Focused language training as a major key for bridging the gap between secondary and tertiary instruction

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Abstract
The paper proposes language-centred options to equip students entering university science courses with the abilities needed to understand and handle science concepts. The suggestions are based on the information on the difficulties experienced by chemistry students at the University of Venda, systematically collected through 15 years. Its analysis – from integrated chemistry-content and language points of view – highlights the dominant role of poor language mastery as the major factor hampering the possibility to access science and preventing the development of the other abilities that are necessary for science learning, like logical abilities and visual literacy. It is inferred that the development of adequate language mastery is the major key for the objective of enabling tertiary students to learn. Focused language training, utilising introductory content for each science and systematically highlighting the connections between language and concepts, is viewed as an optimal option to effectively guide students to understand on reading/listening, to express ideas through sentences that convey the desired meaning and to acquire the other abilities that enable learning. The paper outlines the main features of the suggested approach and illustrates them with examples from preliminarily tests within general and physical chemistry courses.
Key words: epistemological access, language conditioning other skills, language in science, language mastery, secondary-tertiary gap.

Introduction

The issue of the gap between secondary instruction and the first university year is debated worldwide. The characteristics of the gap and the more apt measures to try and bridge it vary widely from context to context. In South Africa, the issue is particularly crucial. The acknowledged frequently unsatisfactory standards of pre-university instruction (Reddy et al, 2006; Fleisch 2008; Heugh, 2009; Mtshali and Smillie, 2011) leave learners largely unprepared for the needs of tertiary education. It also prevents the general/public science-literacy level from meeting the demands of a modern knowledge-based society. When a person working at a big courier company asks whether a single A4 page may weight more than 1 kg and insists that she cannot be expected to know it (author's recent direct experience), it becomes a telling symptom of dire inadequacy in the type of basic scientific literacy that needs to be taken for granted in a modern society.

The situation of students entering tertiary education is particularly worrying, because they constitute the pool of future specialists on which the country's further development will depend and rely. When entering universities, most students have not yet acquired those instruments that are necessary to be able to learn – instruments that are often collectively grouped under the *epistemological access* term (Lotz-Sisitka, 2009). These include:

- language mastery,
- logical abilities,
- visual literacy,
- more basic abilities like the ability to observe and describe,
- and those abilities that go under the concept of literacy "in its fundamental sense" (Norris and Phyllis, 2003) – reading and writing, i.e., understanding what one reads and being able to convey meaning when writing.

The evidence collected in the current study shows that background preparation and epistemological access are getting increasingly poorer from year to year.

The situation in underprivileged contexts can provide particularly detailed information about the difficulties of the secondary-tertiary transition. Fifteen years experience in chemistry teaching at the University of Venda (UNIVEN – a Historically Black University in the Limpopo Province in South Africa) has led to the collection of extensive documentary information on incoming students' difficulties, and on how these difficulties affect performance also through more advanced courses in subsequent years. The courses concerned, and the corresponding student population, are: first year general chemistry (320–420), second year, third year and Honours physical chemistry (50–90, 25–40 and 6–10 respectively) and process technology (5–10). The information was collected to identify and analyse students' difficulties in view of the design of interventions aimed at trying and addressing them; given the time span, it also highlights the evolution of these difficulties through years. The findings show that the skills that are important to understand, to communicate and to link what is done in the class and what is done in the laboratory are often too inadequate to be functional, from the use of mathematics to the use of visualisation, from the ability to make observations to the ability to derive inferences from observations. The often severe inadequacies in the mastery of tools essential for learning prevent the possibility of reasonably fast or effective upgrading of any other skills. The most essential tool is language mastery, where the term is used in a broad meaning comprising the mastery of the second language that is the medium of instruction and the mastery of the basic features of the logic of expression-through-language, which is acquired effectively through the mother tongue and, once acquired, remains part of a person's abilities within any other language (Mammino, 2010a). Students' language mastery is often too poor for them to adequately follow explanations during lectures or to understand what they read in books. The level of language mastery has been deteriorating continuously through recent years, up to the point that a considerable proportion of the students currently taking the first year general chemistry course are unable to write even single-clause sentences that convey an identifiable meaning: several answers are limited to few words whose assembling cannot even be termed clause or sentence, because of the lack of a verb. Students' visual literacy has not developed to levels that could enable at least some degree of communication through images. All this results in a communication deficit largely invalidating teaching and learning actions, as teaching and learning are based on communication. Students' most common response to these difficulties is the resort to passive memorisation, which defeats the very objective of learning.

