Germany[a]

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Introduction

Overview of Education System

To understand the German education system, it is necessary to know that Germany contains 16 federal states that are mainly self-organized. This means every federal state has its own supreme legislative and administrative authority, which leads to heterogeneity in the education system in Germany. However, for all 16 federal states, there are general binding policies that are the responsibility of the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany (KMK). The KMK is a national consortium that consists of education ministers and senators of all federal states.[1] In 2004, critical guidelines for mathematics and science were developed and have been steadily revised as part of the national education standards. These frameworks specify which competencies students have to achieve at different school levels. For mathematics, there are national education standards for all (primary and secondary) levels; for science, standards exist for secondary education only.[2,3,4,5,6,7]

Before starting primary school in Germany, children have the option to attend a preschool, kindergarten, or a similar alternative, which has been legally assured since 2013 (e.g., childminder, *Tagespflege*).[8] Similar to the national education standards, there are also frameworks for basic education goals (e.g., early numeracy) for early childhood education.[9] Generally, children start the compulsory part of their education with primary school at the age of 6 or 7.[b] In 14 states, primary school (*Grundschule*) includes Grade 1 to Grade 4; in Berlin and Brandenburg, primary school lasts until Grade 6. At 10 (or 12) years of age, children leave primary school and attend different secondary school tracks based on assessment by teachers and parents (*Schullaufbahnempfehlung*). Secondary education starts in Grade 5 (or

a This is an updated version of Wendt, H., Schwippert, K., Schulz-Heidorf, K., Walter, D., & Steffensky, M. (2020). Germany. In D. L. Kelly, V. A. S. Centurino, M. O. Martin & I. V. S. Mullis (Eds.), *TIMSS 2019 encyclopedia: Education policy and curriculum in mathematics and science*. Boston College, TIMSS & PIRLS International Study Center. Retrieved from https://timssandpirls.bc.edu/timss2019/encyclopedia/

b The indicated and actual ages can differ for various reasons, e.g., starting school earlier or later, or skipping or repeating classes in cases of very high or low achievement.

Grade 7) and contains lower and upper secondary education. Lower secondary education ends with the graduation certificate *Hauptschulabschluss*, first school leaving certificate (*Erster Schulabschluss*, ESA) (Grade 9), or the intermediate school leaving certificate (*Mittlerer Schulabschluss*, MSA) (Grade 10). Receiving this certificate qualifies a student for upper secondary education or vocational training. Secondary education provides the opportunity to achieve the *Allgemeine Hochschulreife* (*Abitur*) or *Fachhochschulreife* (Grade 12 or 13), which allows direct entrance to the tertiary education sector. In the federal states, there are many different types of schools for earning graduation certificates (e.g., *Realschule*, *Integrierte Gesamtschule*, *Gymnasium*). Depending on a student's academic achievement, it is possible for the student to switch between the different school types and tracks.[10]

In 2011, the KMK released a recommendation that children with diagnosed special needs should be able to attend regular schools instead of special education schools (e.g., *Förderschule*). However, students can still attend special education schools if needed.[11]

Use and Impact of TIMSS

Since the resolution of the 16 federal states in 2006 regarding education monitoring strategies, Germany participates in the large-scale studies PIRLS, TIMSS (for Grade 4), and the Programme for International Student Assessment (PISA).[12] Participation in these studies aims to increase the transparency in measurement of education quality and to provide reliable scientific knowledge for different actors in the education system, e.g., schools, education administration, and education policy.[13] Guided by past TIMSS results, multiple noteworthy projects in different subjects and domains have been developed.

Following the results of TIMSS (and national large-scale assessments), increased efforts were made, in the areas of mathematics and science but also literacy, to professionalize teachers and to develop the education system. These efforts included the Enhancement of the Efficiency of Mathematics and Science Education (*Steigerung der Effizienz des mathematisch-naturwissenschaftlichen Unterrichts*, or SINUS), Education through Language and Writing (*Bildung durch Sprache und Schrift*, or BiSS), Little Scientist Foundation (*Stiftung Kinder forschen*), and the German Centre for Mathematics Teacher Education (DZLM). Additionally, it is possible for the scientific community to request TIMSS data at a research data center (Forschungsdatenzentrum, or FDZ) for further analyses, e.g., for theses or articles, to increase knowledge about education in Germany.

The Mathematics Curriculum in Primary and Lower Secondary Grades

Fourth-Grade Mathematics Curriculum

Mathematics education at the primary school level 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.[c]

Exhibit 1: Mathematics Curriculum Guidelines for the Primary Level (up to Grade 4) in North Rhine-Westphalia[d,14]

Content Domain	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 (that require adding and combining or taking away and separating) to the respective basic mathematical operations, such as addition, subtraction, or completion • match basic situations (that 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

c 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.

d Exhibit 1 represents the guidelines that were valid for teaching fourth graders in 2023. There will be updated national education standards that will be relevant for TIMSS 2027.

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

Content Domain	Content-Based Student Competencies*
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) • orient in two-dimensional space using a map • describe spatial relations on the basis of pictures, arrangements, plans, etc., as well as from imagination • 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

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

Content Domain	Content-Based Student Competencies*
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.)

