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Introduction

Overview of Education System

In Taiwan, education administration follows a unified, two-tiered system with the central Ministry of Education and local education bureaus. Historically, the central government dominated local education policy, but reforms since the 1990s have empowered local governments.[1,2]

From preprimary school to college, formal education includes 9 years of compulsory education (Grades 1 to 9).[3] The duration of formal education can vary, typically comprising 2 years in preprimary school, 6 years in primary school, 3 years in junior high school, and 3 years in either senior high school or senior vocational school. Students may also opt for a 5-year vocational school program after completing junior high.

The curricula of all subjects for Grades 1 to 12 (primary school to secondary school, including the first 3 years of vocational school) were regulated by the Curriculum Guidelines of 12-Year Basic Education, officially implemented in September 2019.[4]

Use and Impact of TIMSS

Taiwan has been actively participating in TIMSS since 1999. The results of TIMSS have influenced curriculum reform and evaluated the effectiveness of mathematics and science education. While the results of TIMSS 2007 validated the success of curriculum guidelines for Grades 1 to 9 in terms of outstanding student achievement,[5] the subsequent TIMSS 2011 exposed persistent challenges. These challenges encompass low student interest in mathematics and science compared to other countries, a notable proportion falling below the intermediate intenational benchmark of mathematics and science achievement, wide rural-urban achievement gaps, less engaging teaching in eighth-grade mathematics and science, and a limited emphasis on scientific inquiry.[6,7] These issues have prompted attention from educators and policymakers, catalyzing substantial reforms.[8] One notable initiative was enacting the Act for Education Development of Schools in Remote Areas in 2017. This act addresses rural-urban education disparities by enhancing education quality and resources in rural areas.[9]

The Ministry of Education and the National Science Council continue using TIMSS and other large-scale studies (e.g., PIRLS and the Programme for International Student Assessment

[PISA]) as crucial benchmarks for policymaking in Taiwan. For example, the National Science Council developed the *White Paper on Science Education Research Development and National Science Literacy* in 2011. This project utilized insights from international large-scale studies to reassess existing policies for mathematics, science, and technology education research.[10] In 2016, the Taiwan International Large-Scale Study Center (TILSSC) was established to enhance the coordination and utilization of TIMSS and other large-scale survey results. This initiative aims to build prime indicators for assessing the efficacy of education policy and forming the foundation for evidence-based policymaking.[11]

TIMSS 2023 is particularly significant as it assesses students' learning outcomes following the implementation of the Curriculum Guidelines for 12-Year Basic Education. The results of TIMSS 2023 will provide essential feedback to the TILSSC for evaluating the efficacy of the guidelines.

The Mathematics Curriculum in Primary and Lower Secondary Grades

This section summarizes *Curriculum Guidelines of 12-Year Basic Education for Elementary, Junior High Schools, and General Senior High Schools: Mathematics*.[12] The goals of the mathematics curriculum for primary and lower secondary grades include the following:

- provide students with adaptive learning opportunities while nurturing a positive attitude and confidence in mathematics
- cultivate students' curiosity and abilities in pattern observation, computation, abstraction, reasoning, communication, and solving problems mathematically
- foster correct attitudes toward utilizing mathematical instruments for solving problems
- apply mathematics knowledge and skills in daily life
- establish mathematics knowledge and skills as a foundation for learning other subjects
- cultivate an appreciation for the aesthetic aspects of mathematics

The time allocation for mathematics in Grades 1 to 9 is four sessions per week, totaling 160 minutes. The learning objectives of the mathematics curriculum are primarily developed based on mathematics content in seven domains: Number and Quantity, Space and Shape, Coordinate Geometry, Relation, Algebra, Function, and Data and Uncertainty. It is important to note that the domain of Relation is specific to primary education and is replaced by Algebra and Function in secondary education.

