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Training disciplinary teachers: the specialised language of Mathematics

Abstract

Extensive research has consistently highlighted the critical importance of linguistic proficiency in facilitating the comprehension and mastery of subject content, thereby ensuring effective learning across the entire curriculum. Consequently, it is essential to foster an understanding among educators - at all levels and across disciplines - of the principles underpinning language instruction. This paper presents the findings of a professional development program tailored for secondary school teachers, emphasizing the specialized linguistic demands of mathematics and the integration of innovative, data-driven learning approaches within digital learning environments to support its teaching and acquisition.

Keywords

Data-Driven Learning, Digital Learning Environment, Mathematics, Secondary school, Specialised language of Mathematics, Teacher Training.

1. *Introduction*

Recent developments in mathematics education have brought heightened attention to the critical role of linguistic competence in the learning of the subject. This focus stems from emerging research in the field, as well as the growing need to teach mathematics in multilingual contexts (Ferrari, 2021) and in communities characterized by diverse linguistic repertoires (Cascella et al., 2022). In the last two decades, numerous national and international studies and projects have emphasized that challenges related to the acquisition, comprehension, and use of mathematical language are significant contributors to difficulties in disciplinary learning (Ferrari, 2004; De Renzo & Piemontese, 2016; Radford & Barwell, 2016). As stated in the framework of the European project Language(s) in Education, Language(s) for Education (Thürmann, 2012), mathematical literacy has both cognitive and linguistic dimensions. Learning activities in the mathematics classroom should relate thought and language to each other as studying a discipline means not only developing knowledge of the content, but also being aware of the linguistic means that a language requires to express it: lexical-grammatical features, textualisation models, appropriateness and acceptability (De Mauro, 2016). Studying the language of Mathematics and the correct way of expressing oneself in this field can help students to better understand mathematical concepts. Indeed, mathematical language plays a fundamental role in learning processes and in problem solving (Ferreri, 1998).

Mathematics texts, exercises, and particularly problem statements in school settings often pose significant challenges due to their unique linguistic characteristics and the contrast between the language used in everyday contexts and that employed in disciplinary texts. Students' difficulties in comprehending mathematical texts are frequently linked to issues with vocabulary—such as challenges with technical terminology or the functional rigidity of mathematical lexicon—and syntactic complexity. It is increasingly evident that students' success or failure in mathematics is closely linked to their ability to accurately interpret the texts through which mathematical content is presented. This encompasses not only theoretical explanations in textbooks but also the wording of exercises and their accompanying instructions, which students are required to comprehend in order to solve them (Cascella et al., 2022).

The development of mathematical thinking is a lengthy and progressive process that necessitates the gradual acquisition of its specific language (MIUR, 2010). In contemporary education, the link between language and subject is only explicitly considered in CLIL (Content and Language Integrated Learning) contexts, where teachers receive specific training to enable them to integrate language for specific purposes (LSP) into classroom practice (Corino & Onesti, 2019). Another aspect of the Italian school system is the distinct separation between linguistic and scientific education. This separation is likely why many students do not apply the linguistic skills they exhibit in other contexts to mathematical situations. Overcoming this separation necessitates increased collaboration between teachers of both subjects, positioning mathematical language as a subject of linguistic reflection in the same manner as other languages (D'Aprile & Ferrari, 2003). The Italian National Guidelines for high school education specify that learning the Italian language must be cross-disciplinary and considered by all teachers (MIUR, 2010). It is crucial to make teachers at all levels and across all disciplines aware of the principles of language education and specialised languages. Nevertheless, educational linguistics is not included in the pre-service teachers' curriculum, and minimal attention - if any at all - is given to the development of their metalinguistic competencies. Consequently, teachers are often unaware of the scaffolding strategies for LSP that need to be employed to support their students in accessing content through the language that codifies it.

The central research question guiding this study concerns how to effectively raise awareness among mathematics teachers and provide them with training in the specialized language of the discipline. This paper reports on the outcomes of a workshop and training program designed for Italian secondary school teachers, focusing on the specialized language of mathematics. The program also introduced innovative, student-centered methodologies, including data-driven learning and automated formative assessment, within Digital Learning Environments (DLE) to support the teaching and learning of Languages for Specific Purposes (LSP) (Corino et al., 2022).

