Adv Educ Res Eval, 2025, 6(1): 318-331
DOI: 10.25082/AERE.2025.01.002

REVIEW

Secondary Science Teacher Preparation: A Scoping Review of Challenges, Structures, and Interventions

Benard Chindia[1*] **Sheilla N. Wawire**[1] **Harvey Henson**[1]

[1] STEM Education Research Center, Southern Illinois University, Carbondale, USA

Correspondence to: Benard Chindia, STEM Education Research Center, Southern Illinois University, Carbondale, USA; E-mail: benard.chindia@siu.edu

Received: March 13, 2025;
Accepted: September 8, 2025;
Published: September 15, 2025.

Citation: Chindia B, Wawire SN, Henson H. Secondary Science Teacher Preparation: A Scoping Review of Challenges, Structures, and Interventions. *Adv Educ Res Eval*, 2025, **6**(1): 318-331.
https://doi.org/10.25082/AERE.2025.01.002

Abstract: This scoping review synthesizes literature on secondary science teacher preparation programs across five continents, drawing on 22 peer-reviewed studies. It examines program structures, prevailing challenges, and strategies aimed at addressing science teacher shortages, with a particular focus on rural contexts. The countries represented in the review include the United States, Canada, Germany, China, and others from diverse geographic regions. The findings highlight dominant challenges, including shortages of qualified science teachers, technological, pedagogical, and content knowledge (TPACK) gaps, and limited opportunities for interdisciplinary or transdisciplinary training. Shortages are mitigated through lateral/alternative entry pathways and structured programs offering 3–4-year training, combined with clinical experience to enhance TPACK and meet licensure requirements. Some countries train teachers to teach multiple science subjects and provide incentives through scholarships and higher salaries for those who commit to working in rural schools. These findings offer valuable insights for stakeholders, suggesting adaptable strategies to improve the quality and supply of science teachers and strengthen science education.

Keywords: secondary science, teacher shortage, rural schools

1 Introduction

The quality of teacher preparation greatly determines the performance of new teachers and makes a significant difference not only in the immediate learning outcomes but also in the long-term scientific literacy of society. For this reason, governments and school districts prioritize having classrooms staffed with well-qualified teachers with the recognition that teacher quality significantly influences students' learning and development [1]. Science teacher preparation programs have consequently strived to match this reality by producing new science teachers with a strong foundation in their content and pedagogical skills to support, accelerate, and inspire learning in the 21st-century classroom.

All these efforts to improve science teacher education have, however, been hindered by concerns about the structure of pre-service teacher training programs and their ability to balance teacher supply with quality. A key question is whether these programs effectively address the current demands of science learning. Challenges related to low-quality teaching have often been linked to inadequate training and certification or licensing standards criticized for lacking rigor, breadth, and depth, resulting in many underqualified teachers entering the workforce [1]. Globally, science education faces a critical challenge, with fewer than one-third of secondary students meeting proficiency benchmarks in science, and teachers reporting that they feel underprepared to teach science subjects effectively in many countries [2]. Such trends threaten to widen the global STEM skills gap and underscore the urgent need for stakeholders to examine and strengthen science teacher preparation programs worldwide. Strengthening teacher preparation programs and providing ongoing professional development can equip teachers to deliver high-quality science education, ultimately benefiting students and society. However, even with these steps in mind, examining the full scope of challenges inherent in science education is a crucial step toward understanding the complexity of the problem and finding solutions.

Numerous studies examine secondary science teacher preparation challenges, structures, or policies in isolation within specific countries. However, there are few studies (if any) that adopt a unified analysis, and this review fills the gap by systematically mapping the entire preparation landscape, from problems and designs to contextual solutions, in selected countries across five continents. We selected our research questions to create a logical and comprehensive progression of inquiry by first identifying the dominant challenges to establish a universal problem space. We then mapped the structures of preparation programs to understand how different systems operationalize quality training and finally investigated the specific policies and strategies for mitigating the core issue of teacher shortages and attrition.

This approach is meant to provide stakeholders with evidence-informed, practical strategies that have been adopted to improve the quality and supply of science teachers globally. Stakeholders can tailor their systems by adopting effective methods that have worked elsewhere to enhance the quality and supply of science teachers, ultimately improving science education and achieving a scientifically literate society [3].

Research Questions:

(1) What are the dominant challenges in science teacher preparation programs across different countries?
(2) How are the teacher preparation programs structured to prepare secondary science teachers for effective teaching?
(3) What institutional strategies, Policies, and reforms have been implemented to address the secondary science teacher shortage and attrition?

2 Methods

The current study adopts a scoping review to analyze the literature on secondary science teacher preparation programs across various countries, identifying significant challenges, program structures, and institutional strategies to address teacher shortages and attrition. Following the Joanna Briggs Institute (JBI) guidelines, our review has a global scope, focusing on the available evidence and presenting this evidence through data charting. The review begins by developing an inferred order that details the inclusion and exclusion criteria related to the objectives. We review targeted research questions and outline relevant data extraction methods [4] within the scoping review framework [5].

We defined our inclusion criteria to guide us in deciding what sources to include in the scoping review [4]. Our data analysis followed a thematic analysis approach to uncover themes inherent in the dataset [6]. This approach allowed us to identify and analyze the themes and patterns that emerged from the data and to guide our reporting of the findings.

2.1 Search Strategy

Our approach to gathering full-text resources on secondary science teacher preparation involved a strategic open search in electronic databases such as ERIC and Scopus to ensure comprehensive data collection. We narrowed our focus to peer-reviewed articles using key terms like "*Secondary Science Teacher Education," "Science Education," and "Pre-Service Teacher Education.*" This ensured a comprehensive yet targeted search. Some peer-reviewed articles were downloaded directly from the databases, while others were accessed through the institutional library.

We chose ERIC for its authoritative, education-focused coverage of peer-reviewed content, while Scopus offered a multidisciplinary scope and robust citation indexing. Together, they offered both the depth of subject-specific content and the breadth of cross-disciplinary perspectives needed to examine global trends in secondary science teacher education.

Our research process also involved a manual search, which yielded more articles. In this case, we evaluated the appropriateness of these resources by reviewing titles and abstracts, focusing on the quality of the English language used. This methodological rigor was appropriate to ensure a thorough selection process and yield a broad collection of relevant literature, enhancing the robustness of our study.