Fourth-Grade Mathematics Curriculum

In Grade 4, the mathematics curriculum centers on equipping students with fundamental knowledge and skills in Number and Quantity, Relation, Space and Shape, and Data and Uncertainty. Students are expected to acquire the following knowledge and skills described in the mathematics curriculum in Grade 4:

- Number and Quantity
  - perform computations (adding, subtracting, and multiplying) and estimations with place values up to 100 million
  - understand the meaning of division, fractions, and decimal numbers, and calculate fractions with the same denominator and numbers with two decimals
  - express and compare whole numbers, fractions, and decimals on a number line and perform addition and subtraction on the line
  - calculate addition and subtraction involving time; however, the calculation of time zone differences is excluded
  - measure length, angle, area, and volume and convert them between different units
  - solve two-step application problems in everyday scenarios, showcasing practical mathematical skills
- Relation
  - solve a two-step problem by converting it into a single expression using the rules of the four arithmetic operations
  - express simple equations verbally or in written form
  - observe and reason about number patterns in two-dimensional tables and figures
- Space and Shape
  - identify two-dimensional geometric figures and their properties through angles and sides
  - calculate squares' and rectangles' area and perimeter
  - identify the congruence of plane figures
  - identify triangles, quadrilaterals, and circles through their composing constituents
- Data and Uncertainty
  - interpret bar charts and line graphs and make inferences from reading

Eighth-Grade Mathematics Curriculum

In Grade 8, the curriculum introduces more sophisticated mathematical concepts to give students a deeper understanding of Number and Quantity, Algebra, Function, Space and Shape, Coordinate Geometry, and Data and Uncertainty. Students are expected to acquire the following knowledge and skills described in the mathematics curriculum in Grade 8:

- Number and Quantity
  - understand the concept of a square root, including its symbols, simplifying radical forms, and finding the approximate value of the square root with a calculator
  - identify patterns in sequences (arithmetic and geometric sequence) and apply the summation formula for arithmetic series to solve problems
- Algebra
  - perform the four operations of polynomials, including the multiplication of two binomials and the factorization of a second-degree polynomial
  - solve a quadratic equation with one unknown using factorization and completing the square

- Function
  - understand the concept of a function, the constant function, and the linear function, and draw graphs of constant functions and linear functions
- Space and Shape
  - solve problems involving various relationships between two angles and polygons' interior and exterior angles, including the sum of interior angles in convex polygons and the angle at the vertex of a regular *n*-polygon
  - solve problems involving the properties of perpendicular and parallel relationships between two straight lines and justify the congruence of plane figures, especially triangles
  - apply the Pythagorean theorem to calculate areas of various types of triangles (e.g., equilateral, isosceles, right-angled triangles), special quadrilaterals, and regular polygons
  - apply the basic properties of triangles, squares, rectangles, kites, parallelograms, and trapeziums to solve problems
  - replicate a given plane figure (e.g., a circle, a triangle, a perpendicular bisector, an angle bisector, a parallel line) by straightedge and compass and list the geometrical properties that support geometrical reasoning
- Coordinate Geometry
  - apply the formula for the distance between two points in a rectangular plane coordinate system
  - draw the graph of a linear equation in two unknowns and a unique solution to a simultaneous system of two linear equations in two unknowns
- Data and Uncertainty
  - use statistics to describe or summarize data, including cumulative frequency, relative frequency, and cumulative relative frequency

The Science Curriculum in Primary and Lower Secondary Grades

This section summarizes *Curriculum Guidelines of 12-Year Basic Education for Elementary, Junior High Schools, and General Senior High Schools: Natural Sciences*.[13] The goals of the science curriculum for primary and lower secondary grades include the following:

- offer students ample opportunities for inquiry and problem-solving to develop their scientific inquiry ability
- foster students' comprehension of core scientific concepts and how scientific knowledge is generated
- help students to develop a positive attitude toward science and the nature of science through applying scientific thinking and inquiry ability

The science curriculum's learning objectives are organized not by specific grade levels but by distinct stages. The learning progress for Grades 1 to 12 is divided into five stages: Stage I spans Grades 1 and 2, Stage II covers Grades 3 and 4, Stage III covers Grades 5 and 6,

Stage IV covers Grades 7 to 9, and Stage V covers Grades 10 to 12. Formal science education commences at Stage II. Thus, the science curriculum is designed for Grades 3 to 12. The time allocation for science from Stages II to IV is three sessions per week.

