



Inclusive Chemistry Teaching Strategies for Upper Secondary Students with Dyscalculia: A Review of Innovative Practices

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Abstract

Specific Learning Disorders (SLDs), particularly dyscalculia, affect 4.9% of Italian students and pose significant barriers to STEM education, especially in chemistry, where numerical reasoning and unit conversions are essential [1]. This review synthesizes innovative strategies for inclusive chemistry teaching in upper secondary school, grounded in Italian Law 170/2010, which mandates early identification, Personalized Didactic Plans (PDPs), and compensatory tools.

Drawing on neurobiological profiles of dyscalculia [2] and empirical studies, the analysis highlights deficits in numerical cognition that exacerbate chemistry challenges, such as stoichiometric calculations and formalism inconsistencies (e.g., molar mass notations). Key innovations include proportion-based methods over equations (13% efficacy gain), video instructions for experiments (16% improvement), and ball-and-stick models for nomenclature (13% gain), adapted from dyslexia research [3]. Inclusive textbooks, like Zanichelli's "Chimica: molecole in movimento," [4] incorporate concept maps and everyday analogies (e.g., eggs for Avogadro's number) to reduce cognitive load.

Self-esteem interventions, such as biographies of dyscalculic scientists, counter the "low self-esteem spiral" [5], fostering neurodiversity normalization. PDPs emphasize cooperative learning and ICT for active participation, benefiting all learners [6].

Findings reveal gaps in secondary chemistry-specific interventions; recommendations include teacher training in multisensory pedagogies and policy advocacy for equitable STEM access. This work advances inclusive science education by bridging research-practice divides.

Keywords: *dyscalculia, chemistry education, inclusive pedagogy, STEM, self-esteem, Specific Learning Disorders*

1. Specific Learning Disorders

Specific Learning Disorders (SLDs) include specific disorders of reading (dyslexia), writing (dysgraphia and dysorthographia), and calculation (dyscalculia). These disorders can occur in isolation, but more often coexist in comorbidity. They are defined as "specific" because they affect a specific skill domain in a significant yet circumscribed way, leaving general intellectual functioning intact, in subjects with an IQ (Intelligence Quotient) equal to or above the average [7].

The Consensus Conference on Specific Developmental Learning Disorders — drafted by the Italian Dyslexia Association (AID) and scientific societies in Montecatini Terme (July 22–23, 2006) and Milan (January 26, 2007) — defined the basic criterion necessary for diagnosis, namely the discrepancy between the affected ability (deficient compared to expectations for the age and/or grade level) and general intelligence (adequate for the age) [8].

The Consensus Conference defined discrepancy as:

- the specific ability is lower than -2SD (- 2 standard deviations) below the normative values expected for age or schooling,
- IQ is within the normal range, equivalent to ≥ 85 (IQ < 85: non-specific learning disorder, IQ < 70: intellectual disability).

SLDs are a disorder of neurobiological origin with significant familiarity. They have a chronic, yet evolutionary course; they therefore change in relation to age and school demands. Environmental factors such as school, family, and social context intertwine with neurobiological ones, leading to a greater or lesser degree of maladjustment [7].

The ICD-10 (International Classification of Diseases) classifies the various learning disorders using the following code: F81.0 for specific reading disorder (dyslexia), F81.1 for specific spelling disorder (dysorthographia), F81.2 for specific disorder of arithmetic skills (dyscalculia), F81.8 for other developmental disorders of scholastic skills (dysgraphia) and F81.3 for mixed disorder of scholastic skills (SLD in comorbidity) [9].



Furthermore, according to the DSM-5 (Diagnostic and Statistical Manual of Mental Disorders), SLDs can be classified based on their level of severity: a) mild: slight difficulties in learning skills that the student can overcome with some didactic measures, b) moderate: marked difficulties in learning skills, requiring recovery and strengthening activities and c) severe: serious deficits in learning skills, requiring intense recovery and strengthening activities [10].

In the 2016/2017 school year, students certified with SLD represented 2.9% of the total, in the 2018/2019 school year 4.9%, and in the 2022/2023 school year 6.0%. The increase is attributable to greater attention to the identification of SLDs both by families and by the school institution [10, 11].

