Journal of Computational Intelligence and Decision Analytics

Journal homepage: www.cida-journal.org
eISSN: 3102-6125

Neutrosophic Logic in Education: A Thematic Review of Methods, Applications, and Research Directions

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ARTICLE INFO

Article history:
Received 1 June 2026
Received in revised form 17 July 2026
Accepted 4 September 2026
Available online 13 September 2026

Keywords:
Neutrosophic Logic; Education; Decision-making; Teaching Quality; E-learning; Educational Analytics

ABSTRACT

Neutrosophic logic has increasingly been used in education to represent situations in which evidence, judgments, and outcomes are incomplete, inconsistent, or indeterminate. Yet the literature is dispersed across teacher evaluation, learning management systems, student assessment, curriculum design, institutional strategy, and educational analytics. This review reorganizes the 68 studies in the supplied literature corpus into a coherent thematic structure and examines the principal ways in which neutrosophic concepts have been applied to educational problems. Four methodological families are prominent: neutrosophic multi-criteria decision-making, neutrosophic statistics, graph/soft-set and relation-based models, and intelligent or data-driven educational systems. The main application domains are teacher and teaching-quality evaluation, e-learning and learning-management assessment, student performance and educational guidance, and institutional or curriculum-level decision support. The literature shows a shift from isolated conceptual applications toward hybrid decision models and intelligent educational systems. However, cross-study validation, benchmarking, reproducibility, and evidence of practical deployment remain limited. Future research should emphasize transparent validation, comparative analysis, longitudinal educational data, interpretable hybrid AI-neutrosophic systems, and clearer links between mathematical innovation and measurable educational outcomes.

1. Introduction

Educational decision-making rarely operates with complete and perfectly consistent information. Teacher performance is assessed through multiple perspectives, student outcomes depend on interacting academic and contextual factors, learning technologies are evaluated using both quantitative indicators and subjective judgments, and institutional decisions must often be made despite incomplete evidence. These characteristics make education a natural domain for methods

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that can explicitly represent uncertainty and indeterminacy rather than forcing all information into a single precise value. Neutrosophic logic and neutrosophic sets provide such a representation through three components associated with truth, indeterminacy, and falsity, and they have consequently attracted attention in educational assessment and decision support.

The educational literature considered in this review developed from several different starting points. Early studies explored neutrosophic information processing and decision models [1–3]. The field then moved toward concrete educational applications, including teacher recruitment, school choice, primary-education quality, and learning-management systems. Subsequent research broadened the methodological base through complex and Q-neutrosophic relations, neutrosophic statistics, graph models, dynamic neutrosophic sets, and hybrid multi-criteria decision-making (MCDM) techniques. From 2022 onward, the application spectrum expanded further to teaching-quality evaluation, distance education, smart education, student psychological and academic assessment, university sustainability, curriculum design, personalized e-learning, and hybrid intelligent systems. These developments are examined in detail in the thematic synthesis that follows.

Despite this breadth, the existing manuscript originally presented the literature mainly as a sequence of individual study summaries. That structure makes it difficult to see how the field has evolved, which educational problems receive the greatest attention, which methodological families dominate, and where substantive research gaps remain. The purpose of the present review is therefore to reorganize the same literature corpus into a thematic and methodological synthesis without altering the reference list. The review focuses on three questions: (i) how neutrosophic concepts have been operationalized in educational research; (ii) which educational application domains have been most prominent; and (iii) which methodological and empirical limitations should guide future work.

2. Conceptual Foundations

2.1 Neutrosophy, Neutrosophic Logic, and Neutrosophic Sets

Neutrosophy is a philosophical framework concerned with neutrality and with the coexistence of determinate and indeterminate information. In operational form, neutrosophic logic represents an assessment through a triplet (T, I, F), where T denotes the degree of truth, I the degree of indeterminacy, and F the degree of falsity. In the commonly used single-valued setting, these components are expressed within the interval [0, 1]. A neutrosophic set therefore differs from a conventional crisp set because membership is not reduced to a binary decision, and it differs from many fuzzy formulations because uncertainty is not represented only through a degree of membership; indeterminacy is modeled explicitly as a separate component.

For educational research, this distinction is practically important. Ratings of teaching quality may contain disagreement between evaluators; student behavior may be only partially observed; expert judgments may be linguistically expressed; and institutional indicators may combine reliable data with missing, vague, or contradictory evidence. Neutrosophic representations allow these characteristics to be retained during modeling rather than removed at the data-preparation stage. Early decision-oriented applications illustrate this role in teacher selection and related educational problems [3, 4]. Complex and Q-neutrosophic formulations extend the representation of incomplete and multidimensional information [5, 6], while graph-based educational models provide another route for capturing uncertain relationships [7, 8].

2.2 Why Educational Problems Fit a Neutrosophic Representation

Four recurring features of educational decision problems explain the appeal of neutrosophic modeling. First, many decisions are multi-criteria by nature: teacher recruitment, teaching-quality assessment, university ranking, course or program choice, and sustainability evaluation all require simultaneous consideration of several criteria. Neutrosophic AHP has therefore been used in LMS selection and related evaluation settings [9–11]. TOPSIS-based formulations support lecturer assessment and dynamic educational decision problems [12–14]. Other studies employ MARCOS, DEMATEL, and hybrid decision models for teaching-system assessment and causal analysis [15–17]. More recent work also includes physical-education evaluation and sustainability-oriented applications [18–20]. These methodological variations reflect the same underlying conditions: much of the evidence is subjective, educational systems change over time, and different stakeholders may provide internally inconsistent assessments.

