Germany[a]

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Introduction

Overview of Education System

Germany is a federal republic with 16 federal states. Each state has supreme legislative and administrative authority over all its cultural policy issues, including its education system. Certain crucial aspects of the German school system, such as the definition of a grading scale, are standardized across the country through interstate agreements.

Since 2003, national education standards have determined the curricula for primary and secondary mathematics and for secondary science (except science education at the primary and geography at secondary level). The Ministry of Education and Cultural Affairs in each state manages its curricula in accordance with the standard. As a result, almost every state has its own curricula for specific secondary school tracks, subjects, and grade levels.

Primary school is the first level of the compulsory education system and generally comprises Grades 1 to 4 (ages 6 to 10). In 2 of the 16 states, namely Berlin and Brandenburg, primary school covers Grades 1 to 6 (ages 6 to 12). After completion of primary school, children are assigned to different secondary school tracks according to their ability level and predicted academic aptitude. Secondary education is divided into lower and upper secondary education. Lower secondary education begins at Grade 5/7 and ends at Grade 9 or 10 (ages 15 to 16). Lower secondary education

[a] This is an updated version of Wendt, H., Smith, D. S., Bos, W. (2016). Germany. In Mullis, I. V. S., Martin, M. O., Goh, S., & Cotter, K. (Eds.), TIMSS 2015 Encyclopedia: Education Policy and Curriculum in Mathematics and Science. Retrieved from Boston College, TIMSS & PIRLS International Study Center website: http://timssandpirls.bc.edu/timss2015/encyclopedia/

is taught separately either at specific types of secondary schools or in parallel within schools that offer two or three of the tracks. School types and their descriptions differ between the federal states.

After completing lower secondary schooling, most students continue their education at the upper secondary level (ages 15 or 16, to 18 or 19). Students are most commonly either assigned to full-time general education, which leads to a higher education entrance qualification, or take on full-time vocational schooling, which is combined with vocational apprenticeship training at the workplace.

Use and Impact of TIMSS

After an absence of systematic monitoring of its education system of nearly 20 years, Germany took part in several studies, including TIMSS 1995.[1] Since 2007, Germany has participated in all study cycles of TIMSS at the fourth grade level.

Several states, foundations, and other organizations have introduced a number of initiatives and programs that promote education in mathematics and science in direct response to TIMSS across the study cycles.[2] One such initiative is the Enhancement of the Efficiency of Mathematics and Science Education (*Steigerung der Effizienz des mathematisch-naturwissenschaftlichen Unterrichts*, or SINUS),[3] a model program for secondary schools to increase the efficiency of the mathematics and science curricula. The program was complemented by the SINUS at Primary School Program from 2009–2013.[4] Other noteworthy projects resulting from TIMSS studies in Germany include Physics in Context, Chemistry in Context, and Biology in Context.[5]

The Mathematics Curriculum in Primary and Lower Secondary Grades

Mathematics education at the primary school level currently is regulated across the 16 German states by 14 curricula, all of which are informed by the national education standards. Although 12 states have passed their own curricula, some states (Berlin, Brandenburg, Bremen, and Mecklenburg-Western Pomerania) have collaborated in developing and approving a common core curriculum. Exhibit 1 presents an overview of the mathematics topics taught in primary school in North Rhine-Westphalia.[b]

[b] In this chapter, North Rhine-Westphalia, the largest state in terms of population, serves as an example in cases where the specificity of particular topics makes it impossible to give a universal description for all states, given the federated nature of education policy and practice in Germany.

Exhibit 1: Mathematics Curriculum Guidelines for the Primary Level (up to Grade 4) in North Rhine-Westphalia