Ideally, the best way to effectively address these problems would imply major upgrading of secondary education and the shift to mother tongue instruction. However, such measures require time and enormous investments and may not be short-term viable. Since it is urgent to ensure that students entering universities become able to learn, it is necessary to design specific interventions to this purpose. In the following sections, interventions targeting incoming students are collectively grouped under the *foundation courses* term and viewed as an intensive ensemble of activities for a tentative duration of one year, aimed at equipping students with essential learning tools. It is further considered that foundation courses – although meant to bridge the gap between secondary instruction and university – should not aim at providing all the information that learners have not acquired during their pre-university instruction, because this would be unrealistic in the space of one year, and massive information accumulated in a short time would not be sufficiently digested and internalised for students to benefit from it and to be able to build on it. The provision of the information that they have not yet acquired can be incorporated into the normal university courses, with suitable adaptations of syllabi and teaching approaches. The main goal of foundation courses needs to be the development of those abilities that are essential for learning, i.e., the development of epistemological access.

Professional experience and documented evidence lead to the conclusion that language mastery is the key to epistemological access. Since language is the fundamental communication tool, it is also the key to the development of all the other skills (Mammino 2010a, 2010b). Enhancing the general level of language mastery and familiarising students with the use of language in the sciences becomes the first priority, as it constitutes the major key to enable students to learn. The other skills – most of them clearly language-related, but deserving specific attention and fostering – include: the ability to observe, describe the observations and make inferences from them; the ability to read textbooks and analyse sentences; the ability to write texts that convey the wanted meaning; visual literacy; and logical thinking abilities. Their development can utilise a minimum content-material, providing the very basics of each broad science area (physics, chemistry, mathematics, biology) as working ground. Practical approaches are outlined in the next sections, on the basis of trial-options tested within general and physical chemistry courses at UNIVEN.

Language mastery as the key to science learning

The fundamental importance of language mastery for science learning is broadly acknowledged among science educators (Munby, 1976; Carré, 1981; Wellington and

Osborne, 2001; Brooks, 2006). The difficulties that many students experience on reading and understanding science books (Davies and Green, 1984; Fang 2006) or expressing ideas in their own words (Muralidhar, 1991) are largely determined by language mastery inadequacies. Recommendations to enhance science understanding include the use of reading and writing as literacy tools (where literacy is meant "in its fundamental sense", Norris and Phyllis, 2003), the epistemological approach of "teaching science as a language" (Sutton 1992 & 2003; Brown and Ryoo, 2008), and other forms of attention to language (Kali et al, 2008).

In many Sub-Saharan Africa contexts, including South Africa, the issue of the language of instruction has a determining impact on students' ability to learn. It is amply documented that second language instruction enormously increases understanding difficulties (Benson, 2004; Alexander, 2005; Brock-Utne and Hopson, 2005; Brock-Utne and Skattum, 2009; Heugh, 2009; Mammino, 2010a). Furthermore, the fact that students do not sufficiently master the theory of the mother tongue is the major factor responsible for the poor development of logical abilities (Mammino, 2010a) as well as for the poor mastery of the second language (Qorro, 2011).

In the study of the difficulties encountered by science students at UNIVEN, language-related difficulties were investigated specifically, integrating the science-content point of view and the language point of view (Mammino 1998a, 2005, 2006a, 2006b, 2007, 2009, 2010a, 2011a). Furthermore, separate studies focusing on the difficulties concerning the understanding of specific chemistry concepts or of important method-related aspects showed that language-related difficulties regularly appear as a major cause. The concepts investigated include:

- the hybridization of atomic orbitals (Mammino, 2003a),
- phase transitions (Mammino, 2008),
- the relative tendencies of elements to be in an oxidised state (Mammino, 2011b, 2011c).