1.2 Dyslexia

The specific reading disorder is due to difficulties in text decoding, consisting of the failure to recognize the correspondence between letter and sound. Confusion in reading letters, such as m/n, f/v, a/e, d/b, p/q, negatively affects the ability to read correctly and fluently [8, 9].

The necessary characteristics for the examination of reading skills are the administration of standardized tests for reading letters, words, non-words, and passages, the joint evaluation of performance in the parameters of speed and accuracy and the detection in at least one of the two parameters of a distance of -2SD from the expected values for the age and/or grade level.

The minimum age at which a diagnosis of dyslexia can be made coincides with the completion of the second year of primary school, where there is a significant reduction in the high inter-individual variability in the acquisition times for reading [7, 9].

1.3 Dysgraphia and Dysorthographia

The specific writing disorder includes dysgraphia and dysorthographia. Dysgraphia is a motor type of disorder, which leads to graphically unclear (often illegible) realization of writing and difficulty mastering drawing tools. Dysorthographia is a linguistic disorder and derives from the failure to recognize the correspondence between sound and letter, which therefore leads to a deficit in encoding processes.

For the examination of writing components, it is necessary to administer standardized tests. Regarding dysgraphia, fluency and the qualitative analysis of the characteristics of the graphic sign are evaluated. In the case of dysorthographia, the correctness parameter, i.e., the number of errors, is evaluated. The Consensus does not contain indications regarding a minimum age for diagnostic evaluation, although it is very often carried out in conjunction with the evaluation for dyslexia [7, 9].

1.4 Dyscalculia

The specific calculation disorder concerns the mastery of fundamental skills such as addition, subtraction, multiplication, and division; reading and writing of numbers; comparison of quantities; counting skills, and problem-solving [8].

The Consensus distinguishes two distinct profiles of dyscalculia:

- weakness in the cognitive structure of numerical components (i.e., quantification, comparison mechanisms, mental calculation strategies),
- weakness in executive and calculation procedures (including reading, writing, and columnar alignment of numbers, retrieval of number facts, and written calculation algorithms).

The necessary characteristics for the examination of calculation skills are the administration of standardized tests of numerical intelligence and executive and calculation procedures, the joint evaluation of performance in the parameters of speed (particularly important in the evaluation of numerical cognition skills) and accuracy and the detection in at least one of the two parameters of a distance of -2SD from the expected values for the age and/or grade level.

The minimum age at which a diagnosis of dyscalculia can be made coincides with the completion of the third year of primary school [7, 9].

2. Italian Law 170/2010

Around the 1990s, SLDs students fell under Law 104/92. Even before the entry into force of Law 170 of 2010, the MIUR (Ministry of Education, University and Research) provided guidance through ministerial circulars regarding school situations not yet regulated [8]. Based on the concept of



"centrality of the person," MIUR circulars indicate the use of desirable compensatory tools and dispensatory measures, the importance of extending verification times, the search for methodologies that can support the learning of students with SLDs, the preparation - by the Class Council - of personalized paths, and the need to protect the privacy of SLD students, avoiding making the modalities of the tests taken by SLDs individuals known.

With Law no. 170 of 8.10.2010 and Implementing Decrees, focus includes early SLD identification, with schools obligated to report suspicions to families for referral to accredited diagnostic services, teachers' commitment to personalized didactics via the Personalized Didactic Plan (PDP) for educational success, SLDs students' right to compensatory tools and dispensatory measures, training for teachers and school leaders and strengthened healthcare services for diagnosis [8].

SLDs engage schools in adopting strategies to ensure success for all. Law 170 acknowledges the risk of exclusion, frustration, and impacts on employment and life opportunities for a significant student portion [10, 12].

