A View on Mathematical Discourse in Research and Development

Vasco Alexander Schmidt

1 Introduction

Awareness is rising that mathematics plays a crucial role for innovation in many industries, including logistics, finance, electronics, and the chemical and pharmaceutical industry. The growing demand of mathematical expertise in industry has led to a series of initiatives from mathematical communities in many countries. Aiming at a more systematic cooperation, new university programs for applied mathematics have been defined and research centers for industrial mathematics, special interest groups, and faculty positions focusing on industrial mathematics have been founded within the last decade.

These initiatives have had a positive effect, in some cases boosting the knowledge transfer into R&D departments. Nevertheless, a systematic exploitation of mathematical knowledge in industrial settings does not happen yet, at least not on a large scale. Reasons for this gap are seen in a different terminology and language use in mathematics and the application domain, deficits in the education of engineers, as well as in practical and organizational conditions (Grötschel et al. 2009:16). In addition, there are educational issues within mathematics that go beyond the sheer knowledge of mathematical theories and application domains. Many graduates pursuing a career in industry feel that they are not able to apply their mathematical knowledge in the industrial setting except their general ability of logical thinking. One reason might be the discourse that takes place in R&D units. There, mathematicians must carry through their ideas in a setting of conflicting views and different levels of mathematical knowledge, with constraints in time and budget and hierarchies to take into account.

This chapter argues that analyzing this discourse in industrial mathematics is key to understand how mathematics innovates, where obstacles occur, and how

V. A. Schmidt (✉)
Products and Innovation, SAP AG, Dietmar-Hopp-Allee 16,
69190 Walldorf, Baden, Germany
e-mail: vasco.alexander.schmidt@sap.com

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innovation can be organized more systematically in the future. Analyzing the use of language—whether in oral or written form—may show how mathematicians use their mathematical knowledge in practice. It can even help to reveal a specific mathematical way of thinking. A new form of participatory research will be introduced. It is based on the role of a "useful linguist" who takes an active role in research and development teams as he helps with the creation and review of documents such as technical documentation and PR articles. In addition to interviews and observations, he uses the work on documents to make visible and document the discourse that is taking place in the research and development teams.

This Linguistic research may reveal best practices and help to manage a fruitful application of mathematics, including consulting and training offerings for mathematicians who work in R&D departments or study mathematics.

2 Role of Language

Focusing on language has been a promising approach for analyzing the nature of mathematics. Mathematics is a science that examines abstract objects and methods. It therefore relies on language when it comes to defining and communicating the objects under investigation and proving mathematical findings. This is why the reflection on mathematics must always take into account the language of mathematics and the language use of mathematicians.

There is a significant difference between both terms. The first one stands for an internal view on mathematics, whereas the second term allows for an external view on mathematics. Mathematics is often seen as an exclusive domain that is only accessible for those who can understand the formalisms that are used by mathematicians. This view is mirrored in numerous popular math books written by mathematicians. Best example is the classic book "What is mathematics?" (Courant and Robbins 1941). When reading the book title one could get the impression that the book is an essay about mathematics. But it is not. It is rather a textbook that invites readers to learn mathematics by doing it. The message is that learning the language of mathematics is a prerequisite for talking about mathematics.

This view has been challenged. Another classic mathematics book, "Experience Mathematics" (Davis and Hersh 1981), paved the way to external accounts on mathematics. It catches the essence of mathematics in an every day language without explaining mathematics in the traditional sense. It focuses on explaining how the mathematicians' practice looks like. This approach is the basis of the following argumentation that argues for a meta-research on mathematics using linguistic and ethnographic methods for analyzing discourse at the work place of mathematicians in industrial research and development. The idea is not to focus on the mathematical core of innovations, but to investigate how these innovations evolved. It takes a closer look on the conversations that precede and follow mathematical innovations. This view on industrial mathematics can be based on philosophical and sociological groundwork.