Content Domains	Content-Based Student Competencies*
Understanding Numbers	▪ Illustrate the number range up to 1,000,000 using the decimal system ▪ Analyze and describe structural relationships between different number systems based on examples ▪ Use structures in number systems to understand numbers in extended number ranges ▪ Work in the number range up to 1,000,000 by counting in steps, as well as by arranging and comparing numbers according to various characteristics ▪ Discover relationships between individual numbers and in complex number systems, and describe them using mathematical terminology and symbols
Understanding Operations	▪ Match basic situations (which require adding and combining or taking away and separating) to the respective basic mathematical operations, such as addition, subtraction, or completion ▪ Match basic situations (which require repeated addition of the same numbers or repeated subtraction of the same numbers) to the respective mathematical operations, such as multiplication or division (distribution) ▪ Switch between different representations of operations (e.g., material, symbolic, figurative, or language-based representations) ▪ Discover and describe characteristics of operations and laws of arithmetic based on examples ▪ Use mathematical terminology and symbols correctly
Fast Mental Arithmetic	▪ Have sound knowledge and quick mental arithmetic skills in the number range up to 1,000,000 ▪ Repeat all multiplication tables (up to 10) automatically and be fluent in the inverses
Arithmetic	▪ Solve problems using all four basic operations (orally or in a partly standardized written form) by making use of arithmetical laws and analyze strategies using relationships between numbers and arithmetic laws (e.g., distributive law and commutative law of addition) in all four operations ▪ Solve problems using multiplication table relationships ▪ Describe and evaluate different arithmetic operations based on aspects of arithmetic and demonstrate clear understanding of these structures in writing
Numerals	▪ Explain in writing operations such as addition (with several addends), subtraction (with one subtrahend), multiplication (with multiple digits), and division (using remainder notations with single-digit and important double-digit divisors), describing the steps of calculation logically using examples ▪ Calculate fluently, confidently, and in written form using addition, subtraction, and multiplication
Estimations	▪ State approximate results of problems using numbers up to 1,000,000, and round and estimate to the appropriate accuracy
Flexible Calculating	▪ Calculate using individually preferred methods or standard methods, with and without a calculator
Dimension and Form	
Spatial Orientation and Spatial Visualization	▪ Trace lines with a pen (eye-hand coordination), name overlapping figures (figure-ground discrimination), and identify forms (visual consistency) ▪ Orientation in two-dimensional space using a map ▪ Describe spatial relations on the basis of pictures, arrangements, plans, etc., as well as from imagination

Content Domains	Content-Based Student Competencies*
	▪ Visualize the movement of shapes and objects and describe the results of movement in advance
Shapes	▪ Explore, name, and describe shapes using mathematical terminology (e.g., perpendicular, horizontal, parallel, square) ▪ Construct shapes by replacing, overlaying, or spreading elements; filling in spaces; and constructing, deconstructing, or continuing patterns ▪ Continue, describe, and construct patterns (e.g., band ornaments, tessellations) ▪ Name and compare areas of shapes and their perimeters ▪ Construct similar shapes from card paper by enlarging or reducing according to scale
Solid Figures	▪ Identify geometrical objects, sort them according to geometrical characteristics, and describe them using mathematical terminology (e.g., area, edge) ▪ Construct wireframe and solid models of objects and build more complex cube constructions ▪ Find various nets for cubes ▪ Identify two- or three-dimensional views of buildings and construct buildings according to a plan ▪ Define and compare volumes of objects with unit cubes
Symmetry	▪ Examine shapes for axial (line) symmetry and use their characteristic length preservation and space preservation to explain the symmetry ▪ Construct symmetrical figures and use characteristics of axial (line) symmetry (length preservation and space preservation)
Drawing	▪ Construct line segments, simple figures, patterns, curves, and exact parallel or perpendicular lines using instruments like compasses and set squares, and use grid or point patterns to draw shapes and three-dimensional buildings
Measuring and Quantities	
Perception and Handling of Quantities	▪ Measure quantities (length, time, weight, and volume) using suitable drawing instruments ▪ Compare and organize quantities ▪ Name quantities of familiar objects and use these quantities as a reference for estimations ▪ Read time from analog and digital clocks ▪ Use monetary units (c, €) and units of length (mm, km), time (seconds, minutes, hours), weight (g, kg, t), and volume (ml, l), and convert between units ▪ Convert fractional quantities that occur in daily life into the next smaller unit (e.g., 1/4 l = 250 ml) ▪ Calculate with quantities (also using decimals)
Factual Situations	▪ Formulate arithmetical questions for real or simulated situations (also in project-oriented problem contexts) and for contextual problems, and solve them ▪ Use aids like tables, drawings, and diagrams to solve problems ▪ Reason that estimated values (estimation, evaluation) are sufficient and explain why an exact result is necessary or unnecessary ▪ Construct contextual problems (orally and in writing) for mathematical models (equations, tables, etc.)