The learning objectives are developed based on dimensions of learning performance and learning content. Learning performance comprises three domains: Inquiry Ability of Scientific Thinking, Inquiry Ability of Problem-Solving, and Attitudes Toward Science and the Nature of Science. Learning content comprises three domains: Composition and Characteristics of the Natural World, Phenomena and Mechanisms of the Natural World, and Sustainable Development of the Natural World.

The science course in primary grades (Stages II and III) is structured based on the principle of domain integration. The course in lower secondary grades (Stage IV) is taught according to four science subjects (i.e., biology, physics, chemistry, and earth science) with at least one cross-subject unit in each semester to implement scientific inquiry and practices. There are three themes suggested by the curriculum guidelines to implement the cross-subject unit: from the atom to the universe, forms of energy, and global climate change and adaptation.

While the science curriculum does not specify learning objectives for each grade in Stage IV, textbooks and instruction have specific focuses at each grade. To elaborate, the primary teaching focus is biology in Grade 7, followed by a shift to physics and chemistry in Grades 8 and 9. In addition to physics and chemistry, Grade 9 places a specific emphasis on earth science.

Fourth-Grade Science Curriculum

This section summarizes the science curriculum at Stage II (Grades 3 and 4) by the dimensions of learning performance and learning content.

Learning Performance

The main goal across Grades 3 and 4 is cultivating students' curiosity and fascination with the natural world. Regarding the domain of Inquiry Ability of Scientific Thinking, the curriculum emphasizes the need for students to develop basic skills in imaging, classifying, and explaining phenomena. Additionally, they are expected to understand causal relations underlying phenomena and simple conceptual models. In terms of the Inquiry Ability of Problem-Solving domain, students are introduced to basic experimental tools and techniques. They are encouraged to raise questions based on their experiences, data collection, reading, thinking, and discussion. They learn to make predictions, observe and record experimental processes and results, organize data by using simple charts, generate arguments based on collected data, report in a simple way, listen to others' reports, and give comments. As for the domain of Attitudes Toward Science and the Nature of Science, students are expected to comprehend the importance of raising questions, innovation, and imagination in scientific inquiry and enjoy the pleasure of pursuing their own ideas through hands-on practices.

Learning Content

The national curriculum does not require topics of science knowledge for each grade in Stage II. However, the textbooks at Grade 4 from different publishers select almost the same topics, and teachers' instruction aligns with the textbook arrangement. Therefore, the topics of the science curriculum included in the Grade 4 textbooks used in academic year 2022–2023 are listed as follows:

- composition and characteristics of the natural world
  - Energy manifests in diverse forms. The sun serves as Earth's primary energy source.
  - Force has three properties: magnitude, direction, and point of action.
  - Water exhibits capillary and siphon phenomena. Water in a connecting tube can be used to measure the horizon. Water can transmit force to move objects.
  - The celestial bodies rise in the east and set in the west. The Moon has waxing and waning phases. The brightness of stars depends on their distance from Earth.
  - Earth's surface comprises various environments with distinct characteristics, such as rock, sand, and soil.
  - External morphology (e.g., animals' head, trunk, and limbs; plants' roots, stems, leaves, flowers, fruits, and seeds) and internal structure of plants and animals are interconnected with their growth, behavior, reproduction, and environmental adaptation.
  - Different environments harbor distinct living organisms.
- phenomena and mechanisms of the natural world
  - Substances or natural phenomena can change under the effect of external factors. Changes vary in speed and restorability.
  - Rocks, sand, and soil in nature vary due to water and wind.
  - Organisms have lifespans and diverse growth processes, and they produce the next generation through reproduction.
  - Force causes changes in objects' shape and the state of motion.
  - When an object vibrates, it generates sound, which propagates via solids, liquids, and gases. Animals communicate with one another through sound.
  - Light travels in a straight line and reflects in a specific direction.
  - Substances can be classified as good or bad electrical conductors. By connecting a battery and wires, a complete circuit can power a light bulb or rotate a motor. Batteries or light bulbs can be connected in series or parallel, depending on the intended use.
  - Temperature affects solubility and the processes of burning, rusting, and fermentation.
  - Flowers and leaves can change color as they come in contact with acidic or alkaline solutions.
  - In the natural world, objects, organisms, and the environment often mutually influence each other.