The method-related aspects investigated include:

- the distinction between: physical quantities and their changes (Mammino, 2001a), general and particular (Mammino, 2001b), systems and processes (Mammino, 2002), number and values (Mammino, 2003b);
- cause-effect relationships (Mammino, 2006b).

Extensive documentation in terms of examples from students' works is included and analysed in the just-mentioned references. This documental evidence justifies the inference that the development of language mastery needs to be the major focus of foundation courses and the all-permeating leitmotiv in interventions meant to foster the development of the other learning-enabling abilities. Utilising basic content for each science will make the development contextual, so that students acquire both generally relevant abilities and the capacity to utilise them within the learning of a given science.

The concrete details of the interventions can be aptly designed by systematically targeting diagnosed difficulties. The next paragraphs outline a set of suggestions based on the diagnoses from the information collected at UNIVEN and focusing on individual practical objectives (acquisition of skills), and the next section provides illustrative examples for chemistry. Although the suggestions have not yet been tested in a systematic and interconnected way (i.e., as part of a specific self-consistent project meant for incoming students) because of time and human resources limitations, a number of them have preliminarily been tested within classroom interactions in general and physical chemistry courses.

Objective 1: learning to read. This is the first and most basic objective. The activities to pursue it combine the acquisition of a fundamental skill with the familiarisation with the scientific approach (Norris and Phillips, 2008). Students are invited to read in the classroom. In a foundation course, the reading (from a textbook) should cover the entire selected (minimum) course content. Each sentence is analysed in terms of language features, connecting them with the science information, and with relevant aspects of the scientific method. The science concepts constitute the constant reference in analysing the mode of expression. The progress through the content will be slow, but functional to the development of fundamental skills. The analysis terms may aptly be the following:

- Identification of the meaning conveyed by the sentence.
- Attention to each relevant word (nouns, verbs, adjectives, adverbs) and to why a certain word is utilised in the given sentence and not a different one. Attention to the mutual suitability of pairs of words for which mutual suitability is essential (as in subject-verb, adjective-noun or other crucial pairs) is particularly important because it is a condition to build correct sentences and is also a diagnosed weaknesses in students' language handling. The science concept/s constitutes the reference to analyse both the selection of individual words and the mutual suitability of relevant word-pairs.
- Attention to those features that students tend to neglect, like the distinction between singular and plural forms (with focus on how many items of a certain type are considered on each occasion), the selection of correct prepositions, or the use of articles. The analysis of the use of articles expands to the issue of the fundamental distinction between statements with general validity and the consideration of particular cases. Students often do not perceive the distinction, and this affects not only the conceptual understanding level, but also problem solving (e.g., when they utilise an equation derived for a specific case as if it were a general equation apt for all cases).
- Attention to the logical relationships in a complex sentence or in a paragraph. This comprises specific attention to time relationships (what comes first and what comes subsequently), to cause-effect relationships, and to the various relationships involving a hypothesis or a condition and its implications or consequences. Adequate familiarity with complex sentences is of paramount importance in the learning of physical sciences, where the logic of the reasoning leading to inferences can be expressed only through complex sentences. On the other hand, understanding complex sentences

proves one of the weakest points in students' language abilities, thus requiring particularly intensive attention.

Guided-reading experiments carried out within physical chemistry courses at UNIVEN clearly showed that most of the concepts had remained unnoticed until students received guidance on "how to read", although they had memorised the texts concerned.