2.1 The Personalized Didactic Plan

The Personalized Didactic Plan (PDP) is a program for effective SLDs learning through diversified methodologies, time, tools, and class work planning. It is drawn up by the Class Council at the start of the school year. Teachers freely identify suitable strategies, tools, and measures for each SLD student. The PDP must include student's personal data, prior schooling, difficulties, and strengths, functioning of instrumental skills, learning process characteristics, actual levels, useful strategies, and elimination of dysfunctional ones, disciplinary objectives for core competencies, methodological strategies (limiting frontal lessons, using mediators, encouraging peer work and labs), including tools and measures per discipline, scheduling, modalities, and evaluation criteria per discipline, educational environment information. The PDP is then submitted to the family for approval. Continuous, shared monitoring of the SLDs student's progress between school and family is essential [8, 10].

2.2 Inclusive Education

Inclusive education enables all students to achieve maximum learning and social participation by valuing class differences [12]. These concern the entire community: students' traits, styles, disorders, or disabilities; teachers' approaches and sensitivity. Differences must be accepted, valued, and used in daily activities to foster individual and group growth. True inclusion centers on each student's needs and resources, placing them at the core of their learning regardless of capacities or limits. It requires active knowledge construction and personal strategies [13]. Teachers must respect individual times, rhythms, and styles, adopt strategies minimizing traditional teaching, value individual strengths, use mediators like mind maps, connect learning to life or prior knowledge, propose labs and encourage idea representation via brainstorming [6].

3. Dyscalculia and Mathematics

Developmental dyscalculia is a specific disorder of the basic ability to understand numbers and numerosity. Most people are born with the ability to mentally manipulate numerosity, which depends on specialized brain circuits; this ability is called "numerical intelligence" [14].

Numerical intelligence evolves according to precise stages:

- 0 - 2 years, a pre-verbal numerical knowledge of quantity develops,
- 2 - 4 years, number-words are acquired, and counting skills develop,
- 4 - 7 years, reading and writing skills for numbers develop,
- from 7 years, strategies are refined, and basic operations with numbers stabilize [2].

Numerical intelligence is analogical and strategic and evolves into mental calculation. People with dyscalculia tend to count in units, often using their fingers and usually struggle to learn calculation methods based on reasoning. They therefore struggle to make progress in learning mathematics, with obvious consequences on self-esteem and the relationship with mathematics. The subjective experience of dyscalculia as a barrier to STEM (Science, Technology, Engineering, Mathematics) education varies according to the school level and the type of mathematics taught. In primary school mathematics, students often have difficulties with counting exercises. As mathematics teaching progresses and students are expected to build the required skills on their foundations, the difficulties become even more evident. Students with dyscalculia may have problems with learning multiplication tables and understanding addition, subtraction, multiplication, and division. The unintentional improper



use of arithmetic signs, forgetting to carry over in division, transposing digits, or the inability to solve more complex problems are all issues that students with dyscalculia may encounter [15].

3.1 Didactics Of Mathematics

A specific didactic method is therefore necessary to allow students with dyscalculia to make progress in learning mathematics. The didactics methodology should be based on reasoned understanding, thus avoiding mnemonic learning of arithmetic aspects and using materials and aids (such as drawings, diagrams, and graphs) to make learning more concrete, be carefully structured, limiting memory load, proceeding in small steps, and offering sufficient repetitions, encourage active participation, for example by proposing games in which each student can find their own solutions, formulating questions that help acquire new knowledge and make learning mathematics a positive experience, providing help and confidence, granting an adequate amount of time to think, varying mathematics lessons and using different didactic methodologies, providing adequate support [2, 14]. Secondary school students are generally more open to discussing their learning difficulties with the teacher(s), thus allowing the teacher(s) to further personalize didactic strategies [4, 14]. Furthermore, it is important to remember that mathematics learning is often experiential in nature, as students can learn the same concepts in different ways and at different times. Therefore, the teaching staff should be provided with a certain flexibility in terms of materials and didactic strategies to maximize the success of each student [15]. Both during the lessons and the evaluation tests, the instructions should be well structured in a way that leaves no room for ambiguity or possibility of (mis)interpretation. The font and line spacing should be adapted to make the rendering on the page clearer. It could be useful to add the meaning of the symbol near the symbol itself to favor the mnemonic retrieval of vocabulary. Items could be grouped into two groups of four to avoid overloading memory, which is engaged in decoding and comparing many stimuli [2, 14].