Content Domains	Content-Based Student Competencies*
Data, Frequency, and Plausibility	
Data and Frequency	▪ Collect data from real life situations and present it in diagrams and tables ▪ Extract data from calendars, diagrams, and tables to solve problems with arithmetic content
Probability	▪ Describe the probability of simple events (using terms such as certain, possible, impossible, always, often, rarely, never) ▪ Name the number of different possibilities in simple combination tasks
Learning Processes	**Process-Oriented Student Competencies**
Problem Solving and Creative Thinking	
Select	▪ Find relevant information for solving problems and present it in words
Solve	▪ Try progressively more systematic and results-oriented approaches, and use knowledge of operations to solve problems
Reflect and Check	▪ Check results for adequacy, detect and correct mistakes, and compare and evaluate various approaches
Transfer	▪ Transfer approaches to similar situations
Modify and Invent	▪ Invent tasks and questions
Apply	▪ Select suitable arithmetic rules, algorithms, and tools for problem solving and apply them appropriately
Modeling	
Detect	▪ Distill information from problem situations and tasks, and distinguish between relevant and nonrelevant information
Solve	▪ Transfer information from problem situations into mathematical models and solve problems using these models
Validate	▪ Relate solutions back to the problem situation and test plausibility of results
Relate	▪ Define suitable problems for given mathematical models and develop questions related to the models
Arguing	
Hypothesize	▪ Make hypotheses about mathematical relationships or irregularities
Test	▪ Test hypotheses using examples and question if assumptions, solutions, statements, etc., are correct
Conclude	▪ Prove or disprove hypotheses based on examples, and develop preliminary conclusions related to these hypotheses
Substantiate	▪ Describe relationships and rules using examples and follow the reasoning of others
Illustrating and Communicating	
Record	▪ Record results, procedures, and learning experiences
Present and Exchange	▪ Design and develop suitable means of presentation, such as transparencies or posters, to present solutions, ideas, and results comprehensibly
Cooperate and Communicate	▪ Work on complex problems in groups, organize meetings, and combine opinions
Use Expert Terminology	▪ Use suitable mathematical terminology to present mathematical facts, symbols, and conventions
Change Between Illustrations	▪ Transfer illustrations into other forms of illustrative representation

* Summary of expected competencies at the end of the school entry phase (Grades 1 and 2) and the end of Grade 4.

At the secondary school level, eighth grade mathematics education currently is regulated by more than 40 curricula that all are informed by the national educational standards. There is no

single or common core curriculum across all the states. In fact, the mathematics curricula differ across grades and school tracks in the details of the content covered and the timing of the introduction of topics: generally, the more demanding a secondary school track, the earlier the students are introduced to advanced topics.

Exhibit 2 presents an overview of mathematics topics covered in the eighth grade curriculum for the *Realschulbildungsgang* (extensive general education) in North Rhine-Westphalia, and is fairly representative of the 40 eighth grade curricula in place across the German states.[6]

Exhibit 2: Mathematics Curriculum Guidelines (*Realschulbildungsgang*) in North Rhine-Westphalia, Grade 8

Content Domains	Content-Based Student Competencies
Arithmetic and Algebra—Dealing with numerals and symbols (example)	
Ordering	▪ Order and compare rational numbers
Operating	▪ Execute basic arithmetic operations for rational numbers (mental arithmetic and written arithmetic techniques) ▪ Aggregate terms, multiply them, and factor them using simple factors ▪ Solve linear equations by trial and error, as well as algebraically, and check calculations by applying the solution
Applying	▪ Apply knowledge of rational numbers and simple linear equations to solving mathematical and extra-mathematical problems
Systematizing	▪ Give nonmathematical reasons and examples for the extension of the set of natural numbers to the set of rational numbers
Learning Processes	**Process-Oriented Student Competencies**
Reasoning and Communicating—Communicating, presenting, and reasoning (example)	
Reading	▪ Gather, restructure, and evaluate information from simple mathematical figures
Verbalizing	▪ Demonstrate individual problem-solving steps using simple mathematical operations, in their own words and using appropriate technical terms
Communicating	▪ Compare and evaluate approaches, solutions, arguments, and illustrations
Presenting	▪ Present solutions in short, prepared statements
Associating	▪ Find generalizations and specific instances of mathematical facts, and give examples and counterexamples to support findings
Reasoning	▪ Apply mathematical knowledge to reasoning in multistep arguments

The Science Curriculum in Primary and Lower Secondary Grades

Science at the primary school level is included in the interdisciplinary subject *Sachunterricht*, which covers contents from the areas of natural science and social science such as biology, chemistry, physics, technology, geography, history, economics, and politics. This subject and, accordingly, science education are currently regulated by 14 curricula. In contrast to mathematics, there are no national educational standards defined for science. The curriculum of North Rhine-Westphalia describes educational goals as integrated content and process-oriented competence expectations for the end of Grades 2 and 4. The same can be found in the other federal states.