Objective 2: learning to write. This can partly integrate with the "learning to read" initiatives and partly utilise independent exercises. The main objective is to enable students to write things in their own words, instead of the usual "pasting", either from the internet (on home assignments) or from passively memorised materials during tests and exams (where the impossibility of total recall of ununderstood texts often results in meaningless collages of unrelated sentences or sets of sentences). For the exercises integrated with "learning to read', after reading a conceptually self-consistent paragraph or group of paragraphs, students are invited to express the main ideas in their own words. For the independent exercises, students are asked to describe things with their own words. Initially, they will simply describe objects; then they will learn to describe operations or sets of subsequent and related operations. After writing, students are invited to read what they have written, check if it actually conveys the meaning that they wanted to convey, and analyse it with the same criteria utilised for the analysis of sentences on reading from a book. Learning how to proofread is extremely important for students' performance, as too often students do not realise the meaning actually conveyed by what they write in the works that they submit for assessment. On the other hand, being able to proofread tightly depends on general reading abilities.

Objective 3: developing visual literacy. It also relies on different types of exercises. The description exercises utilised for "learning to write" are simultaneously exercises in visual literacy. Students will also be invited to observe the figures or diagrams in their textbook and express through words the information that they convey, or to communicate pre-selected information through their own drawings.

Objective 4: developing logical abilities. It is partly incorporated in the "learning to read" and "learning to write" exercises. It will further be enhanced by inviting students to explicitly identify complex logical frameworks (frameworks involving more than simple two-clauses relationships) and, when suitable, represent them through flowchart-type diagrams.

All these exercises require interactive teaching/learning options to be effective. The analysis of errors can constitute an important component of classroom interactions, for its ability to attract and focus students' attention on details that would otherwise remain unnoticed (Love and Mammino, 1997). The analysis can expand to misconceptions engendered within previous instruction, to ensure their correction and to contribute to the promotion of critical thinking.

Developing epistemological access through introductory chemistry content

The chemistry content of a foundation course may be limited to three fundamental themes: introductory concepts (atoms and molecules at their simplest – but rigorous – definitions, elements and compounds, symbols and chemical formulas, the mole concept, percent composition); the phases of matter and phase transitions; chemical reactions and stoichiometric calculations. Altogether, these themes – if understood and internalised deeply – constitute a solid basis on which to build the rest of the chemical discourse. The familiarisation with all the other themes (structure of the atom, periodic table, chemical bonding, chemical equilibrium, etc.) can be aptly left for the first year general chemistry course.

The very beginning of this minimum content involves a set of chain-way related definitions (matter, substance, element, compound) providing interesting ground not only for the analysis of each statement, but also for stressing that all the terms/concepts appearing in a definition must have been previously defined (e.g., the *substance* concept must be defined before the *element* or *compound* concepts).

Chemistry requires visualisation as a way of communicating crucial aspects of the invisible world of atoms and molecules. Therefore, the development of visual literacy starts since the beginning of a foundation chemistry course, aptly interplaying with the development of language mastery.

The introduction of the molecule concept offers a variety of possibilities in the earliest stages of the course. A rigorous definition considers a molecule as a "stable grouping of atoms bonded to each other". Exercises in which students are provided with models of molecules and asked to write their formulas (Mammino, 1994, p. 30, and 2003, p. 37) contribute to visual literacy and to the understanding of chemical formulas. Asking students to describe the models reinforces understanding by adding the language component. Exercises in which students are provided with a formula and basic geometry information about the molecular structure and are invited to draw the structure (Mammino, 1994, p.31, and 2003, p. 38) contribute to language mastery (understanding information on reading), to visual literacy (expressing information through images) and to the familiarisation with molecules as objects having a 3D structure. The analysis of other definitions of molecules that they might have encountered previously contributes to better understanding of the molecule concept and to fostering critical thinking. For instance, the obsolete definition that "*a molecule is the smallest part of a compound that maintains the characteristics of that compound*" excludes the molecules of elements; students would then be asked to evaluate whether H_2, O_2, S_8 etc. respond to the molecule concept and whether that obsolete definition would allow considering them as molecules.