3.2 Mathematics and Self-Esteem

SLDs students, especially the ones who received the diagnosis later in school life often suffer from low self-esteem and may find it extremely disheartening to have to endure lessons in a subject they consider difficult and that causes them anxiety and frustration (Fig.1.).

It may be interesting to present the biographies of some scientists, particularly mathematicians, physicists, and engineers who, despite the difficulties shown during their schooling due to disorders and/or disabilities, were successful and are remembered for their discoveries and/or inventions [9]. Some examples may be the following:

- Albert Einstein started speaking very late, yet he won a Nobel Prize in Physics,
- Thomas Edison always had difficulty with spelling and arithmetic, but he is the father of many inventions, including the incandescent light bulb,
- Astronomer Vera Rubin, student of George Gamov, described her teacher in her biography: "He couldn't write or count. It would take him a while to tell you what 7 times 8 is. However, his mind was capable of understanding the universe."

It is of fundamental importance to emotionally support SLDs students, and particularly those with dyscalculia, by adopting didactic strategies that favor their learning and their academic success [16].

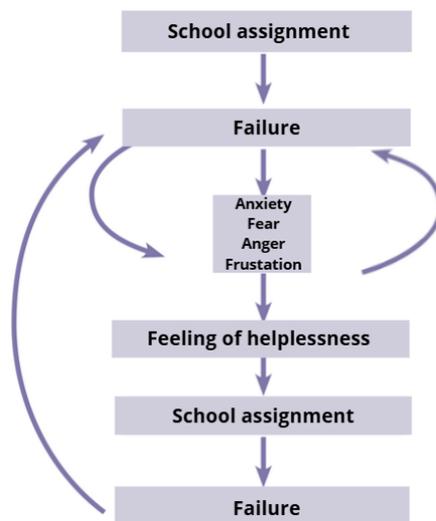


Fig. 1. Spiral of low self-esteem [5].

4. Dyscalculia and Chemistry

Chemistry is based on logical thinking, sequential learning, and the use of interrelated rules. Numbers, letters, and hyper specific terms are fundamental in chemical application; moreover, it is essential to mnemonically remember a series of concepts and processes. A further difficulty concerns formalism, which is not unambiguous and is represented with different terms and/or abbreviations in different texts. Molar mass and molecular weight, for example, represent the sum of atomic masses. However, molar mass has “g/mol” as its unit of measurement and is represented with MM in some texts and M in others. Molecular weight has “amu” as its unit of measurement and is represented with PM (“peso molecolare”) in some texts and Mw (“molecular weight”) in others. The lack of comprehension, memorization, and retrieval of logical-sequential facts leads the dyscalculic person to a high error rate, with consequent frustration [17]. Most studies focus on mathematical difficulties in primary school; few address dyscalculic students’ challenges in upper secondary mathematics, and even fewer explore other STEM subjects for these individuals [3].

4.1 Didactics Of Chemistry

Kamińska-Ostęp and Gulińska conducted a study on 400 students between 13 and 15 years old regarding chemistry didactics. The subject of their study were dyslexic students (about 20% of the total), but some of their considerations on didactic methodologies can be easily transferred to dyscalculic students. The study focused on the didactics of four didactic units, and for each didactic unit, two different approaches were used, as shown in Table 1.

Didactic Unit	Inclusive Method (approach A)	Traditional Method (approach B)
Computational Chemistry	Proportion method	Algebraic equations
Chemical Experiments	Video instructions	Written protocols
Inorganic Nomenclature	Computer games	Board games
Organic Nomenclature	Computer animations	Ball-and-stick models

Table 1. Methodology used in the study. Adapted from [3].

Each class was divided into two homogeneous groups in terms of the composition of SLDs and non-SLDs students. Didactic approach A (specifically designed for dyslexic students) was applied to one group, and method B (a more traditional approach) was applied to the other group.

Computational Chemistry. SLDs students’ limited memory makes unit conversions and multi-step calculations challenging. The proportion method, reducing equation complexity, proved more effective overall and +13% for SLDs students vs. equations.