2.2 Inclusion Criteria

Based on the broader key terms, such as science teacher education, our search yielded many articles and grey literature. Our inclusion criteria for selecting articles required that the resources:
(1) Are published in English between 2015 and 2024;
(2) Be peer-reviewed;
(3) Focus on secondary science pre-service teachers' preparation programs;

(4) Examine the challenges, secondary science teacher education program structure, or policies and strategies that address teacher shortages and attrition in rural settings.

We focused on Secondary Science Teacher Preparation Programs because developing scientifically literate, self-reliant, and innovative students for future STEM careers depends on the competencies and abilities of their high school science teachers.

2.3 Exclusion Criteria

Our initial search on ERIC and Scopus for Secondary Science Teacher Preparation yielded 2084 resources, consisting of peer-reviewed articles and grey literature. After specifically filtering for peer-reviewed articles, we identified 1678 relevant documents. Further refinement using additional vital terms, such as "Science education," narrowed the selection to 240 articles potentially suitable for our study. To establish an interrater agreement for screening, the first and second authors independently screened the first 24 articles, representing 10% of the peer-reviewed articles identified in the initial stage. We then calculated the interrater agreement by dividing the number of agreements by the total number of articles, obtaining a value of 91%, which was well above the acceptable benchmark of 90% [7].

For all cases of disagreement, we discussed and resolved the issues before screening the remaining search articles. This screening process produced 20 qualifying articles for full-text review. We then reviewed these articles to determine their relevance to secondary science teacher preparation. Ultimately, five articles were excluded because they focused on the attitudes and perceptions of students and teachers in science education [8, 9]. The remaining fifteen articles qualified for inclusion in the present review, as illustrated in Figure 1.

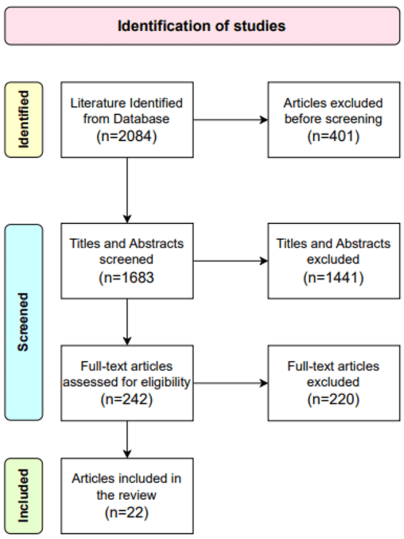

Figure 1 Identification of Studies

2.4 Summary and Data Analysis

We initially summarized each article using a matrix organized by columns with type of study, article name, authors, and journal name. The rows detailed the purpose of the study, findings, and conclusions, providing a comprehensive overview of each research study. We used the research questions to guide us in collating the following information into an Excel sheet for analysis: title of study, country, dominant challenges in secondary science teacher education across different countries (RQ1), structure of teacher preparation programs (RQ2), and strategies or policies addressing science teacher shortage and attrition (RQ3).

We conducted a thematic analysis of the 15 articles to reveal the inherent codes and themes by repeatedly reviewing the data within the Excel sheet to ensure thorough familiarization and extracting relevant insights aligned with our research questions [6]. Through rigorous coding, we identified emergent themes related to our research questions and further refined them through multiple reviews to ensure they aligned with the research goals. This intensive process synthesized findings that directly addressed our research questions and provided valuable insights from the literature, enhancing our understanding of science teacher preparation challenges, program structures, and policy responses.

2.5 Limitations

Most peer-reviewed literature on secondary science teacher programs details various programs offered across different countries. Despite focusing exclusively on the ERIC and Scopus databases, the available literature on secondary science teacher preparation was somewhat limited in scope. Much of the literature explored pre-service and in-service science teachers' perspectives, opinions, self-efficacy, beliefs, and attitudes. Our study specifically emphasized pre-service science teacher preparation programs as part of its inclusion criteria, resulting in a limited number of qualifying articles.

3 Results

The present study investigates critical issues in secondary science teacher education, including the dominant challenges faced in science teacher education across selected countries. We examine how teacher preparation programs are designed to effectively train science teachers and how governments and teacher training institutions address teacher shortages and attrition issues. We categorize results based on research questions, sources, and countries to provide a clear overview of the findings. These results are summarized in Table 1 to offer insights into the structure of teacher preparation programs and the effectiveness of various strategies used to solve the challenges in science teacher education.

Table 1 Charting Summary of Results

Country/Region	Context	Program Duration & Structure	Entry Selectivity	Strengths	Weaknesses	Shortage Strategies	Region Group
Finland, France	High-investment, master's-level model.	5-year master's degree with integrated clinical practice.	High: Rigorous exams and interviews; master's requirement.	Deep PCK integration; high teacher status.	Limited candidate pool; resource-intensive.	N/A (low shortages due to prestige).	[10]
England, Singapore, Germany	Highly structured training.	3–4-year B.Sc. + 1-year PGCE (England); 16-month PGDE or 4-year B.Sc. (Ed) (Singapore).	Moderate: PGCE entry exams (England); stringent interviews/tests (Singapore).	Efficient workforce entry; strong mentorship.	Less pedagogical depth in PGCE (England).	Singapore hires trainees early with salaries; England uses assessment-only routes.	[10–12]
U.S., Canada, Brazil	Large, decentralized systems with flexible pathways.	4-year B.Ed. or alternative routes (e.g., lateral entry). Brazil: 4-year *Licenciatura*.	Low to moderate: GPA 2.5+ (U.S.); entrance exams (Brazil).	Flexibility: addresses shortages quickly.	Variable quality; multidisciplinary licenses risk content gaps.	Lateral entry; underqualified teachers in rural Brazil.	[13, 14]
South Korea, Japan	Highly selective, competitive, with strong cultural respect for teaching.	4-year B.Ed. + competitive exams (Korea); 4-year bachelor's + 1-year certification (Japan).	Very high: Rigorous national exams (Korea); competitive university admission (Japan).	High content mastery; respected profession.	High stress; burnout risk (Korea); aging workforce (Japan).	Korea recruits top graduates; Japan offers rural incentives.	[15]
Russia, Egypt, Morocco	State-centric, with centralized planning.	Russia: 4–5-year specialist degree; Egypt/Morocco: 4-year B.Ed. + 1-year practicum.	Moderate: Entrance exams (Russia, Egypt); decentralized standards (Morocco).	Strong theoretical foundation; government-regulated standards.	Bureaucratic hurdles; theory-practice gap; underfunded practicums.	State-funded placements; in-service training for under-qualified teachers.	[16, 17]
India	Immense scale and unique, multi-tiered structure.	Varied: 2-year B.Ed. after bachelor's or 4-year integrated B.Sc.B.Ed.	Moderate: Competitive entrance exams.	Large scale of training; strong content focus.	Inconsistent quality across institutions; overcrowded programs.	Alternative pathways; para-teachers; scholarship schemes for rural service.	[3, 18]
Middle East (Gulf Cooperation Council, GCC).	Shared economic, linguistic, and cultural context.	4-year B.Ed. common; moving towards PGCE models (e.g., UAE, Qatar).	Moderate to High: Secondary school scores and entrance tests.	Well-funded programs; technology integration.	Cultural/language barriers for expat teachers; gender segregation challenges.	Recruitment of expatriate teachers; incentives for national citizens to enter teaching.	[19, 20]
South Africa (SA)	Relatively advanced infrastructure compared to other Anglophone African nations.	4-year Bachelor of Education (B.Ed.) or 1-year PGCE after degree.	Moderate: National Senior Certificate requirements; program-specific criteria.	Policy-driven reform (e.g., CAPS curriculum); focus on equity.	Severe inequality in resource distribution; high attrition rates.	*Funza Lushaka* bursary program for teaching commitment; recruitment of foreign teachers.	[21, 22]
Anglophone Sub-Saharan Africa (excluding SA)	Low-resource, systemic challenges, and reliance on foreign aid/ colonial heritage.	4-year B.Ed. or 1-year certificate (e.g., Nigeria, Kenya, Malawi).	Low: Resource constraints; minimal science requirements.	Adapts to local needs.	Underqualified teachers, colonial language barriers, and large class sizes.	Incentives (e.g., higher salaries), use of underqualified teachers, and reliance on aid-funded programs.	[17, 21]