Exhibit 3 gives an overview of science content and competence expectations at the primary school level in North Rhine-Westphalia, a fairly representative curriculum for the 16 states.[7]

Exhibit 3: Science Curriculum Guidelines for the Primary Level (up to Grade 4) in North Rhine-Westphalia

Content	Content-Based Student Competencies*
Matter and Changes in Matter	▪ Collect materials from nature and classify them according to specific criteria ▪ Describe and classify matter by its observable properties (e.g., natural and manufactured, color, hard and soft, smell) and describe similarities and differences ▪ Explore and describe visible changes of matter, (e.g., states of matter; drying of fruits; dissolving of solids; and burning)
Heat, Light, Fire, Water, Air, and Sound	▪ Investigate phenomena such as heat, light, fire, water, air, and sound ▪ Observe and describe the importance of water, heat, and light for humans, animals, and plants ▪ Plan experiments and interpret results ▪ Describe changes in nature (e.g., water cycle and seasons)
Magnetism and Electricity	▪ Investigate and describe the effects of magnets on different materials ▪ Construct simple electric circuits, and describe, explain, and follow safety rules when using electricity
Human Body, Senses, Nutrition, and Health	▪ Investigate and describe the meaning of human senses in daily life ▪ Identify and describe the functions of sensory organs ▪ Identify and describe different eating habits and their effects ▪ Describe central structures and basic functions of the human body (blood circulation, respiration, digestion) ▪ Describe hygiene basics, healthy nutrition, and healthy lifestyle ▪ Formulate rules and advice for living a healthy lifestyle
Animals and Plants, and Their Habitats	▪ Identify body structures and living conditions of animals and document the results ▪ Observe and identify plants and their typical characteristics, and describe their habitat ▪ Describe the development of animals and plants ▪ Describe the relationship between habitats and living conditions for animals, humans, and plants
Environment and Mobility	▪ Explore and describe structures of their own habitat and the region (e.g., rural areas, agriculture, cities, industrial areas, recreational areas) ▪ Compare, describe, and document natural and designed characteristics (e.g., waters, surface, flora, fauna, settlements, traffic routes, industry)
Environment and Sustainability	▪ Identify possibilities for waste prevention and prepare a guidebook for this purpose ▪ Investigate and discuss the importance and use of resources and test their careful use (e.g., water, energy, soil, air, paper)

* Summary of expected competencies at the end of the school entry phase (Grades 1 and 2) and the end of Grade 4.

For most tracks at the secondary school level, science is taught in the following separate subjects: biology, chemistry, physics, and geography. Some states offer biology, chemistry, and

physics as an integrated subject in some school tracks and some schools (mostly in nonacademic tracks). Eighth grade science education currently is regulated by more than 40 curricula that are informed by the national educational standards (except geography). The curricula differ across grades and tracks, with the academic tracks covering content more quickly or in more detail. Exhibit 4 presents a representative overview of content areas and content-oriented competencies mentioned in the eighth grade curriculum for the *Gymnasium* (academic track) in biology, chemistry, physics, and geography from in North Rhine-Westphalia.[8,9,10,11]

Exhibit 4: Physics, Chemistry, Biology, and Earth Science Curriculum Guidelines for the Secondary Level (Gymnasium) in North Rhine-Westphalia, Selected Topics

Physics	
Obligatory Content Areas	▪ Electricity ▪ Temperature and Energy ▪ Light and Sound ▪ Forces and Pressure ▪ Energy and Power ▪ Radioactivity and Nuclear Power
Example Exemplary Competencies Core Idea: Interactions	▪ Explain changes in motion or deformations of bodies by using the concept of forces ▪ Describe force and velocity as vector quantity ▪ Relate the strength of the electric current to its effects and link the functioning of simple electrical devices to it
Chemistry	
Obligatory Content Areas	▪ Matter and Changes of Matter ▪ Chemical Reactions and Changes in Energy ▪ Air and Water ▪ Metals and Recovery of Metals ▪ Atomic theory and Periodic Table ▪ Chemical Bonding ▪ Organic Chemistry
Example Exemplary Competencies Core Idea: Matter	▪ Explain the diversity of matter and their properties on the basis of atomic theory and chemical binding (e.g., ionic compounds, polar and nonpolar substances) ▪ Describe the structural principles of the periodic table and use them as a classification scheme ▪ Use knowledge about structure and properties of matter for separation, identification, purification and for the description of large-scale production of materials
Biology	
Obligatory Content Areas	▪ Diversity of life on Earth ▪ Structure and function of human body ▪ Adaption of plants and animals to the seasons ▪ Sex education ▪ Cycles of matter and energy flow ▪ Evolution