Chemical Experiments. Video instructions were more effective for all students involved, regardless of the presence of a SLD. Analyzing only the data of individuals with SLDs, video instructions were significantly more effective than written instructions (+ 16%).

Nomenclature of Inorganic Compounds and Chemical Reactions. The application of computer games allows the review and practice of a determined same skill in an attractive way. Computer-based chemical games promote memorization according to the rule that if something is attractive, it is easier to remember. Computer games, enhancing engagement and retention, were more effective overall and +12% for SLD students vs. board games.

Nomenclature of Organic Compounds and Chemical Reactions. The models (both computerized and ball-and-stick) visualize chemical problems, facilitating the transition from specific concepts to abstract concepts. The ball-and-stick models were more effective for all students involved, regardless of the presence or absence of a diagnosis. Analyzing only the data of individuals with SLDs, the ball-and-stick models were significantly more effective than computer animated models (+16%). The reason for this result is to be found in the fact that the use of ball-and-stick models, enabling direct manipulation, outperformed animated ones by promoting meaningful over rote memorization [3]. These results show that these methodologies can be useful to promote learning for the entire class, with particular attention to students with SLDs [17].

4.2 Chemistry And Self-Esteem

Similarly to what was stated for mathematics, it is also fundamental in chemistry to emotionally support students with dyscalculia [9]. To support self-esteem, it may be interesting to present professional figures who have distinguished themselves in the field of chemistry, biology, or natural sciences and who, despite difficulties, achieved success (Fig. 2.).

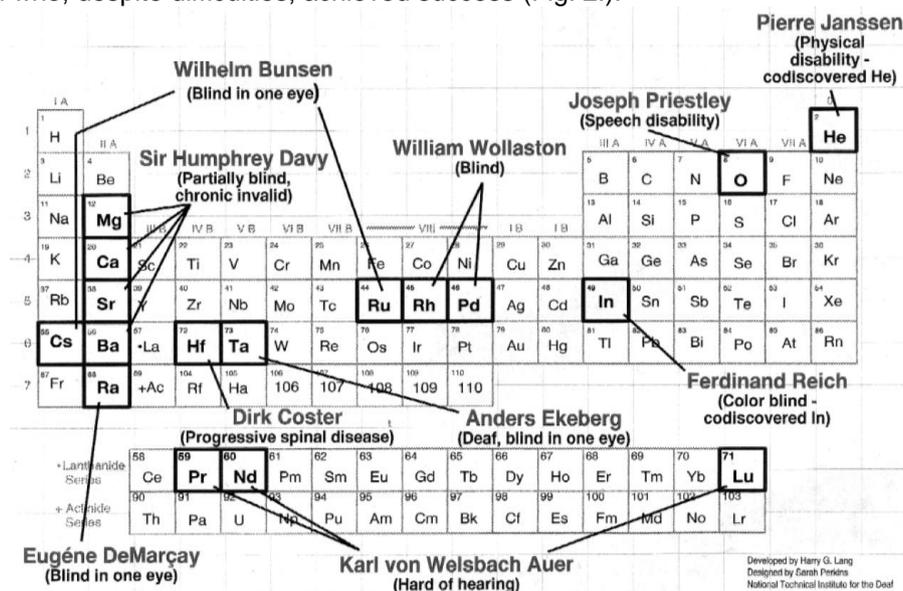


Fig. 2. Disabilities of some scientists related to the period table of elements [18].

Besides the scientists mentioned in Fig. 2., there are some other examples:

- Carol Greider, a molecular biologist who won the Nobel Prize in Physiology or Medicine for the discovery of telomerase, has spoken openly about her dyslexia, which made reading difficult during her studies, but she used visual strategies to excel in research,
- Jacques Dubochet, biophysicist and chemist, who won the Nobel Prize in Chemistry for developing cryo-electron microscopy, was diagnosed with dyslexia at age 14,
- Archer J.P. Martin, a chemist and biochemist, who won the Nobel Prize in Chemistry for inventing partition chromatography, stated that his dyslexia pushed him to visualize problems in innovative ways,
- Benjamin Franklin discovered the electrical nature of lightning and invented the lightning rod, Historical research indicates severe difficulties with mathematics and numbers, despite his scientific successes [18].