- sustainable development of the natural world
  - Earthquakes can lead to severe disasters, but proactive preparation and earthquake protection can reduce damage.
  - Human actions, like polluting water and air, negatively affect the environment and living organisms.
  - The survival and well-being of humans rely on a variety of resources provided by nature. Humans should cherish natural resources because they are limited.

Eighth-Grade Science Curriculum

This section summarizes the science curriculum at Stage IV (Grades 7 to 9) by the dimensions of learning performance and learning content.

Learning Performance

Across Grades 7 to 9, students develop proficiency in basic scientific inquiry skills. Regarding the domain of Inquiry Ability of Scientific Thinking, students are expected to properly connect acquired knowledge to observed phenomena and experimental data, categorize collected data by themselves, and make inferences. Moreover, they learn relatively complex models, develop new models, and evaluate the advantages and limitations of models.

In terms of the Inquiry Ability of Problem-Solving domain, students are introduced to technological equipment and resources suitable for them. They learn to formulate pertinent questions and hypotheses, design uncomplicated experiments, collect data systematically, create graphs and tables, and adeptly present their evidence and conclusions. They should be able to identify the reliability and legitimate use of information. They are also expected to understand classmates' inquiry processes and outcomes, pose reasonable questions, offer justified opinions, and suggest potential ways of improvement.

As for the domain of Attitudes Toward Science and the Nature of Science, the curriculum places emphasis on cultivating self-confidence and interest in scientific inquiry and science learning, as well as experiences of sharing the pleasure of discovery in peer groups. Students learn to comprehend that scientific knowledge's certainty varies depending on the context of scientific research. Moreover, students recognize that scientists, regardless of gender, background, or ethnicity, possess qualities such as perseverance, rigor, logic, curiosity, imagination, and desire to know.

Learning Content

The national curriculum does not require topics of science knowledge for each grade in Stage IV. However, teachers teach based on textbooks, and all publishers of the Grade 8 textbooks select the same topics. Below are the topics of the science curriculum in the Grade 8 textbooks used in academic year 2022–2023.

- composition and characteristics of the natural world
  - Fundamental physical quantities include time, length, and mass. Estimation in the measurement of fundamental quantities is based on the minimum scale of the

tool. Derived physical quantities, such as density and volume, are calculated from fundamental quantities.

- An atom is composed of protons, neutrons, and electrons. Atomic and molecular weight are both relative masses.
- Pure substances encompass elements and compounds. The regularity and periodicity in the characteristics of elements can be shown by the periodic table.
- Matter can be viewed as particles and has three states affected by temperature. Matter can be classified as pure substances and mixtures. A pure substance can be identified by its chemical properties. A mixture can be separated by specific procedures (e.g., crystallization, filtration, and simple filter paper chromatography). The concentration of solutions can be expressed by different methods, such as weight-volume percentage and parts per million.
- Elements' properties depend on the arrangement of their atoms. A compound may have isomers, which have the same molecular formula but different atomic arrangements.

- phenomena and mechanisms of the natural world
  - Heat tends to transmit from high temperature to low temperature. The transmission of heat includes conduction, convection, and radiation. After substances are heated, the temperature change depends on the substances' mass and specific heat. Heat can alter the shape and state of a substance.
  - Waves can propagate as longitudinal waves, such as sound, and transverse waves, such as light. Factors such as the medium's property, density, and temperature affect the speed of sound. Sound reflects as it hits a solid object. The human ear can differentiate sounds based on pitch, loudness, and tone. Ultrasound is beyond the range of human hearing.
  - Light travels in a straight line. Factors such as the medium's refractive index and density, temperature, and light frequency affect the speed of light. Light obeys the reflection law and refraction law as it encounters the interface between mediums. The various colors of objects are caused by the absorption and reflection of light in a selective manner.
  - Force can be measured by the change in length of a spring (Hook's law). The resultant force of a balanced object is zero. Friction can be classified into static friction and kinetic friction. A frictional force's magnitude depends on the normal force at the contacting surface and the roughness between the surfaces. The buoyant force on an object equals the fluid's weight it displaces.
  - Pressure is the perpendicular force per unit area on an object's surface. When pressure is applied to a confined fluid, it is transmitted equally in all directions throughout the fluid (Pascal's law). The weight of the air in the atmosphere causes atmospheric pressure.
  - Chemical reaction is the process of rearranging atoms. Chemical reactions are often involved with phenomena such as precipitation, the release of gas, and changes in color and temperature. Mass is conserved in chemical reactions (the conservation law of mass).