2. *Innovative methodologies to learning the LSP of Mathematics*

To foster both linguistic and mathematical competencies, two teaching methodologies can be employed, both of which position the student at the centre of the learning process. The first methodology, Data-Driven Learning (DDL), is a pedagogical approach originally developed within English-speaking contexts and predominantly applied to foreign language learning (cf. the comprehensive review of research in DDL from 1989 to 2019 by Boulton and Vyatkina, 2021). DDL is the application of the affordances of corpus linguistics to language learning; it conceptualizes language as data and encourages students to take on the role of researchers, engaging in guided discovery linguistic activities (Corino & Onesti, 2019). Central to this approach is the use of a corpus—a finite and organized collection of texts (written, spoken, or multimedia) in electronic format, computationally searchable and manageable (Barbera, 2013). By analyzing large quantities of tokenized and annotated authentic language data, students can act as "researchers," uncovering grammatical patterns, word meanings, or other linguistic features through exploration and analysis (Johns, 1991). Data-driven - or data-based - investigation is particularly appropriate for LSP, as it provides samples of actual language use, especially in terms of typical word choices (sorting by frequency), nuances of meaning and appropriate use of collocations, colligations, lexical bundles and chunks. In fact, secondary school students are often forced to deal with the languages of the disciplines without adequate linguistic scaffolding to allow them to make the essential distinctions and categorisations of LSP with respect to more general language varieties (Sobrero, 2016).

A second student-centered pedagogical approach is formative assessment. The definition of formative assessment that we adopt is that of Black and Wiliam (2009), which is widely recognized in the literature: "Practice in a classroom is formative to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited." This definition emphasizes the collection of evidence, as well as the interpretation and application of the information gathered, to inform learning and provide feedback to students. Formative assessment is a dynamic process in which students actively engage, gaining insight into what they have or have not learned, how to improve, the progress they have made, and the challenges they face in their learning. The university of Turin has successfully developed and tested a model for automatic formative assessment through the use of an Automatic Assessment System (AAS) for STEM and other disciplines. We define Automatic Formative Assessment as the use of formative assessment in a Digital Learning Environment through the automatic elaboration of student responses and the provision of interactive and immediate feedback (Barana et al., 2021). In our research, we adopted a DLE, implemented on a Moodle platform, integrated with the Möbius Assessment (https://www.digitaled.com/products/assessment, previously known as Maple T.A.), which supports adaptive capabilities, so that the next question part is proposed to the student according to the previous answer (Barana et al., 2020). This AAS enables the creation of adaptive questions that offer students another attempt if they answer incorrectly. It can be adjusted to guide the student through the exercise step by step or to provide additional information. This kind of question, with interactive and immediate feedback, is highly suitable for automatic formative assessment.(Marello et al., 2016; Corino et al., 2020).

3. *Teacher training course on corpus-based activities with automatic formative assessment for students*

The action-research project was conducted in 2021 along two parallel tracks: one involving experimental classroom activities with students, and the other consisting of a training course for the teachers of the participating classes. In the latter, mathematics teachers were trained in the methodologies employed and made aware of the linguistic dimensions of their discipline.

The project involved four classes from two Italian secondary schools, comprising a total of 80 eleventh-grade students and their teachers. Two classes participated as the experimental group, while the remaining two classes served as the control group. The instructional experiment consisted of four two-hour classroom sessions. The classroom activities were characterized by the use of the Data-Driven Learning (DDL) methodology within a Digital Learning Environment (DLE), integrated with an Automated Assessment System (AAS), to explore the specialized language of mathematics and the contents that it expresses. The activities were conducted in Italian, the students' native language.

3.1 The tools and workflow

Students used the concordance tool AntConc (https://www.laurenceanthony.net/software/antconc/) for the Data-Driven Learning (DDL) activities, which required them to extract collocates and frequency lists in order to explore the lexicon of the dataset and define the properties and relationships of specific words. Given that the corpora generated by AntConc are neither lemmatized nor part-of-speech (PoS)-tagged, which limits the ability to conduct advanced queries using regular expressions (Schmidt, 1990), the linguistic investigations were supported by clearly defined reasoning pathways. Students were guided through the observation and noticing process with a set of adaptive questions, implemented via an Automated Assessment System (AAS). All activities involved the use of two tools in parallel: AntConc for linguistic research and the DLE for carrying out tests with automatic formative assessment and other activities.

A specific corpus was created for the activities, drawing texts related to the concept of function from secondary school mathematics textbooks. Over 20 activities incorporating automatic formative assessment were designed and implemented within the Digital Learning Environment (DLE). The purpose of these activities was to guide students in consulting the corpus while assessing both their mathematical and linguistic competencies. Linguistically, these activities facilitated a focus on form to enhance students' proficiency and awareness in the specialized language of mathematics (LSP), promoting the development of affordance strategies. Consequently, they provided opportunities to collect data on language use that might otherwise be overlooked in a first language (L1) context, such as typical word choices, appropriate collocations, semantic preferences, and specific morphosyntactic patterns. From a subject-specific perspective, the activities enabled the analysis of mathematical concepts and definitions from a novel standpoint, beginning with the meaning of terms and the construction of sentences.