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

Content Domain	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 Process	**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

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

Learning Process	Process-Oriented Student Competencies
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

Eighth-Grade Mathematics Curriculum

At the secondary school level, eighth-grade mathematics education is currently regulated by more than 40 curricula that are all informed by the national education 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 secondary school level I *Realschule* (extensive general education) in North Rhine-Westphalia and is fairly representative of the 40 eighth-grade curricula in place across the German states.[15]

Exhibit 2: Mathematics Curriculum Guidelines for *Realschule* in North Rhine-Westphalia, Grade 8

Content Domains	Content-Based Student Competencies
Arithmetic and Algebra (Example)	
Basic Operations	• conduct the basic operations of multiplication and division with fractions and explain calculation steps in a comprehensible way
Number Range Extension	• give reasons and examples for number range extensions
Term and Variable	• represent rational numbers on a number line and order them according to quantity
Calculation Laws	• transform terms using binomial formulas and rectify incorrect term transformations
Solution Procedures	• derive sign rules for addition and multiplication by means of examples and use calculation laws and rules

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

Learning Process	Process-Oriented Student Competencies
	Problem-Solving (Example)
Exploring	• reproduce problems in their own words and pose questions about a given problem • select appropriate heuristic tools (sketch, informative figure, table, experimental procedures) • continue patterns and number sequences, describe relationships between quantities, and make reasoned hypotheses about relations
Solving	• select appropriate terms, relations, procedures, and tools for problem-solving • use heuristic strategies and principles • develop ideas for possible approaches, plan processes for solving a problem, and carry out solution plans in a target-oriented way
Reflecting	• check the validity of results • compare different solution methods regarding their similarities and differences and consider their efficiency • analyze and reflect on causes of mistakes • name underlying heuristic strategies and principles and apply them to other problems in a reasoned way

The Science Curriculum in Primary and Lower Secondary Grades

Fourth-Grade Science Curriculum

Science at the primary school level is included in the interdisciplinary subject *Sachunterricht*, which covers natural and social science topics such as biology, chemistry, physics, technology, geography, history, economics, and politics. As of 2023, 15 curricula regulate this subject and, accordingly, science education. In contrast to mathematics, no national education standards are defined for science. The curriculum of North Rhine-Westphalia describes education goals as integrated content and process-oriented competence expectations for the end of Grades 2 and 4. The same can be found in 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.[16]

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

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 a 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

e Meanwhile, new curriculum guidelines are binding but do not apply to students who participated in TIMSS 2023.

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

Content	Content-Based Student Competencies*
Environment and Mobility	• explore and describe structures of their 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

Eighth-Grade Science Curriculum

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 is currently regulated by more than 40 curricula for which the national education standards (except geography) apply. 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 physics, chemistry, biology, and geography from North Rhine-Westphalia.[17,18,19,20]

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

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

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 • adaptation 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

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

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 geo-ecological 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

*Earth science topics are taught as a more general geography course.

In addition, the curricula from North Rhine-Westphalia and the curricula from other federal states describe process-oriented competencies that include 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

Teacher Professional Development Requirements and Programs

In Germany, professional development is mandatory for all teachers as part of quality assurance. Specific policies are defined by the 16 federal states. In most federal states, teachers or the school principal are responsible for their own participation in professional development, which should take place outside of regular classroom time. The number of required hours of professional development is not specified except in a few federal states (e.g., 30 hours per year in Hamburg and Bremen).[21]

The content of professional development includes different fields such as pedagogy and education, subject knowledge, and pedagogical content knowledge, as well as school development or specific competencies (e.g., leadership qualification). Professional development serves as a measure for maintenance, actualization, and advancement following the principle of lifelong learning. The development, implementation, and evaluation of professional development offerings can be offered by different organizations (e.g., higher academic institutions such as universities, external contractors, institutes run by the state or the federal state, supervisory

authorities). Offerings include short-term, extraoccupational long-term, or cumulative forms of professional development and can be held in a school, regional, or central/federal context.[22]

Monitoring Student Progress in Mathematics and Science

At the state level, there are four main areas related to monitoring student achievement: participation in international large-scale assessments (especially for mathematics and science like TIMSS and PISA), evaluation and implementation of national education standards, quality assurance at the school level, and joint constant education reporting by the state and federal states.[23] Furthermore, most of the federal states agreed to administer comparative tests in German and mathematics in Grade 3 and in German, mathematics, and the first foreign language in Grade 8 (*Vergleichsarbeiten*, or VERA)[24] or an assessment to identify competencies (*Kompetenzen ermitteln*, or KERMIT, in Hamburg).

At the school level, achievement and progress of students are generally monitored using numerical grades from 1 to 6, where 1 means "very good" and 6 means "insufficient." In primary school, there is a phase where students receive written feedback rather than grades. How long this phase lasts depends on the different guidelines in the federal states; in many of them, numerical grades start after 1 or 2 years of schooling. Students receive grades on oral, practical, or written performance during the whole school year by their teachers. These grades form the basis for report cards, which are given to students twice a year in most federal states.

Under certain circumstances there are also alternative assessment formats in addition to or instead of grades, e.g., learning process documentations such as *Kompetenzraster* or *Lernportfolio*.[25]

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).[26] At the national level, some of these initiatives are associated with the High-Tech Strategy project, which was launched by the Federal Ministry of Education and Research in 2006 and was further developed in 2014.[27] 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;[28] targeted educational programs at museums of technology or natural science; mathematical and scientific competitions, such as Youth Research (*Jugend forscht*);[29] 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 foundation initiative House of Young Scientists (*Haus der kleinen Forscher*) is particularly important for primary schools, as it provides professional development courses in STEM for

primary school teachers.[30] 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.[31,32] 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.[33]

Suggested Reading

Eckhardt, T. (Ed.). (2021). *The education system in the Federal Republic of Germany 2019/2020: A description of the responsibilities, structures and developments in education policy for the exchange of information in Europe*. Secretariat of the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany. https://www.kmk.org/fileadmin/Dateien/pdf/Eurydice/Bildungswesen-engl-pdfs/dossier_en_ebook.pdf

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