The definition of the mole concept provides some challenges to students' ability to read and analyse a complex sentence, thus constituting a particularly interesting language exercise. The definition states that "a mole is an amount of substance containing a number or elementary particles of the specified type equal to the number of carbon-12 atoms contained in exactly 12 g of carbon-12". Its analysis may involve different perspectives. The first perspective refers to the understanding of the literal meaning of the sentence, and the main identified difficulty from the students' side is to understand the reference for the "equal" term (what is equal to what). The analysis in terms of individual words may also focus on:

- *amount of substance*, to stress that the mole is the unit of amount of substance;
- the adjective *elementary*, to stress that the mole is defined with reference to a number of particles of the microscopic world.

Regrettably, there are textbooks mentioning that we could consider a mole of persons or a mole of horses. If students have encountered statements of this type, it is important to clarify that a person or a horse neither correspond to the *substance* concept nor are elementary entities and, therefore, the mole concept cannot apply to them. An additional analysis – useful to stress that definitions must be operational – invites students to track the operational meaning of the definition.

The study of the phases of matter combines the reading and writing components with method-related interventions. The preliminary definition of the relevant quantities (temperature, pressure, volume and heat) involves also two quantities that students tend to confuse worldwide (temperature and heat). The definition of temperature that many South African students have inherited from previous instruction ("temperature is a measure of the degree of hotness and coldness") provides an opportunity to stress that definitions need to have a clearly-identifiable meaning and to be operational. Students can be asked to reflect on issues like defining "hotness" or "coldness" in a univocal way; or whether it is necessary to introduce both the "hotness" and "coldness" concepts, or only one should suffice; or to search for an operational character in that definition. A definition that is rigorous although simple is that "temperature is a quantity indicating the direction of a heat flow", provided that heat is defined before defining temperature (which, in turn, further contributes to stress the need that any term utilised in a certain definition must have been previously defined).

The study of the gas laws provides ideal opportunities to relate diagrams to their mathematical and physical meaning, or vice versa, through the interplay of expression through language, expression through equations and expression through diagrams. Their statements enable reflections on the meaning of laws in the physical sciences and on their validity extent. These are method-related aspects essential to the familiarization with the scientific approach. Moreover, the gas laws offer ideal and timely opportunity to clarify nearly generalised misconceptions about the direct proportionality and inverse proportionality concepts – misconceptions that often affect students' interpretations and problem-solving applications up to the third year and beyond (Mammino, 2012). The study of phase transitions also provides opportunities to foster critical thinking by comparing the details of the information encountered in the course with what students might have learnt previously. It is important that students discover (or are guided to discover) discrepancies on their own, to better identify and "treat" misconceptions like the one that molecules move considerably far apart during melting (Mammino, 2012).

The great challenge of which language to use

As already mentioned, the major cause lowering literacy "in its fundamental sense" (the ability to read and write) is the poor knowledge of the language that is the medium of instruction, summed up with the poor knowledge of the theory of the mother tongue. The mother tongue is the key medium to learn the logic of a language and how logical relationships are expressed through language. Once this ability is mastered, it can be extended to any other language that a person learns or uses, making the usage of a second language much more skilful (Mammino, 2010a).

Most students entering UNIVEN have never learnt to handle logic within their mother tongue (and it appears that this is true for many students in South Africa). The mutual relationships between language and logic need thus to be part of the training within foundation courses, to ensure the non-perpetuation of the current situation in which many students have at most “two underdeveloped languages” (Qorro, 2011) but are not able to express themselves fully (including writing) in any. Once acknowledged that logic and its expression-through-language can be effectively mastered only through the mother tongue, foundation courses need to find apt ways to interface the mother tongue and the second language. This (assigning a relevant role to the mother tongue) would likely not be in line with many views about the best approaches to the teaching of foreign languages, and may even not apply to students registering for a language degree. It needs however to he born in mind that the purpose of a science course, or of a science degree, is not that of teaching a specific language (e.g., English), but that of teaching science and preparing specialists in science or technology. Therefore, the dominant objective of science foundation courses is to ensure that students learn how to learn, understand and express science. Science learning requires adequate logical abilities to be applied extensively to any activity: on reading, to identify the logic of a discourse; on observing, to ensure that observations are systematic and complete; on writing, to ensure communication through writing (communicating questions, or descriptions, or answers crucial for students’ assessment; and preparing to communicate whichever content will be needed in their future professional life). If the mother tongue is the optimal vehicle for learning to master logic, then the mother tongue needs to play an important role at least until the student has reached a confident mastery of logic.