For example, students were instructed to search the corpus for the term "funzion*" (*function**) and identify the verbs that co-occur with it as the subject, selecting from a predefined list of possible options (*determina, incontra, interseca, combina, assume, dichiara, esprime, associa*). After analyzing the N+V collocational patterns, a subsequent exercise required students to apply these patterns within an extended context, where additional content details were provided.

> [1] Completa le seguenti informazioni utilizzando i verbi individuati nella sezione precedente:
> Una funzione ___________________ agli elementi del dominio un solo valore degli elementi del codominio
> La funzione ___________________ il valore 3 in x=2
> Una funzione ___________________ la relazione tra due grandezze[1]

During the classroom experiment, teachers participated in the activities alongside the students. In the initial sessions, their primary focus was to explore the proposed methodologies, learn to use the two technological tools, and engage in discussions with students on the language of mathematics. Although the activities were conducted individually, each session concluded with a group discussion, during which the exercise was displayed on the interactive whiteboard and the questions were addressed collectively. If students provided different answers, they deliberated together on the correct response under the guidance of the educator. These reflections were always approached from both mathematical and linguistic perspectives, allowing the group discussions to serve multiple purposes: reviewing answers, clarifying and deepening understanding of concepts, training students to justify their answers, and encouraging comparisons among different viewpoints.

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[1] Complete the following information using the verbs identified in the previous section:
A function ___________________ to the elements of the domain one value of the elements of the codomain
A function ___________________ the value 3 in x=2
A function ___________________ the relationship between two quantities

3.2 The teacher training course

The teacher training occurred in February 2022, following the classroom experiment, and was organized into three synchronous one-hour online sessions. The training sessions were attended by both the teachers of the classes where the activities were conducted and the teachers from the control classes. The topics covered during the meetings included:

1. teachers' and students' reflections on the experiment and the activities carried out; theoretical introduction to the methodologies used during the experiment; group reflection on the importance of language in learning and teaching Mathematics.
2. presentation of the structure of the training course (available at the link: https://linguaggispecialistici.i-learn.unito.it) and its contents; group discussion on the students' responses to the initial test.
3. explanation of corpus-based activities with automatic formative assessment and how to design these activities for students; illustration of some examples of students' responses to the activities; reflection on students' reflections on the proposed methods and activities.

All online meetings involved active participation from the teachers and were characterized by group discussions and reflective activities. Upon the completion of the action-research project, teachers answered an evaluation questionnaire and received certificates of participation.

3.2.1 Considerations and satisfaction of teachers

The teacher training began with an analysis of the students' responses to the preliminary assessment. These responses were presented anonymously to the teachers, allowing them to evaluate the accuracy of the answers from both mathematical and linguistic perspectives. Interestingly, in several cases, teachers were able to identify their students based on the submitted answers. This recognition led the teachers to reflect on the influence of their own language, as well as that of the textbooks used, on the development of students' language skills. Additionally, it prompted teachers to consider the importance of the language employed in various contexts, particularly in the teaching of mathematics.

In the preliminary test, 6 students coming from the same class answered the question "what's a function?" as

> [2] "Una funzione è una macchina che associa ad ogni valore di x uno e uno solo valore di y"[2].

It came out that this response was related to a metaphor used by the teacher to explain the concept of function or an example in the students' textbook. From a conceptual point of view, the metaphor is effective in understanding the concept of function, if we imagine that the word machine is used as a synonym for 'algorithm'

[2] A function is a machine that associates each value of x with one and only one value of y.

or 'computer' that associates input and output, and not with its meaning in common language.

Other definitions were relatively vague or employed terms from general language rather than those specific to the LSP (cf. *interazione/rapporto* vs *relazione*), resembling the approach a teacher might take to enhance accessibility during classroom explanations.

> [3] "La funzione è la relazione tra due insiemi (dominio e codominio)"
> [4] "La funzione è una relazione tra elementi appartenenti a insiemi diversi"
> [5] "La funzione è l'interazione tra insiemi detti dominio e codominio"
> [6] "È un rapporto tra una variabile dipendente e una variabile indipendente, spesso rappresentato su un piano cartesiano tramite una retta"

The term "rapporto" (*ratio*) is semantically clearer than the terms "relazione" and "interazione" (*relation* and *interaction*), but in mathematics the term 'ratio' has a specific meaning because it indicates the division between two numbers or quantities, and this can lead to misunderstandings.