2.1 Philosophy of Mathematics

The early investigations on mathematics were conducted by mathematicians themselves. They portrayed the ideal use of mathematical language with emphasize on mathematical formalism. This was mirrored in the opinion that mathematics is a "hard science" that is error prone and produces findings of eternal truth. The body of mathematical knowledge is seen as cumulative, consensual, and historical invariant. This view was challenged in the second half of the twentieth century by philosophers that followed the ideas of social constructivism (and others). They stated that even mathematics is socially construed and therefore not free from human influence, for example, power, taste, and will. This thesis made possible a sociological and linguistic investigation of the practices of mathematicians (for example Ernest 1998, Heintz 2000). This research could not transform mathematics into a "soft science," not even from a theoretical point of view. But it opened the view to the basic characteristics of mathematics and how they are influenced by people and historic circumstances.

The essay "Proofs and Refutations" (Lakatos 1976) can be seen as a milestone. Lakatos constructed a fictive dialog of students with a teacher who moderates the conversation. The group talks about the Euler formula $E - K + F = 2$. They exchange ideas, claims, proofs of their statements, and counterexamples. The dialog is fictive, but it is not created from scratch. All contributions from the students are in fact historical statements from mathematicians who worked on the Euler formula. The statements are composed in the form of a conversation. The dialog shows that the invention of a mathematical proposition is not a linear process. It involves detours, errors, and controversies. The mathematical form and content of the proposition were developed under heavy influence of opinions, feelings, and taste of the involved persons. The main arguments are written in the natural language, not in the language of mathematics.

Analyzing mathematical discourse in industrial contexts, as proposed in this chapter, uses the idea of analyzing a mathematical discourse, but without creating it from historical sources. Similar conversations occur when mathematicians work in interdisciplinary teams with a common goal but team members who have different views on how to reach this goal. Analyzing discourse in industrial mathematics takes Lakatos' approach one step further since it is focused on the discussion in our time and analyzes the language use not within a discipline (as did Heintz 2000), but investigates the interface between mathematics and other disciplines. In doing so, assumptions become visible that underlie the common understanding of the application of mathematics.

2.2 Mathematics as Lingua Franca

One claim is that mathematical formulas are the lingua franca of science and technology—an opinion that is closely linked to the famous quote from Galileo saying that mathematics is the language of the book of nature. Two more sayings gained fame within the mathematical community. Eugene Wigner saw an “unreasonable effectiveness” of mathematics in science and technology (Wigner 1960), and the David Report concluded that high technology is always mathematical technology (David 1984).

Observing the daily work of interdisciplinary R&D teams lead to the impression that mathematics is indeed useful in industrial settings and can serve as lingua franca. But this is not the complete picture. When mathematicians talk at their work place, mathematical formulas are always embedded in natural language. Mathematicians use a mixture of formulas and words, which makes the natural language as crucial for industrial mathematics as formulas are. They use metaphors, examples, and stories to explain mathematical ideas to colleagues and to convince them that these ideas are the right ones. Natural language serves also as a means for searching the right abstraction of phenomena within the application domain. The goal of this mathematical discourse might be a mathematical formalism, but formulas are only reached through a discussion with extensive use of natural language.

2.3 Transfer of Mathematical Knowledge

The transfer of mathematical knowledge is often seen as a mechanical process, which covers the packaging of mathematical ideas and methods and their working into a technical product. This might include stimulation of mathematical research through the interdisciplinary work with engineers. Nevertheless, knowledge transfer is mainly seen in the opposite direction using preexisting mathematical knowledge in an application domain. A first view on mathematical discourse in an industrial setting shows that knowledge is not transferred in this sense. It rather changes while being applied, since it must be verbally constructed anew in discussions with engineers and managers of the application domain. Even more: Mathematicians must see to get their perspective and ideas applied. Engineers and managers are supplied with different knowledge and different views on the technical product in development. Technical products can be construed with less (or no) mathematics although more mathematics promises to make them better. To carry through the mathematical ideas is a central challenge for mathematicians working in R&D units. This challenge is taken up verbally in the interdisciplinary dialog. As fieldwork shows, this dialog includes rhetoric strategies for hiding mathematical content, showing its usefulness and proving its cost-efficiency. These characteristics of the mathematical discourse in R&D shed a light on the actual behavior of mathematicians, how they integrate themselves in interdisciplinary teams and which rules and strategies they use for positioning mathematics.