Foundation courses of the type outlined here require an adequate number of instructors because their interactive nature requires that students are assembled in not-too-large groups. Groups may then be made on the basis of a common mother tongue, to optimise the mother-tongue/second-language interface. The educational challenge is the design of the ways in which the two languages interface with each other and with the science content, in a situation in which students will read sentences (science information) in a textbook that will likely be written in English, while the analysis of their logic will benefit from mother-tongue references.

The challenges posed by the cross-discipline nature of the interventions

The approach outlined in the previous sections attempts to respond to the difficulties encountered by students entering science university courses, by specifically targeting the diagnosed features and details of those difficulties. It is not the first approach envisaging collaboration of different specialists in the classroom; for instance, Marshall et al. (2011) report an experiment involving collaboration between physics teachers and academic literacy practitioners. The main novelty of the approach outlined in the current work is its language-centred character, where the development of language mastery is the key to science learning and to the acquisition of the other abilities needed for science learning.

The main challenges in the design and implementation of the approach stem from the interdisciplinary nature of the envisaged interventions. The content utilised as reference – although at a basic level – is science content. The need to facilitate students' understanding of all its aspects requires the engagement of a specialist (a chemist, a physicist, a mathematician, a biologist, etc.). On the other hand, most science specialists do not have the type of language expertise that is needed to guide students through the analysis of sentences in language terms (why specific words are selected; why specific prepositions are selected; why a sentence is built in a specific way; or what is the grammar and logical framework of a sentence or the logical framework of a discourse). Conversely, most language specialists do not have the type of expertise needed to relate the language terms to the characteristics of the science object, phenomenon or broader discourse considered. Experts in the language-of-science are rare, too rare to cover the needs of foundation courses throughout the country. Options where science experts and language experts operate synergically could be ideal if suitable working interfaces can be designed, although such design may not be easy. In particular, it is difficult to assign a leading role. Ideally, the leading role should be for a science specialist who is also expert in the language-of-science, to better highlight the intimate connections between science and language. Given the lack of such specialists, it becomes necessary to envisage that the conceptual reference in the course is given by the science content and the leitmotiv by language in the perspective of developing language mastery. Then the three-fold interface (science content, mother tongue and English) needs to develop considering students' needs and responses, so as to optimise their acquirement of epistemological access.

A basic option could entail the preparation of detailed guidelines for each science − integrating the science perspective and the language perspective − and the corresponding training of instructors. Instructors' training would involve explorations for the three-fold interface and implementations within interactive teaching options. The guidelines would not constitute a final answer, but a starting point, to be re-optimised year after year on the basis of feedback from students' responses and progress.

Conclusions and recommendations

Ensuring epistemological access for students entering science or technology university courses requires the development of skills like: reading and writing ability; the ability to observe, describe and make inferences; the ability to read/interpret images and to communicate through images; and all-permeating logical-thinking abilities. The development of these abilities is tightly linked to the student's language-mastery level, which is often heavily inadequate. Intensive upgrading of language mastery becomes the key to science understanding and to the acquisition of the other abilities that can facilitate science understanding. Focused upgrading of language mastery, fostered within the context/content of specific science areas, is viewed as the most prospective intervention to build the ensemble of learning tools that can enable a student to proceed and effectively learn science or technology material. The essential role of the mother tongue for the development of general language mastery and of logical abilities requires three-fold synergism – science content, mother tongue language-perspective and English language-perspective. The design of optimal synergism-pathways requires novel collaboration-patterns between science teachers and language teachers. Although interventions of this type may appear quite demanding in terms of pedagogical research and in terms of investment, the outcomes of pilot trials of selected components (mostly focused on reading abilities) and the overall expected benefits justify at least preliminary explorations through pilot courses, to evaluate feasibility and effectiveness on a larger application scale.

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