Note: Anglophone Africa* included Lesotho, Botswana, Zimbabwe, Ghana, Malawi, Nigeria, Cameroon, Kenya, and Uganda. NCERT: National Council of Educational Research and Training. DHET: South African Department of Higher Education and Training.

The findings highlight various challenges in secondary science teacher preparation across the countries studied. The most common issues included science teacher shortages, insufficient content, pedagogical and technological knowledge, and limited interdisciplinary or transdisciplinary learning opportunities, as illustrated in Figure 2.

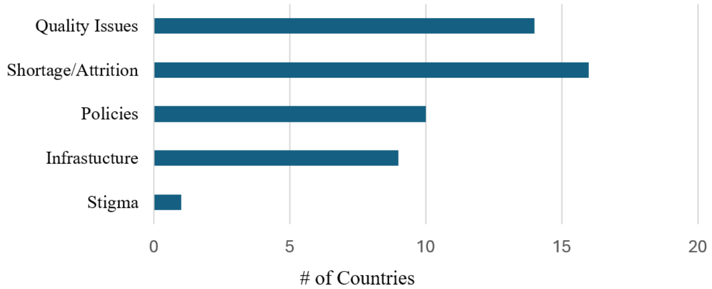

Figure 2 Challenges

Policies concerning recruitment and the structure of science teacher education programs also revealed notable gaps. For example, pre-service teacher admission criteria involved lower standards and minimal science content requirements, with some countries adopting multiple avenues for entry [13, 21, 23]. In North and South America, the lack of rigorous selection for candidates and policies allowing inadequate teacher preparation were noted [13, 14]. Conversely, South Korea's policies emphasize academic testing to ensure teacher quality. Additionally, some African countries face challenges related to colonial language influences, reliance on foreign aid, and inadequate infrastructure for teacher education programs [21]. In Thailand and Australia, science teaching is less attractive to students, resulting in low enrollment in science teacher education courses.

For the second research question, teacher preparation programs were found to span 3 to 5 years of higher education, leading to either a bachelor's or a master's degree. These programs provide both theoretical and practical knowledge for effective secondary school science teaching. However, there are variations in content and experiences across countries. For example, whereas the English model adopts a three-year B.Sc. in Biology, Chemistry, or Physics, followed by one year of training in a Postgraduate Certificate in Education (PGCE), Finland and France require five years of training to earn a master's degree, with an emphasis on applying knowledge. After the first year of pre-service training, teacher trainees are attached to a school and continue their second year of training to complete a master's in education [10].

The bulk of credit hours in teacher preparation programs in most of these contexts are dedicated to content areas, although pedagogical knowledge is also thoroughly covered through courses and classroom practice. The teacher trainees are expected to major in one high school science subject and minor in another, ensuring depth and breadth of knowledge. For instance, if a student's major is physics, they must complete more credits in physics than in their minor subject, with a specific number of credits required in pedagogical knowledge to ensure they are well-prepared for effective teaching. These pedagogical studies are conducted within teacher education units or departments, while content courses are completed in the respective science departments. The pedagogical knowledge requirements for the US and Canadian systems are met through a one-semester general science methods course and two semesters of clinical practice. The clinical practice involves classroom observation and actual teaching supervised by a mentoring teacher and university clinical supervisors, ensuring that pre-service teachers balance theoretical learning with hands-on application to prepare them for effective and independent teaching.

The secondary science teacher training program in China takes 2 to 4 years and includes general, professional, and teacher education courses [24]. Pre-service teachers must complete at least six weeks of supervised teaching practice overseen by two certified supervisors to gain hands-on experience. The African countries we reviewed have adopted a similar model, where secondary school teachers specialize in two science subjects in a 4-year program emphasizing science content, science methods, general education, and supervised teaching practice.

Beyond the requirements relevant to science teaching, pre-service science teachers in China must also take general courses in Art and History to enhance their spirit and literacy in the humanities and instill a sense of patriotism. This comprehensive approach ensures that teachers are well-rounded and culturally aware. However, due to program timeline constraints, these additional demands have been reported to result in insufficient coverage of science content and pedagogical knowledge.

The literature further revealed that many countries manage recruitment and policy decisions centrally, with top-down governance, to address the widespread challenge of teacher shortages. However, the US, Canada, and Finland have decentralized their science teacher education programs and licensure to the state or regional level.