When evaluating their students' responses, it became evident that teachers prioritized mathematical skills over linguistic ones, often considering linguistic accuracy only when a sentence was incomprehensible or nonsensical. Teachers frequently engaged in semiotic mediation, reconciling the students' actual, linguistically approximate answers with what they believed the students intended to express with a faulty use of the specialized language of mathematics. The analysis of the open-ended questions was highly valued by the teachers, as they seldom conduct written argumentative activities. In fact, argumentative tasks are primarily undertaken during oral questioning, where the language used by students varies significantly, and the semiotic mediation by teachers is often substantial. One of the subjects under discussion was the degree to which teacher-mediated interventions were deemed acceptable and what extent a definition given using inaccurate LSP could be considered acceptable. Students' preliminary responses were reviewed, and, notably, there was a lack of consensus among the teachers regarding their evaluation. For instance, the answer "Una funzione è una relazione tra due insiemi dove gli elementi dell'insieme di partenza hanno una e una sola volta una relazione con l'insieme di arrivo"[3] was not considered correct as a definition of function, due to various mathematical aspects (the elements of the set are related to a set and not to its elements, it is not specified that every element of the starting set must be included in the relation) and linguistic aspects ('having a relation with' instead of 'being related to'). According to the teachers:

> [7] docente2_sper: "I would honestly consider it correct. There is some ambiguity because it could say every element of the starting set, but all in all I would consider it correct";

[3] A function is a relationship between two sets where the elements of the starting set have one and only one relationship with the target set.

> [9] docente1_sper: "I mean, I would mark it at least with a sign of imprecision. Then maybe the concept is there, but..."

What emerged from the teachers was that, according to them, one cannot be too strict in analysing the language the students use because otherwise all the students would be in trouble and there would be very few correct answers.

Building on these considerations, teachers were invited to examine their approach to language choices in both the preparation and delivery of their lessons. Their responses revealed a mix of instinctive and reflective approaches to language use in their teaching. One teacher (cf. [10]) noted that while they strive to be precise and rigorous, their use of mathematical terms is often instinctive, based on familiar language patterns. Another teacher (cf. [11]) emphasized the importance of starting with intuitive concepts, particularly for younger students, before progressing to more formal definitions, though they acknowledged that not all students reach this level of understanding. They also highlighted the challenge of students' perceptions that mathematics is primarily about performing exercises, with language considered "optional." The teacher reflected on how the experiment prompted them to reconsider their own approach to language in mathematics instruction, recognizing that while they may not always consciously focus on language during teaching, they become aware of its impact when listening to students' oral responses, realizing that some inaccuracies are a result of their own language use.

> [10] "I always try to be precise and rigorous, but we actually have to think about it. I often do it instinctively, using terms that I am used to in Mathematics"
> [11] "The job of the teacher in high school, especially with younger students, is to start with the intuitive concept and understanding of the concept and then perhaps get to more rigorous definitions. But not everyone gets there. Also because, in my opinion, they come from middle school with the belief that Mathematics consists of knowing how to do the exercises, knowing how to speak is almost "optional". The fact that I ask questions orally is a shock for some students, because for many students talking about Mathematics is useless. The fact that I have carried out this experiment has certainly raised many questions and doubts in me and has put me in a bit of a crisis. When I speak, I listen to myself and think about it. However, in some aspects I have realised over the years that I have paid more attention to how I talk about Mathematics. Sometimes I don't think about the language when I speak, but then when I listen to the students during oral questions, I realise that the inaccuracies they say are my fault".

None of the teachers had ever attended workshops, training courses or carried out experiments on the language of Mathematics. Table 1 shows the extent to which the teachers agreed with various statements about the proposed experiment, on a scale from '1= strongly disagree' to '4= strongly agree'. According to their feedback, the proposed activities were deemed clear and engaging, and most importantly, prompted them to reflect on the language both they and their students utilise in the classroom. They also expressed appreciation for the synchronous online meetings, both in terms of the topics covered and the methodologies employed in conducting these meetings.

Table 1 – *Teachers' observations on proposed activities*

	Mean	Dev.st.
The proposed activities were interesting	3,67	0,58
The activities were clear	3,67	0,58
The proposed activities made me think about the language I use in class	4,00	0,00
The proposed activities made me reflect on the language used by the students	3,67	0,58

Table 2 shows the teachers' opinions on the technologies and methodologies proposed during the experiment. Teachers were required to rate their agreement with the statements provided in the table on a scale from '1=not at all' to '5=very much'.

