual authority of postwar American physics, and argued that the skills developed by technical typists were primarily responsible for its resolution.

In addition to arguing against the characterization of typists as automata, I have offered a positive account of their epistemic roles in the material culture of intra-scientific communication. I analyzed the new research questions that emerged in the field of mathematical typesetting and how the typists were both sources of data and active critics in that new field. In doing so, I have argued that the typists had a significant epistemic role in the emergent mathematical typesetting trading zone, but not an epistemic role in critiquing the physics itself. I have differentiated these contributions from those of the human computers, scanners, and telescope assistants whose knowledge has also been instrumentalized, but were engaged in a critique of scientific ideas.

Material production abounds in the history of science and physics. Peter Galison's trading zone analysis got us closer to understanding how the production of instruments and data are cooperatively constructed by different groups, and how these objects reflect and shape epistemic practices of practitioners. I see this project as an extension of that analysis in the sense that there are many more material objects besides objects of the laboratory that are created in the scientific process. Tracking who made them, what skills they needed to make them, and how this work interfaced with the science will help us be sensitive to the different research questions that can be generated in large scientific pursuits. In categorizing the different kinds of instrumentalized knowledge we find, it is necessary to track the epistemic roles of those agents – not to create a hierarchy between contributions, but rather to more accurately understand their contributions to scientific and non-scientific developments.

Finally, I believe this framework is compatible with Galison's original proposal: it merely broadens the notion of the trading zone to arenas of non-scientific expertise, and asks what developments could occur in these zones of interest to both parent fields. Depending on where one draws the boundaries between questions of science and questions relevant to the progress of science, the material culture of intra-scientific communication can either be considered auxiliary or central. That choice I will leave to my reader and my reader's purposes.

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