To attract prospective teachers, China, Thailand, and Taiwan incentivize the training by covering tuition and fees for trainees from rural areas, who are then required to teach there for a specified period. In Singapore and Taiwan, trainees are hired at the beginning of their training programs and are committed to teaching upon graduation. Many African countries' strategies to tackle teacher shortages include offering higher salaries to science teachers.

Mozambique and Malawi address teacher shortages by utilizing underqualified teachers, like elementary science teachers, to teach high school science. Some Middle Eastern countries and South Africa, on the other hand, recruit expatriate teachers, while the US, Canada, and other African countries accept minimal science teacher qualifications for entry into teacher education programs and licensure.

Teaching was highly valued in China and South Korea, attracting top high school graduates into teacher education programs. In contrast, this remains a challenge in other countries. Meanwhile, Uganda, Australia, Singapore, and Colombia have implemented policies that require pre-service teachers to be trained in two science subjects.

The results reveal a complex, contextual interplay between policy design, program structure, and local needs in strategies employed to address secondary science teacher shortages and preparation gaps. High-investment systems (Finland and Singapore) leverage on extended training with strong research–practice links to ensure both pedagogical depth and classroom readiness. On the other hand, resource-constrained countries use accelerated pathways, alternative certification routes, or multipurpose teacher training to expand the supply quickly, at the expense of depth in subject mastery.

Incentive structures consistently emerge as effective tools for attracting and retaining science teachers in underserved areas. Additionally, partnerships between universities and schools, mentorship systems, and targeted rural recruitment programs help sustain teacher engagement and professional growth. The interaction of these strategies suggests that no single approach is universally optimal across contexts and that each context should adapt and layer multiple interventions to strike a balance between immediacy and competency.

4 Discussion

4.1 Challenges

The first research question explored the dominant challenges in secondary science education. As shown in Figure 2, the most prevalent challenge was the shortage of qualified science teachers in secondary schools. This study brought to light a global issue of a mismatch between teacher supply and demand, with economically disadvantaged regions the most affected. The significant impact on educational equity is alarming, as students in these marginalized communities are deprived of high-quality science education, perpetuating educational inequalities [25].

4.1.1 Science Teacher Shortage

In North America, the National Association of Credential Evaluation [26] reported a science teacher shortage in all fifty US states and all Canadian provinces, with rural secondary schools being the most affected [13]. In addition to struggling to attract qualified teachers, these schools face significant challenges in retaining those already employed. The high turnover rate, which is often due to factors such as lower salaries, fewer resources, and less support, causes significant disruption. The constant need to replace teachers disrupts the continuity of education and places additional strain on the remaining staff, underscoring the need for stability in education.

This shortage of qualified science teachers can also be understood from the perspective of teachers being licensed to teach subjects in which they were not specifically trained. For instance, the review revealed that more than half of the US states allow teachers to teach subjects they are not licensed in [1]. While many states offer licenses specific to biology, chemistry, and physics, some states permit a teacher licensed in chemistry to also teach physics and biology without having specific licenses in those subjects [13]. This approach (known as multidisciplinary or integrated science teaching), unless specifically designed to train teachers in all science subjects, can deprive students of quality education in areas outside the teacher's primary expertise. Moreover, this strategy does not address the underlying shortage of specialized science teachers but rather masks it by spreading existing teachers thinly across multiple disciplines.

In selected Sub-Saharan African countries, the shortage of science teachers is due to the inability to train and retain qualified science educators in sufficient numbers. A poor infrastructure for science teaching has resulted in a supply that cannot meet the growing demand. Even among the few qualified science teachers, the large class sizes and poor working conditions result in high attrition rates, as the few qualified teachers emigrate to countries with better terms. Additionally, conflicting educational policies and underfunding by successive regimes have exacerbated the problem, leading to insufficient training and employment of science teachers to meet the needs of the large student population [16]. These systemic challenges are worsened by an overreliance on foreign aid from developed nations and former colonial powers, who often impose educational models that do not fit the local infrastructure or context [27]. For example, most former British colonies adopted the British curriculum and use English as a second language for science instruction. Since the teachers are themselves English learners, teaching science in English creates an additional cognitive load in ensuring both language proficiency and science subject comprehension.

In the German system, each of the sixteen states is responsible for its education system, and despite efforts to address educational challenges, a science teacher shortage is rampant across all the states. The shortage has been attributed to the increasingly unattractive teaching career, leading many university students to abandon teaching programs. Consequently, science teacher education programs have seen a decline in enrolments, worsening the teacher shortage situation.

The review revealed a widespread shortage of physics teachers in England and a struggle for schools to attract and retain the few available teachers due to competition from other sectors. Consequently, physics teachers leave the profession for better-paying jobs in industry with attractive working conditions and career progression opportunities. The rigorous demands of the curriculum and the lack of sufficient support and resources further discourage teachers from staying in the profession. This persistent shortage directly impacts the quality of science education and, consequently, student outcomes [10].

Similar trends are observed in Australia, Brazil, Mexico, Taiwan, and Indonesia. Schools in rural areas of Indonesia and Australia face significant challenges in attracting science teachers. Not only are the facilities in these poor and remote regions often inadequate, but access to these schools can be difficult due to their location, forcing students to travel long distances in challenging terrain and conditions to reach their schools [23]. In Taiwan, the situation is equally troubling, with an aging teaching workforce, declining birth rates, and fewer students enrolling in teacher education programs all contributing to a bleak outlook for the future of science education [15].

The evidence across different countries highlights how science teacher shortages create a ripple effect of systemic barriers to quality science education. The outcomes of these shortages are strikingly similar across the board, with reduced access to qualified instruction for students, overreliance on underprepared teachers, and limited opportunities to develop deep scientific understanding. This not only widens educational inequalities within and across regions but also compromises the preparation of students for higher education in STEM disciplines [1, 21, 28].

More broadly, the shortages have long-term implications for national and global development. By weakening the pipeline of future STEM professionals, they risk slowing innovation, reducing workforce readiness, and perpetuating disparities in scientific literacy [2, 25]. The few existing teachers may also be constrained in adopting innovative pedagogical practices or responding to emerging challenges as they are overstretched and under-supported. These findings underscore that addressing the shortage of science teachers is not only a matter of staffing but a critical policy priority for sustaining equitable, high-quality science education worldwide. This creates a vicious cycle where poor science instruction leads to low student achievement and negative attitudes toward STEM, which in turn diminishes the pipeline of future prospective science teachers.