- An aqueous solution containing electrolytes can conduct electricity due to the dissociation of the electrolytes into anions and cations. Reactions with ions in aqueous solutions include precipitation, acid-base neutralization, and redox reactions.
- The process of gaining oxygen by a substance is called oxidation, and the loss of oxygen is reduction. Each metal element exhibits a distinct level of activity with oxygen. Material combustion, respiration, photosynthesis, bleach, vitamin E in preserving food, and zinc-copper batteries are all related to oxidation-reduction reactions.
- Acidity and alkalinity result from dissolving metal oxide compounds or nonmetal oxide compounds into aqueous solutions. The acidity and alkalinity of an aqueous solution can be expressed by the pH value, which is measured by universal indicators and pH meters. The product of concentrations of hydrogen ions and hydroxide ions in an aqueous solution is constant as long as the temperature remains constant. The process of acid-base neutralization forms salt and water and releases heat.
- The energy transformation in a chemical reaction occurs in endothermic or exothermic reactions.
- The rate of a chemical reaction is affected by factors such as the nature of the compounds, temperature, concentration, contact area, and catalysts. Chemical reactions are equilibrium reactions. Alterations in concentration, temperature, and pressure can affect the state of chemical equilibrium.
- Organic compounds such as alkanes, alcohols, organic acids, esters, and plastic are found in everyday life. Alcohol and acid react to form ester and water. Oil and alkali react to produce soap and glycerin.

- sustainable development of the natural world
  - Thorough research on sound's characteristics can help prevent noise pollution.
  - Various wastes, such as plastic waste, domestic wastewater, and air and heavy metal pollution, seriously impact our environment. Environmental pollutants affect the growth of organisms.
  - Environmental quality depends on the sustainable utilization of resources and the preservation of ecological equilibrium. Methods like reduction, recycling, reuse, and using green energy can make Earth more sustainable.
  - Environment preservation is the basis for developing human society.

Teacher Professional Development Requirements and Programs

While there is no mandated requirement for professional development among elementary and secondary school teachers, the Ministry of Education and local education bureaus play a pivotal role in encouraging teachers by offering awards to teachers who actively engage in professional development programs.[14] Moreover, teachers may receive a salary increase if they earn an advanced degree through continuing education.[15]

Various ongoing professional development programs and systems are supported by the Department of Teacher and Art Education within the Ministry of Education. Teachers have a range of options for professional development, including workshops, seminars, credit classes, and in-service continuing education degree programs. To enhance teaching quality, the Ministry of Education allocates funding to local education bureaus or schools for activities like open classroom observation and discussions, organizing workshops or seminars tailored to teachers' needs, and establishing teachers' professional learning communities within schools or spanning across multiple schools. Since 2001, the Ministry of Education has been allocating funding for the Science Education Projects in Primary and High School program for mathematics and science teachers. This program offers primary and high school teachers opportunities to improve their teaching ability through conducting research and promoting activities related to teaching materials, pedagogy, assessment, gifted student education, local science teaching materials, and creative science learning activities.[16] In addition, schools can request consultation services from compulsory education advisory groups at local bureaus.[17] These groups provide assistance in designing curriculum, improving teaching skills, or providing teaching resources.

Furthermore, to support new teachers in honing their teaching skills and styles, both the Ministry of Education and local education bureaus hold workshops specifically designed for them.[18] At the school level, there is a mentorship system to provide one-on-one guidance for new teachers, ensuring they have the necessary support to excel in their roles.

Monitoring Student Progress in Mathematics and Science

In Taiwan, student progress in mathematics and science undergoes monitoring at the school, local, and national levels. At the school level, teachers utilize multiple assessments, including paper-and-pencil tests, performance assessments, and learning portfolios, to monitor students' performance.[19] Regarding paper-and-pencil tests, the school conducts two or three schoolwide examinations every semester, and teachers may design quizzes or homework to assess students' progress. Teachers also assess students' skills and thinking processes in mathematics and science through hands-on activities, classroom discussions, oral reports, or conducting an inquiry experiment.