4.3 Inclusive Textbooks

There are countless publishers of school textbooks; the author believes that books published by Zanichelli are the most attentive to inclusive education.

Zanichelli textbooks offer a range of content and tools designed for Special Educational Needs, which the publisher includes under linguistic needs, Specific Learning Disorders (SLD), ADHD, and hearing and visual disabilities [19].

A prime textbook example is the 2nd edition of *Chimica: molecole in movimento* by Valitutti (Zanichelli [4]). It includes three volumes: the main text, lab book, and *Idee per imparare* booklet, designed with an inclusive approach and uniquely bound on the short side. A particularly challenging didactic unit for students with dyscalculia is the one on the mole. The difficulty lies in the fact that the amount of substance can be expressed in mass, moles, or number of molecules, requiring constant unit conversions. The main textbook covers this unit in about 25 pages of text, with extensive explanations and exercises, while the *Idee per imparare* booklet structures the didactic unit in 7 pages, using diagrams, mind maps, highlighted boxes, and visual examples.

The chapter begins with a simple concept-activating map of the topic and uses the egg example (something tangible and linked to everyday life) to explain how Avogadro's number is used to determine the number of molecules in a substance. On the next page (page 42), in addition to the section on atomic mass, there is the definition of isotope, a true/false exercise to reinforce the concepts just learned, and a box reminding students that the periodic table already contains the atomic mass information for each atom. Page 43 introduces the first unit conversions, a review box, and a section with an exercise. The exercise is guided, with clear steps indicated to students on how to solve it. On page 44, the concepts of mole and molar mass are introduced, and the egg example is used again. The following page combines the concepts of mole, mass, and number of particles in a table. There is also a box with three multiple-choice questions to reinforce the concepts just learned. The final page of the chapter (page 46) is dedicated to a summary concept map of the chapter [4].

Inclusive chemistry teaching cannot rely solely on this booklet, but it is a good starting point in terms of font (the text is written in a larger size), use of colors (different units of measurement are represented with different colors), activating and summary concept maps, and examples linked to everyday life.

Therefore, classroom methodologies should also include hands-on examples (perhaps using actual eggs, leveraging the same example proposed in the book) and the use of software and computerized models. ICT can, thus, support various learning objectives, promote active participation of individuals, enhance their potential, and foster their growth and learning [20, 21, 22].

The teaching of chemistry must be a positive experience that values students' logical and reasoning skills, mitigating the difficulties related to numerical and mnemonic aspects [13].

5. Conclusion

Dyscalculia, a SLD related to calculation abilities and number sense, has a significant impact not only on mathematics didactics but also on scientific disciplines such as chemistry, which require the application of logic, formulas, and calculations [21].

The results of the study by Kamińska-Ostęp and Gulińska, although focused on dyslexia, provided valuable indications, such as the effectiveness of the proportion method for chemical calculations, the use of video instructions for experiments, and the use of manipulable models (like ball-and-stick models) for organic nomenclature [3]. These approaches reduce the mnemonic and verbal load, favoring concreteness, practical activity, and visualization, which are also fundamental elements for overcoming difficulties related to numerical sense typical of dyscalculia.

The adoption of inclusive textbooks and attention to the student's self-esteem, through the presentation of successful figures in the STEM fields who have faced similar challenges, complete the picture of a chemistry didactics that is not limited to transmitting notions but aims to develop competence and self-confidence [20, 21].

In conclusion, the teaching of chemistry for students with dyscalculia does not require a revolution of content, but an evolution of methodologies. Breaking down complexity into manageable sequences, using visual and manipulative mediators, and allowing the use of compensatory tools are not just support measures, but elements of an effective and inclusive didactics that benefit the entire class. The final goal is not to eliminate the difficulty but to provide every student with the tools to face and it successfully, ensuring equitable and quality education [21, 22].



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