4.1.2 Teaching Readiness

We evaluate the quality and competence of secondary science teachers using the pedagogical content knowledge (PCK) framework by focusing on how well pre-service science teachers are prepared to teach in secondary schools. By examining the integration of these areas, we aim to determine how teachers are admitted, prepared, and licensed to effectively deliver science education and engage students in meaningful learning experiences.

In the US and Canada, policies in some states/provinces allow for inadequate preparation of science teachers. Each state or province sets the minimum qualifications for entry into teacher preparation programs and licensure. This variability, especially for science content requirements, raises concerns about whether many licensed teachers have the necessary science knowledge to engage students effectively [29].

The state of Iowa, for example, allows multidisciplinary science teaching where teachers are required to take coursework across multiple science areas but not as much in any single area as would be required for a license in that area [13]. For instance, a license in chemistry requires 24 credit hours in chemistry. In contrast, a multidisciplinary science license, which allows teaching all secondary science content areas, requires only nine credit hours in chemistry, with the rest spread across physics, biology, and earth science. Although this approach is designed to mitigate teacher shortages, it results in teachers who are not adequately trained, at least in content knowledge, for effective science teaching.

Similarly, from a Pedagogical Knowledge perspective, insufficient pedagogical requirements in distinct subjects have been cited as a significant issue affecting the quality of secondary multidisciplinary science teachers in many US states and Canadian provinces. Most science teachers complete only a one-semester course in science methods and at least a semester of clinical practice [30]. This design often limits the pre-service science teachers' opportunities for in-depth science content and pedagogy courses, resulting in weaker foundational competencies in specific content areas such as science and mathematics [28].

Unsurprisingly, teaching remains unattractive, especially in the African context, leading to the admission of lower-caliber candidates into pre-service science teacher education programs. This, combined with underdeveloped infrastructure, significantly limits the effectiveness of science teacher education programs, ultimately compromising the quality of science teachers who graduate and enter the workforce. In other countries such as England, Finland, Cyrus, Thailand, Malaysia, Argentina, Colombia, Chile, Macau, Turkey, Taiwan, and Indonesia, similar knowledge gaps exist among the teachers for science subjects, compromising the preparedness and competence of graduating science teachers.

Even as the science teacher preparation programs aim to recruit the best teacher candidates, focusing solely on academic excellence by way of testing does not necessarily guarantee high-quality science teachers. In the case of South Korea, the government aims to maintain high standards for teacher preparedness through a rigorous testing process; this emphasis places significant pressure on teachers due to high academic expectations and a competitive exam culture. Consequently, teachers in South Korea are reported to experience high stress levels that have often been linked to increased cases of burnout and mental health issues.

Conversely, the relative lack of rigor in recruiting teacher candidates, as witnessed in Argentina, Colombia, and Chile, presents significant challenges to secondary science education. In such cases, lowering the bar so much may expose the science teacher programs to admitting unqualified candidates who lack the necessary science PCK to teach effectively, negatively impacting the overall educational quality. Furthermore, this inadequacy contributes to a cycle of poor science learning outcomes, perpetuating educational disparities and hindering the development of a robust science education framework [31].

The consequences of inadequate readiness affect both teacher retention and student learning outcomes in low-resource settings and high-income countries, where teacher education may be rigorous but disconnected from classroom realities. Teachers who feel underprepared are more likely to leave the profession early, contributing to cycles of attrition [1]. Similarly, inadequately prepared, less-confident science teachers may contribute to lower engagement and reduced student motivation to learn and pursue science-related fields [32]. This can also, over time, erode students' confidence in their own science abilities and the stereotype threat of science as overly difficult or inaccessible, particularly for underrepresented groups.

4.2 Science Teacher Education Structure

Cross-national comparisons reveal that secondary science teacher preparation program structures are often tightly linked to policy contexts and local needs, meant to balance between depth and expediency. These program structures are to a larger extent shaped by government policies that fund and regulate teacher education, with varying degrees of success in meeting demand. They share a general framework that spans between 3 and 5 years of training, although the depth and balance of content, pedagogy, and practice differ significantly across contexts.

High-investment systems such as Finland, France, and Singapore emphasize extended preparation, often at the master's level, with rigorous entry requirements and strong school–university partnerships. This elevates teacher status and ensures that they enter the profession with robust content and pedagogical preparation, though they are resource-intensive and limited in scalability.

On one end of the spectrum, nations like Finland, France, and South Korea exemplify a high-investment, high-trust model characterized by extended, rigorous training. Their 4-5 year integrated master's programs or highly competitive post-graduate certifications are built on the principle that teaching is a research-informed clinical practice that requires deep pedagogical content knowledge (PCK) and extensive supervised experience [10]. This resource-intensive model produces deeply specialized and highly respected professionals, although it may limit the number of candidates.

Conversely, systems in the United States, Canada, Brazil, and much of Sub-Saharan Africa often employ more flexible, decentralized structures with multiple entry pathways, including 4-year B.Ed. Degrees and alternative certifications. While the flexibility addresses the immediate acute shortages, the variability in content and pedagogical requirements with minimal subject-specific credit hours may raise serious concerns about the depth of teacher preparedness and create uneven quality across regions [13, 14]. Such models, however, risk uneven preparation and may produce teachers lacking sufficient depth in specific science domains.

Systems (England and Singapore) that have developed hybrid models that blend content depth and expediency offer both undergraduate and compressed post-graduate routes that provide flexibility while maintaining stringent entry standards and a strong emphasis on mentorship during practicum [11].

The effectiveness of any structure depends on its ability to balance between ensuring rigorous pedagogical and content preparation and maintaining a sufficient supply of qualified teachers. The most successful systems, such as those in Finland and Singapore, achieve this balance not merely through program length but through the deliberate integration of theory and practice, supported by a culture that values the teaching profession.

4.2.1 Entry Criteria

In order to attract highly qualified entrants into science teacher education programs, a common strategy is to require a minimum examination score for admission to higher education. These exams normally take various forms, including general state examinations, pedagogical and content exams, or personal interviews to assess the preparedness of prospective candidates. Most undergraduate teacher education programs in the US require a minimum GPA of 2.5 for admission, typically starting in the junior year of one's studies [30]. China and Singapore utilize a centralized system of selection, where teacher candidates are selected for higher education and teacher education programs (TEP) based on their performance in the national exam. Qualifying candidates from rural areas in China are enrolled in TEP with tuition and a stipend to cover accommodation, subject to the requirement that they return to their rural homeland to teach for at least ten years upon graduation.