At the local level, local education bureaus only implement mathematics assessments to monitor student progress city- or countywide, without monitoring science. The local education bureau can choose to administer the mathematics assessment in Grades 3 to 8 or only to a specific grade.[20,21]

At the national level, the Ministry of Education also develops screening tests and tests of academic progress for mathematics remedial programs. Students identified as low achievers through the screening test receive remedial instruction. After attending a year of the remedial program, the students undergo a test of academic progress, which helps teachers monitor students' learning progress and determine whether they need to remain in the remedial program.[22] Notably, at Grade 9, all students are mandated to take the Comprehensive

Assessment in May. This assessment is a standard reference test covering Mandarin, English, mathematics, science, and social science. This assessment serves not only as an application requirement for senior high school but also as a tool for the Ministry of Education to evaluate and improve the quality of secondary education.[23] Furthermore, the Ministry of Education implemented the Taiwan Assessment of Student Achievement: Longitudinal Study in i-Generation (iTASAL) in 2023 to monitor students' learning progression across grades in order to establish an evidence base for a new wave of curriculum and policy planning in the future.[24] This survey covers five subjects: Mandarin, English, mathematics, natural sciences, and social science.

Special Initiatives in Mathematics and Science Education

In a steadfast commitment to nurturing a generation proficient and retaining interest in mathematics and science, the Ministry of Education in Taiwan has orchestrated a series of strategic initiatives. For mathematics, the Just Do Math project, initiated in 2004, seeks to kindle students' interest in mathematics.[25] Through comprehensive engagement, including teacher training, material design, and hands-on math camps, the project provides an interactive and stimulating educational experience. To promote scientific inquiry ability, the Ministry of Education has been funding the Project of Improving Elementary and Junior High School Science Experiment Skills since 2014. It provides teachers with opportunities to enhance their experimental skills and pedagogical design abilities in scientific inquiry,[26] and it offers students science experiment camps to foster their interest and confidence in learning science.[27] Since 2015, the Ministry of Education has been subsidizing the Project of Enhancing Primary and Secondary School Science Teachers' Scientific Inquiry Teaching to improve science teachers' competence in teaching scientific inquiry. In order to help teachers implement scientific inquiry teaching, the project requires teachers to attend workshops and form professional development groups with coaches, which includes joint lesson preparation, lesson observation and discussion, and reflection on lessons.[28] Moreover, the Ministry of Education promotes mathematics and science careers through programs such as the National Primary and High School Science Fair[29] and the Young Scientists Development Program Fair.[30] These initiatives offer students opportunities to conduct independent research and collaborate with teachers or experts, fostering a deeper engagement with scientific pursuits.

Aligning with the Curriculum Guidelines of 12-Year Basic Education, students in Taiwan delve into programming tools and Internet usage starting in Grade 4.[31] By Grade 8, they are expected to apply these programming skills in their daily lives.[32] The Curriculum Guidelines of 12-Year Basic Education encourages teachers to integrate technology into various subjects. Recognizing the significance of technological integration, the Ministry of Education has supported schools in acquiring equipment and establishing computer and technology classrooms since 2018[33] and has initiated The Digital Learning Enhancement Plan for Grades 1–12 Students since 2021.[34]

To better support students with special needs, the Ministry of Education has consistently revised The Special Education Act for both students with disabilities and gifted students.[35] In

the latest revised version, the setting of special education classes is extended to kindergartens. To create adaptive learning environments and leverage the benefits of information technology, the Ministry of Education initiated the development of the Adaptive Learning website in 2016, a Teacher Adaptable Teaching Assistance Platform.[36] It uses diagnostic tools to identify students' weaknesses and provide personalized learning paths and interactive learning interfaces that improve their academic achievement, learning interests, and abilities for independent learning.

To reduce the achievement gap between low and high achievers, the Project for Implementation of Remedial Instruction, initially aimed to close the achievement gap between rural and urban students, is now provided for any student with low achievement in mathematics. In addition, the Ministry of Education has sponsored summer camps for students in rural areas to close the achievement gaps between students in urban and rural areas.[37]

Suggested Reading

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