3 Methodology

Analyzing mathematical discourse requests methods that are stringent and provide general insights. They must go beyond examples that mathematicians tell from their individual experience and point of view. This is why we propose a participatory observation, including the work with documents that are created within development projects such as technical documentation and marketing collaterals. A linguist takes part in the project work as a "useful linguist"; aside from observations he prepares for example documentation and other writings and manages review cycles that allow mathematicians, engineers, and managers to articulate their views in written form (Schmidt 2009).

Fieldwork should include observation of the daily work of R&D groups in mathematical industries like finance or optimization in logistics and transportation, as well as the application of simulation and control theory across the industries. Collaboration is planned with university institutes as well as research centers designed for knowledge transfer and R&D departments of private companies.

3.1 Ground Work in Linguistics

Much work has been conducted in the area of analyzing public discourse on scientific results, showing that a funneling process takes place which shapes the presented knowledge (Liebert 2002) and which adds—by using natural language—specific views on this knowledge resulting in a semantic battle (Felder 2006).

Semantic battles usually take place in the public arena, when a group of individuals want to dominate the discourse on a topic, but others with an opposed view try the same. The semantic battle can concern topics that are per se controversial and belong to the sphere of politics, such as taxes or school education. Linguists have observed a specific language use in discourse about those topics. Each party tries to set their views dominant by using terms that support their views and criticize the view of others. Even if the used terms are neutral, they normally set one aspect dominant, which is used to influence the direction of the conversation. Research had been conducted for analyzing semantic battles in several domains, including public debates on biology, especially genetics (see Felder and Müller 2009).

When analyzing discourse in R&D units, the scope is of course different. Not public debates are analyzed, but discourse within an organization. One assumption is that the linguistic tools for observing public discourse can be applied to organizational communication. As already mentioned, this discourse contains also different views on a subject, and each team member in an interdisciplinary team brings in his specific knowledge, ideas, and goals which lead to semantic battles in a similar way.

When it comes to analyze documents with respect to their mathematical content, there is also linguistic work available. Text linguistics focuses on text structures, language use in texts, but there is also research conducted on mathematics and its popularization in different texts types (Schmidt 2003).

3.2 Ground Work in Sociology

The investigation of scientific knowledge and its creation has also a tradition in sociology. Groundwork for the proposed approach are studies that have challenged the opinion, natural sciences are sciences that are clean from human influence such as battles on power or pressure from outside the research teams (Knorr Cetina 1984). The proposed work applies studies that identify different scientific cultures across disciplines (Knorr Cetina 2002) and that define a research program for a sociology of knowledge (Keller 2005). It expands existing studies on (pure) mathematics which were conducted in this tradition (Heintz 2000).

The mentioned sociologists used the participatory observation to analyze the behavior of individuals and groups, organizational set-ups, and power structures. Knorr Cetina spent time at the CERN in Geneva regularly to talk to scientists, conduct interviews, watch them, and take notes. Heintz joint the Max Planck institute for mathematics in Bonn for several weeks and gained her insights also by watching and talking to the mathematicians there. In addition, both sociologists analyzed documents that had been written by the scientists and how they were reviewed.

The method of participatory observation is also at the heart of our approach. However, it will be adapted to the domain of industrial mathematics and to the purpose of analyzing innovations in this domain.

3.3 The Useful Linguist

The work on documents is an important part of the scientific work, since results must be published, and scientists must apply for grants. Knorr Cetina showed that all insights she got from participatory observation were mirrored in the joint work of the scientists on a scientific paper, including the text revisions, comments from reviewers and the kind of document cycling during the writing and review process.

In industrial research and development, documents have a similar importance as in natural sciences. Nevertheless, they are of another kind and variety. In software development, there are for example internal documents like specifications and design documents that are used to prepare the development of technical artifacts, such as algorithms or interfaces. In addition, there is project documentation including project charters, minutes of team meetings, and status reports. Other documents are prepared for the external audience. They include product documentation that is shipped with the technical product, for example installation guides or operating instructions. Companies prepare also marketing documents such as White Papers, Solution Briefs, or Leaflets about products.