Similarly, prospective teachers in Singapore undergo stringent selection processes, including interviews and tests, before being admitted to the Teacher Education Program. Once selected, they are hired by the Ministry of Education and receive a salary during their pre-service preparation, with a commitment that they will be posted to schools across the country for a service bond of at least three years. South Korea's recruitment of science teachers is highly competitive, with only the best candidates being hired after passing a rigorous employment test, which helps select from the oversupply of graduating teachers.

4.3 Addressing Teacher Shortages

Government or state policies largely shape the teacher preparation curriculum used by institutions within a given territory. These agencies establish minimum requirements for licensure and directly or indirectly regulate the content of science TEPs. As a widespread issue, the secondary science teacher shortage is recognized by both governments and teacher education institutions, which have adopted various strategies, including multiple entry pathways, centralized or decentralized recruitment, higher pay to incentivize science education, and training in multiple science subjects or multidisciplinary teaching. We first examine institutional approaches to addressing the teacher shortage and then highlight government measures to tackle the problem.

4.3.1 Multiple Entry & Certification Pathways

Except for Finland and France, which require a relevant master's degree, most countries have flexible higher education qualifications for teaching secondary school science. Requirements generally range from a bachelor's to a master's degree. For example, in England, prospective teachers complete a three-year B.Sc. in Biology, Chemistry, or Physics, followed by one year of training in a Postgraduate Certificate in Education (PGCE), with a variety of routes to obtaining a Bachelor of Education (B.Ed.) degree [10]. Similarly, prospective science teacher candidates with university degrees in Singapore and Malaysia are enrolled in the 16-month PGDE program, while fresh high school graduates are enrolled in a 4-year Bachelor of Science program.

4.3.2 Lateral Entry

In addition to hiring already retired teachers [33], German state governments address the science teacher shortage by recruiting individuals who have not completed a traditional science teacher preparation program to become certified teachers [34]. These lateral entrants undergo preparatory service and acquire their teaching qualification through a state examination, even without a teaching degree. However, the candidates must have completed a degree in a science field from which two secondary science teaching subjects can be derived. Lateral entrants start teaching immediately while completing educational and subject-related pedagogical content, sometimes alongside the preparatory service.

England, Canada, and the United States employ a similar model to curb science teacher shortages by allowing candidates with extensive classroom experience, such as unqualified teachers or teaching assistants, to obtain Qualified Teacher Status through an assessment-only route while employed in schools, as illustrated in Figure 3. In this pathway, trainees must demonstrate they meet training requirements comparable to the traditional science teacher preparation track. These alternative certification pathways are essential for quickly addressing teacher shortages and bringing diverse experiences into science classroom teaching.

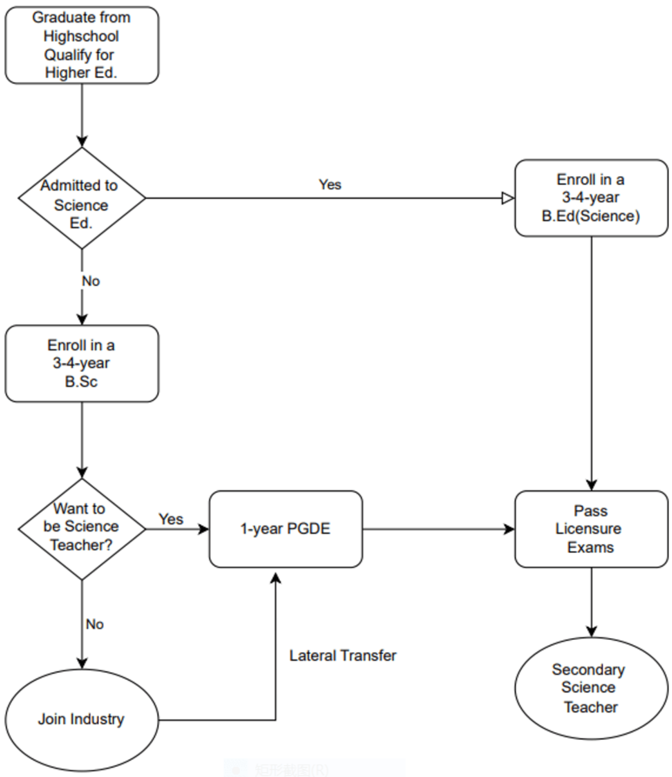

Figure 3 Different Pathways to Science Teacher Education

China, on its part, broadens its pool of science teachers by hiring graduates with degrees in science or natural science disciplines to teach at the high school level [24]. In contrast, Malawi and Mozambique employ underqualified teachers, such as elementary science teachers, to teach high school science [21]. As much as these measures are meant to alleviate the shortages, inadequate content and pedagogical preparation in high school teaching may easily result in quality issues in actual lesson delivery. Consequently, there are concerns about whether teachers recruited through this pathway possess sufficient science content and pedagogical knowledge for effective teaching.

Alternative science certification pathways are usually adopted as a stopgap measure to address science teacher shortages, although their long-term implication on science education quality remain debatable. For rural and underserved schools with acute staffing shortages, alternative certification can provide essential relief, but its long-term impact depends on integrating these teachers into professional learning communities, aligning their pedagogical training with national curricula, and supporting them through context-specific induction programs.

Existing literature suggests mixed long-term effects of this strategy on teacher retention and instructional quality. While teachers entering the profession through this pathway bring industry experience and fresh perspectives to the classroom, they are more likely to exit the profession within the first five years, undermining workforce stability and exacerbating shortages in high-need areas. Countries that use alternative certification pathways typically incorporate robust mentorship programs, structured pedagogical training, and provide opportunities for teachers to engage in ongoing professional development [35]. Singapore and Canada achieve better retention rates and sustained instructional quality due to the structured support provided to these teachers. These findings underscore the need for policy frameworks that strike a balance between addressing immediate teacher shortages and investing in long-term teacher development and professional stability.

4.3.3 Interdisciplinary Science Teaching

Educational programs can better meet the diverse needs of high school science curricula by preparing science teachers to teach more than one subject. This approach has been utilized to maximize the use of available science human resources and alleviate shortages by broadening the scope of teachers' qualifications for varying educational demands [36]. This flexibility allows educational institutions to deploy teachers where they are most needed, thereby improving overall educational efficiency in high school science learning.