	▪ Information processing ▪ Basics of heredity ▪ Individual development of humans
Example Exemplary Competencies Core Idea: Development	▪ Describe a particular ecosystem in the changing seasons ▪ Describe the ancestry of humans ▪ Describe long-term changes in ecosystems
Earth Science (Without Social Geographic Aspects)	
Obligatory Content Areas	▪ Relevance of selected location factors for industry (e.g., natural resources) and agriculture (e.g., climate, soil) ▪ Inappropriate use of water resources ▪ Physiognomic changes in a community caused by tourism
Example Exemplary Competencies Core Idea: Development	▪ Describe selected natural geographical structures and processes (surface form, soil, geohazards, climate and vegetation zones) and explain their influence on human living and economic conditions ▪ Discuss the risks associated with human interventions in geoecological cycles and ways of avoiding them ▪ Establish a connection between natural geographical conditions, different production factors, and economic policy, and show the associated consequences for agricultural production

In addition, the curricula from North Rhine-Westphalia and the curricula from other federal states describe process-oriented competencies including the following:

- Observe and describe processes and differentiate between observation and interpretation
- Identify questions that are possible to investigate scientifically
- Plan and carry out simple investigations
- Obtain and evaluate information from different sources

Professional Development Requirements and Programs

To ensure ongoing professional development, teachers are required to participate regularly in training and development. In-service training focuses on keeping teachers up to date in the subjects they teach and the teaching methods they use, as well as in the broader fields of psychology and sociology of education.

Monitoring Student Progress in Mathematics and Science

In June 2006 (and extended in June 2015), the Standing Conference adopted a comprehensive strategy for educational monitoring, which consists of four interconnected areas: participating in international comparative studies of educational achievement; conducting sample-based studies for a central review of the achievement of the education standards in a comparison between the federal states; conducting cross-state comparative studies to review the efficiency of individual schools within the states; and the joint education reporting of the federation and the states.[12]

In response to this strategy for educational monitoring, all states have administered cross-state comparative studies (*Vergleichsarbeiten*) in mathematics and German in third grade, and in

mathematics, German, and students' first foreign language (English or French) in eighth grade.[13] The tests are administered like regular classroom tests, and they also serve as standardized school achievement tests based on the national education standards (*Bildungsstandards*). The test results provide teachers with information about the strengths and weaknesses of their students, as well as subject-specific pedagogical and educational psychology recommendations to help them improve their instruction.

In state-run schools, teachers monitor individual student progress based on written, oral, and practical work and tests. The individual student progress and development is documented and defined within performance standards for each subject in report cards. Examination results constitute one component of report cards, which may determine students' promotion to the next grade or entry to upper secondary school or university. The report cards are given to students in the middle and at the end of the school year.

According to a resolution passed by the Standing Conference in 2010, teachers are asked to develop special monitoring and feedback methods for low-performing students. These methods comprise individualized learning plans as well as intensified and individualized monitoring activities, such as documenting progress in learning diaries or language portfolios.[14]

Special Initiatives in Mathematics and Science Education

A number of European, national, and regional initiatives are designed to encourage students to pursue careers in science, technology, engineering, and mathematics (STEM; in German, *MINT*).[15] At the national level, some of these initiatives are associated with the High-Tech Strategy, which was launched by the Federal Ministry of Education and Research in 2006, and was further developed in 2014.[16] The strategy aims to support the development of new products, innovative training, and continuing education services to meet the increasing demand for highly skilled workers in Germany.

STEM initiatives include Science Days, which focus on career orientation and typically are organized by associations, societies, or foundations and attract more than 18,000 visitors;[17] targeted education programs at museums of technology or natural science; mathematical and scientific competitions, such as Youth Research (*Jugend forscht*);[18] university activities for children (e.g., touring a university and participating in children's university lectures); and special vacation academies to support the talent and development of youth in STEM subjects. The *Haus der kleinen Forscher* (House of the Young Scientist) initiative is particularly important for primary schools, as it provides professional development courses in STEM for elementary school teachers.[19] This initiative has professional development networks throughout Germany. Some of the programs, such as Girls' Day and Boys' Day, introduce boys and girls to career possibilities in which men or women are underrepresented.[20,21] In addition, the National Pact for Women in STEM Professions—a program that aims to increase the proportion of women in STEM careers—sponsors projects that target girls and women.[22]

Suggested Readings

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