Usually all those documents are written and reviewed by project members and other experts, normally leading to a number of revisions and several document versions. The revisions, especially in this variety of document types, make visible technical problems, discussions, and solution proposals as well as different views on how to position the later product in the market. That is why the work on texts serves as a tool for gaining a closer look on semantic battles that come with the application of mathematics.

The useful linguist joins research and development projects in order to draft and edit documents, and to organize the cycling of documents for reviews. He uses his role as technical writer to get to know the inner world of the project. As a project member he is at the core of the innovation and can observe how mathematics comes into play. He joins the project on a long-term basis so that he is able to dive deeply into the topics and to communicate at eyes level with the engineers and mathematicians. This helps to reveal what is happening in the project and to draw the right conclusions.

As a technical writer he does not belong to the inner group of colleagues in the project, since he is a co-worker with focus on language. Therefore, he has an internal, but distant view on the product development. He is not concerned with the product itself and also not with the mathematics in use. He focuses on the communication about the product, its features, and how the mathematicians were involved during development. As a linguist he can use the creation and review of document to control the document cycling and to enrich the participatory observation.

4 Lines of Investigation

Industrial mathematics is a diverse field. It takes place at university departments, mostly as project-based collaboration with companies. There are spin-offs that often productize one specific mathematical invention. Innovation in small and medium enterprises may come from local or regional collaboration with universities or public research institutes. Larger companies can afford an own research and development department, some companies even have units that focus on mathematical consulting. The different industries have their own culture and tradition, also from a mathematical point of view. For example, insurance companies build their business on statistics, others on operations research.

This diversity must be taken into account when conducting research about industrial mathematics. Since a full coverage of all possibilities of mathematical innovation is not possible, only exemplary studies are realistic. However, they need a central theme and guiding research questions.

The following questions may lead to a clearer picture of mathematical innovation in research and development:

- How do mathematicians argue for the use of mathematics? What barriers are conceived by the mathematicians that hinder mathematical innovation? How do they position their mathematical ideas in this context?
- How is mathematics sold? Do mathematicians use arguments from an economic point of view such as addressing costs and benefits of the use of mathematics? Which roles have patents?
- How do mathematicians find a mathematical model of the central objects of the application domain? What strategies are used for developing a common language? How are objects of the application domain changed or redefined to make them fit to the mathematical model? What issues influence the mathematical model? Are only aspects from the application domain relevant or also organizational issues like time constraints and the availability of budget?
- Which mathematical theories and tools are in use? Are they developed anew or reused, for example from a software library? Which level of proficiency do the project members have? Do the team members judge the level of sophistication of the used and proposed mathematical models?
- Which strategies are used to make the mathematical tool set visible or to hide the mathematical content? How is the mathematical content documented in the product documentation? What is explained and what is left out? Are mathematical artifacts visible on technical interfaces or user interfaces?
- Which role has proofs in industrial mathematics? Which standards from research mathematics are applied? Do mathematicians refer to truth, beauty, or similar concepts?
- Is there a mathematical way of thinking that goes behind the application of mathematical models and methods? How do mathematicians bring in their implicit knowledge and their experience with abstract mathematical structures?

5 Outcomes

When addressing the interface of mathematics and industry, the organizational development of industrial mathematics and education are without doubt the main issues.

The proposed analysis of mathematical discourse is meta-research that can support organizational concerns. It may contribute to both mentioned areas of activity and help to leverage the use of mathematics in industrial settings and to leverage communication skills in R&D teams. Linguistics and Sociology help to find best practices for the transfer of mathematical knowledge, which may lead to a better management of organizations for industrial mathematics and a better integration of mathematicians in R&D units.

Fieldwork may lead to the documentation of best practices; it can reveal success stories and can help to detail out shortcomings of today. In addition, it can be a means for specifying needs for mathematical research and education, addressing them to the mathematical research community. Outcome of the linguistic field-work can include the specification of technical tools, platforms for community building across mathematicians in academia and industry.

Last but not least, training can be developed that focuses on soft skills that are needed by mathematicians who work in R&D units. This can lead to a higher impact of mathematics in industry through people at their work place. Furthermore, industrial mathematics will be promoted as a whole, which helps to close gaps in the interface of mathematics and industry.

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