In models that employ this strategy in teacher preparation, pre-service teachers are trained to teach two science subjects: one major science subject and one minor. However, this arrangement may often focus heavily on the major subject, leading to under-preparedness for teaching the minor subject due to fewer credits being taken in the minor. For instance, if a student's major is physics, they must complete more credits in physics than in their minor subject, along with a single semester of pedagogical training. This is common in the US and Canada, where minimal preparation for teaching science is permitted and encouraged. In contrast, South Korea, Chile, Finland, France, England, and Taiwan maintain high standards with stringent qualifications for prospective teachers. The lower science content requirements in the US and Canada raise concerns about whether licensed teachers possess a balanced science content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK) in both subjects for effective classroom teaching.

Interdisciplinary training enhances instructional flexibility in contexts with subject-specific teachers and enables educators to competently teach multiple science domains without compromising content depth. This makes interdisciplinary science teaching (IST) a strategic response to systemic staffing and curriculum challenges. IST integration in secondary schools has been attributed to deeper conceptual understanding, transferable skills, and real-world problem-solving abilities. By blending content from biology, chemistry, physics, and earth sciences, IST enables students to see connections across domains, promoting cognitive flexibility and engagement [37].

Recent studies have shown that students exposed to well-designed IST curricula outperform peers in traditional standalone courses in scientific reasoning and application. However, the effectiveness of IST depends on teacher preparation programs that equip educators with broad content mastery, collaborative planning skills, and access to interdisciplinary teaching resources. As global challenges increasingly demand cross-disciplinary STEM solutions, IST offers a promising avenue for improving both student achievement and science literacy [32].

4.3.4 Centralization of Recruitment and Incentivization

Rural schools worldwide have many documented challenges concerned with attracting and retaining qualified science teachers, leading to disparities in educational resources and student outcomes. Xu (2021) [38] highlighted the inadequate financial investment and uneven distribution of educational resources between rural and urban schools as significant obstacles to urban and rural education development. As long as these imbalances persist, rural high schools will remain unable to attract the best talent to teach science in their high schools.

Our review revealed that the countries with centralized recruitment and regulation at the federal level have addressed science teacher shortages relatively better by attracting, evenly distributing, and retaining teachers in rural and marginalized schools. This approach is meant to ensure a fair distribution of the limited number of science teachers, providing all schools, including those in underserved areas, with quality science education. In China, for instance, the federal government fully covers tuition and living expenses for pre-service trainee teachers from rural areas, with the students committing to teach in their rural hometowns for at least ten years upon graduation.

Taiwan and South Africa have a similar model that offers government-funded scholarships with tuition waivers for pre-service teachers who must also teach in rural schools for five years after graduating. This strategy not only alleviates shortages but also guarantees that disadvantaged regions have access to qualified science teachers. Also, these governments try to make science teaching more appealing by offering higher salaries to science teachers compared to their peers in other subjects [21].

5 Conclusion

Secondary science teacher preparation contexts vary widely in the reviewed countries. A persistent challenge across the board is the imbalance between the demand for and supply of teachers, resulting in acute shortages, especially in rural areas. Analyzing these challenges further reveals a complex interconnected cycle, where efforts to resolve one issue create another. For instance, lowering the entry requirements and broadening pathways to attract more teacher candidates and address shortages may inadvertently affect the quality of science teachers entering the profession. On the other hand, enforcing strict entry and licensing criteria to improve the quality of teachers' TPACK could unintentionally exclude qualified candidates and worsen the shortages.

The findings demonstrate that teacher preparation programs, whether through traditional, alternative, or interdisciplinary approaches, play a role in shaping teacher quality in rural and underserved contexts. While no single model universally applies, the evidence highlights common success factors, including strong mentorship, practical teaching experience, interdisciplinary training, and targeted incentives for rural service.

From a policy perspective, governments and education stakeholders need to diversify science teacher preparation and entry pathways to address the shortages. Such measures, however, should be well-structured and supported to accelerate the entry of qualified teachers into classrooms without compromising instructional quality. Embedding professional development and opportunities for progression within the profession should also be a priority to ensure long-term retention and effectiveness. Policymakers should also incentivize service in high-need rural areas through scholarships, housing support, or salary differentials, as seen in several successful examples from other countries.

Finally, interdisciplinary science teaching offers both opportunities and challenges for student learning. Policies should encourage flexible curriculum frameworks and teacher training that equip educators to deliver integrated science instruction in rural settings where subject specialists are scarce. Integrating interdisciplinary approaches with strong content and pedagogical support can help towards deeper conceptual understanding and better prepare students for STEM pathways. Implementation should be guided by ongoing monitoring and research to ensure that these strategies are adapted effectively to local contexts.

Conflicts of Interest

The authors declare that they have no conflict of interest.

References

[1] Ingersoll R. A Comparative Study of Teacher Preparation and Qualifications in Six Nations. Consortium for Policy Research in Education, 2007.

https://doi.org/10.12698/cpre.2007.rb47

[2] UNESCO. Reimagining our futures together: A new social contract for education. United Nations Education. 2021.
https://unesdoc.unesco.org

[3] National Council of Educational Research and Training (NCERT). National Education Policy 2020. Government of India. 2019.
https://www.education.gov.in

[4] Joanna Briggs Institute. The Joanna Briggs Institute Reviewer's Manual 2015: Methodology for JBI Scoping Reviews, The Joanna Briggs Institute. 2015.

[5] Arksey H, O'Malley L. Scoping studies: towards a methodological framework. International Journal of Social Research Methodology. 2005, 8(1): 19-32.
https://doi.org/10.1080/1364557032000119616

[6] Efron SE, Ravid R. Action research in education: A practical guide. Guilford Publications, 2019.