Table 2 – *Teachers' observations on proposed methodologies*

	Mean	Dev.st.
I learned new things during the online meetings	4,33	0,58
I am satisfied with having followed these online meetings	4,67	0,58
I would recommend this type of online meeting to a colleague	4,00	1,00
I would like to do other linguistic activities with students	3,33	1,53
In the future I would like to take part in training courses on experimental topics.	3,33	1,53
I am interested in other materials on other mathematical topics to work with this methodology.	3,33	1,53
I would like to collaborate with teachers from other disciplines to work with this methodology.	2,67	1,15

On the whole, the outcomes were predominantly positive. Teachers expressed considerable interest in conducting additional language-focused activities with students in the future and in participating in training courses related to the themes of the experiment. The area that received the least agreement among teachers was the collaboration with colleagues from other disciplines to integrate this methodology into classroom practice. While it would be highly advantageous for mathematics teachers to collaborate with colleagues from subjects such as Italian language to conduct activities centered on the language of mathematics, implementing such collaboration may present challenges.

4. *The follow up: further training*

In response to the preliminary findings of this pedagogical experiment, the researchers convened a conference in Turin (Northern Italy) in April 2021, titled "The Specialized Language of Mathematics: A Transversal Competence for Secondary Schools". The event was attended by secondary school educators specialised in mathematics and language instruction. Following the presentations, a workshop was conducted on LSP, featuring demonstrations of linguistic analyses aimed at enhancing mathematics learning. Subsequently, the teachers were invited to complete a questionnaire regarding the workshop's content.

40 teachers participated in the conference, and 18 of these educators actively engaged in the workshop and completed the questionnaire. Notably, among the 40 participants, only two were Italian language teachers. Of the teachers who responded to the questionnaire, 17% had previously participated in conferences, workshops, and training courses focused on the language of mathematics. Table 3 illustrates the degree to which the teachers agreed with various statements regarding Mathematics and its language, on a scale from 1="not at all" to 5="very much."

Table 3 – *Teachers' observations on Mathematics and its language*

	Mean	Dev.st.
To do well in Mathematics, you need to know how to express yourself correctly in Italian	4,0	0,8
To do well in Mathematics, you need to know how to write correctly in Italian	3,8	0,7
Mathematics is all about numbers, symbols and graphics, not words.	1,2	0,5

The findings presented in Table 4 indicate that, using the same scale, teachers valued the activities proposed during the workshop and found them beneficial for reflecting on the language used by either themselves or their students. Furthermore, teachers expressed interest in pursuing additional training on these subjects and in engaging in language-focused activities with their students.

Table 4 – *Teachers' observations on workshop*

	Mean	Dev.St.
The suggested activities were clear	4,7	0,5
The proposed activities made me think about the language I use in class	4,6	0,6
The proposed activities made me think about the language students use	4,6	0,8

I would like to carry out language activities with students	4,4	0,6
I would like to take part in training on these topics in the future.	4,5	0,6

In response to the open-ended question, "Did the proposed activities give you ideas for teaching? If so, which ones?" the teachers all responded positively. Some of the most remarkable responses were:

> [12] "Logic and period analysis activities for mathematical texts".
> [13] "Laboratory on the differences between general and specialised language and on the meanings of specific terms".
> [14] "Greater attention to the language used, required and evaluated".
> [15] "Mathematics is also a humanistic subject with its own specialised language".
> [16] "I would like to carry out some interdisciplinary learning units with Italian and languages in order to highlight the link between Mathematics and language. I think it could also be useful for some students who do not like Mathematics but are more passionate about literary subjects to be more involved in the study and learning of both disciplines".
> [17] "Use the textbook more to get used to approaching the text and its specialised language and make more use of technology".

It is noteworthy that one out of every three teachers expressed a desire to enhance collaboration with the Italian language teacher and to develop interdisciplinary lessons and projects.

5. *Conclusions*

The activities proposed to the teachers and discussed in this paper have elicited deep reflections on the specialised language of Mathematics and the relationship between linguistic competencies and Mathematics learning. Teachers valued the methodologies introduced during the experiments, and these preliminary findings support the argument for a broader application of corpora (and linguistic approaches in general) within educational settings. Clearly, substantial efforts are required in enhancing the linguistic proficiency of subject-specific teachers. Training mathematics teachers in the analysis of specialised texts through corpus consultation and in the creation of corpus-based activities with automatic formative assessment could significantly benefit both educators and learners. This approach would not only aid in developing teachers' understanding but also enhance students' linguistic and digital competencies.

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