[7] Ekegren CL, Hart MJ, Brown A, et al. Inter-rater agreement on assessment of outcome within a trauma registry. Injury. 2016, 47(1): 130-134.
https://doi.org/10.1016/j.injury.2015.08.002

[8] Ryu M, Mentzer N, Knobloch N. Preservice teachers' experiences of STEM integration: challenges and implications for integrated STEM teacher preparation. International Journal of Technology and Design Education. 2018, 29(3): 493-512.
https://doi.org/10.1007/s10798-018-9440-9

[9] Park S, Jung H. Bridging the Gap: Integrating Theory and Practice for Early Childhood Physical Education Teacher Education in Korea. Sustainability. 2023, 15(19): 14397.
https://doi.org/10.3390/su151914397

[10] Evagorou M, Dillon J, Viiri J, et al. Pre-service Science Teacher Preparation in Europe: Comparing Pre-service Teacher Preparation Programs in England, France, Finland and Cyprus. Journal of Science Teacher Education. 2015, 26(1): 99-115.
https://doi.org/10.1007/s10972-015-9421-8

[11] Tan AL. Journey of science teacher education in Singapore: past, present and future. Asia-Pacific Science Education. 2018, 4(1).
https://doi.org/10.1186/s41029-017-0018-8

[12] Seeliger S, Håkansson Lindqvist M. Dealing with Teacher Shortage in Germany—A Closer View of Four Federal States. Education Sciences. 2023, 13(3): 227.
https://doi.org/10.3390/educsci13030227

[13] Olson JK, Tippett CD, Milford TM, et al. Science Teacher Preparation in a North American Context. Journal of Science Teacher Education. 2015, 26(1): 7-28.
https://doi.org/10.1007/s10972-014-9417-9

[14] Cofré H, González-Weil C, Vergara C, et al. Science Teacher Education in South America: The Case of Argentina, Colombia and Chile. Journal of Science Teacher Education. 2015, 26(1): 45-63.
https://doi.org/10.1007/s10972-015-9420-9

[15] Tuan HL, Lu YL. Science teacher education in Taiwan: past, present, and future. Asia-Pacific Science Education. 2019, 5(1).
https://doi.org/10.1186/s41029-019-0044-9

[16] Fredriksen B, Onsrud SV, Rinholm H, et al. Who takes part in participation? Challenges to empowering student voice in music teacher education. Music Education Research. 2023, 25(3): 253-268.
https://doi.org/10.1080/14613808.2023.2210159

[17] World Bank. Building Better Formal TPD Systems: A Strategic Guide for Policy Makers in Middle East and North Africa. World Bank Group. 2021.
http://documents.worldbank.org

[18] Bhattacharjee J, Sultana T, Roy M. Teacher education in India: Issues and perspectives. Journal of Education and Practice. 2020, 11(15): 38-44.

[19] Wiseman AW, Alromi NH, Alshumrani S. Teacher Quality and Educational Development in the Gulf Cooperation Council Nations. Routledge. 2021.

[20] Alayan S. Education in the Arab World. Bloomsbury Publishing. 2022.

[21] Ogunniyi MB, Rollnick M. Pre-service Science Teacher Education in Africa: Prospects and Challenges. Journal of Science Teacher Education. 2015, 26(1): 65-79.
https://doi.org/10.1007/s10972-014-9415-y

[22] South African Department of Higher Education and Training (DHET). Revised Policy on the Minimum Requirements for Teacher Education Qualifications. Government Gazette No. 38487. 2015.
https://www.dhet.gov.za

[23] Treagust DF, Won M, Petersen J, et al. Science Teacher Education in Australia: Initiatives and Challenges to Improve the Quality of Teaching. Journal of Science Teacher Education. 2015, 26(1): 81-98.
https://doi.org/10.1007/s10972-014-9410-3

[24] Liu E, Liu C, Wang J. Pre-service Science Teacher Preparation in China: Challenges and Promises. Journal of Science Teacher Education. 2015, 26(1): 29-44.
https://doi.org/10.1007/s10972-014-9404-1

[25] Zhao Y. From Deficiency to Strength: Shifting the Mindset about Education Inequality. Journal of Social Issues. 2016, 72(4): 720-739.
https://doi.org/10.1111/josi.12191

[26] National Association of Credential Evaluation Services. National Association of Credential Evaluation Services. 2025.
https://www.naces.org

[27] Goodson IF, Ball S, eds. Defining The Curriculum. Routledge, 2012.
https://doi.org/10.4324/9780203815663

[28] Robinson KA, Perez T, Carmel JH, et al. Science identity development trajectories in a gateway college chemistry course: Predictors and relations to achievement and STEM pursuit. Contemporary Educational Psychology. 2019, 56: 180-192.
https://doi.org/10.1016/j.cedpsych.2019.01.004

[29] Gess-Newsome J, Lederman NG, eds. Examining Pedagogical Content Knowledge. Kluwer Academic Publishers, 2002.
https://doi.org/10.1007/0-306-47217-1

[30] Rhemer DM, Rogers W, Southerland SA. Examining the Influence of Secondary Math and Science Teacher Preparation Programs on Graduates' Instructional Quality and Persistence in Teaching. Education Sciences. 2024, 14(5): 506.
https://doi.org/10.3390/educsci14050506

[31] Alemu M, Tadesse M, Michael K, et al. Pre-service physics teachers' physics understanding and upper primary teacher education in Ethiopia. Bulgarian journal of science & education policy. 2019, 13(2).

[32] Sæleset J, Friedrichsen P. A Case Study of Specialized Science Courses in Teacher Education and Their Impact on Classroom Teaching. Journal of Science Teacher Education. 2021, 33(6): 641-663.
https://doi.org/10.1080/1046560x.2021.1971859

[33] Doil M, Pietzner V. Shine a spotlight on the preparatory service within science teacher education in Germany: A systematic review. European Journal of Science and Mathematics Education. 2023, 11(3): 475-487.
https://doi.org/10.30935/scimath/12980

[34] Bresges A, Dawkins DJ, Del Gobbo G, et al. Second-career teachers and lateral entry programs: the state of the art in England, Germany, and Italy. Pedagogical Perspective for Lifelong Lifewide Guidance. 2023, 25.

[35] Darling-Hammond L, Hyler ME. Preparing educators for the time of COVID … and beyond. European Journal of Teacher Education. 2020, 43(4): 457-465.
https://doi.org/10.1080/02619768.2020.1816961

[36] Arnhold N, Bassett RM. Steering Tertiary Education. World Bank, Washington, DC, 2021.
https://doi.org/10.1596/36328

[37] Lederman JS, Lederman NG, Bartels S, et al. International collaborative follow-up investigation of graduating high school students' understandings of the nature of scientific inquiry: is progress Being made? International Journal of Science Education. 2021, 43(7): 991-1016.
https://doi.org/10.1080/09500693.2021.1894500

[38] Xu Y. The Research of Uneven Educational Resources. Proceedings of the 2021 International Conference on Education, Language and Art (ICELA 2021). Published online 2022.
https://doi.org/10.2991/assehr.k.220131.204