3. Review Scope and Organization

This paper is a structured narrative review of the 68 references contained in the supplied literature corpus. The review does not claim to be a systematic review based on a newly executed database search; rather, it improves the analytical organization of the existing source set. The studies are examined according to publication period, educational application domain, and methodological family. This approach makes it possible to retain the original references while replacing an author-by-author chronology with an integrative synthesis.

The thematic coding used in the review distinguishes four major application domains: (1) teacher selection, teaching-quality evaluation, and academic performance management; (2) learning-management systems, e-learning, distance education, and smart education; (3) student assessment, learning analytics, and educational guidance; and (4) curriculum, institutional strategy, sustainability, and educational management. A second coding dimension distinguishes neutrosophic MCDM models, neutrosophic statistical approaches, graph/soft-set/relation models, and intelligent or data-driven systems. Some studies naturally belong to more than one category, and such overlap is retained because it reflects the hybrid nature of the field.

4. Development of Literature

4.1 Early Foundations and Initial Educational Applications

The earliest contributions in the corpus established the conceptual and computational relevance of neutrosophic reasoning. Arora and Biswas [1] applied neutrosophic ranking ideas to imperfect and heterogeneous information retrieval, while Smarandache and Vlăduţescu [2] discussed a neutrosophic communication-collaboration function in the university context. Kharal [3] then demonstrated a neutrosophic MCDM framework using university teacher selection as an application, helping to connect neutrosophic set theory with educational decision analysis.

From 2014 to 2016, literature moved decisively toward educational applications. Studies examined teacher recruitment and school choice [21, 22], similarity-based decision support [23], primary-education quality through neutrosophic cognitive maps [24], teacher selection [25], and foundational neutrosophic soft functions [4]. A particularly visible cluster addressed learning-management-system evaluation through neutrosophic AHP and related expert-system formulations [9, 26, 27]. A complementary expert-system study further developed this line of work [28]. Faculty teaching evaluation and m-polar graph modeling also appeared during this phase [7, 29]. The common feature of these early applications is the treatment of educational evaluation as a decision problem in which expert judgments and incomplete information must be combined.

4.2 Diversification from 2018 to 2021

The period from 2018 to 2021 broadened both the mathematical tools and the types of educational problems considered. Relation-based approaches were extended through complex and Q-neutrosophic formulations [5, 6]. Student guidance and department selection were modeled with neutrosophic similarity measures [30, 31], while neutrosophic analysis of variance introduced an explicit statistical route for handling imprecise observations in university data [32]. Teaching audit and graph-based educational-system analysis were also developed [12, 33]. Lecturer-performance and research-productivity assessment became additional application areas [13, 34], while dynamic ranking frameworks addressed changing educational decision environments [14, 35].

The same period also marked a transition toward digitally mediated learning. Intelligent microservice architectures and adaptive learning-management systems used neutrosophic theory as part of personalization mechanisms [36]. Student engagement in mathematics [37], sentiment analysis of educational tweets [38], assessment of English teaching systems [15], and evaluation of online-learning adequacy [39] showed that neutrosophic methods were increasingly being coupled with data-driven or computational educational settings. Strategy choice in higher education [40], entrepreneurship competence [41], and neutrosophic regression for student performance [42] extended the application spectrum beyond conventional teaching evaluation.

4.3 Rapid Expansion in 2022-2023

The largest concentration of studies in the supplied corpus appears in 2022 and 2023 (Figure 1). The research themes include causal analysis of teaching quality [16], multilevel teacher evaluation [43], Pythagorean and plithogenic extensions [44, 45], problem-based learning [46], reading-stimulation programs [47], e-learning experiences [48], sports and psychological-health assessment [49], performance gaps between public and private schools [50], ideological and political education quality [51], sustainable distance education [10], personalized exercise recommendation [52], and teaching-quality evaluation under simplified neutrosophic indeterminate information [53].

Digital and smart education also became more prominent. Studies considered digital-education evaluation [54], Internet of Things and Internet of Behavior applications in smart education [55, 56], predictive models for student performance [57], and teaching-learning efficiency using rough neutrosophic sets combined with random forests [58]. At the institutional level, physical-education teaching quality was examined through several decision models [17–19], with EDAS providing an additional formulation [20]. Other studies addressed teaching-modality prioritization [59], university sustainability risk [60], engineering accreditation [61], university ranking [62], curriculum design [63], and project-driven immersion teaching [64]. This diversification indicates that neutrosophic educational research is no longer concentrated on a single decision problem; it is increasingly used as a general uncertainty-handling layer across educational analytics and decision support.

5. Major Application Domains

5.1 Teacher Selection, Teaching Quality, and Academic Performance Management

Teacher- and teaching-related applications form one of the strongest thematic clusters. Early work used neutrosophic MCDM to support teacher recruitment and selection [3, 21, 25]. A later study extended this line to teacher-training candidate selection [11]. Faculty teaching and lecturer-performance assessment were subsequently examined using several neutrosophic decision models [12, 13, 29]. Research-productivity and teaching-quality evaluation broadened the focus from personnel selection to institutional performance [16, 34, 43]. More recent studies further developed teaching-quality assessment through indeterminate and information-entropy-based formulations [53, 61]. The central modeling challenge in this domain is the integration of heterogeneous criteria such as academic qualifications, subject knowledge, teaching competence, research performance, student feedback, and expert judgment. Neutrosophic representations are used to preserve uncertainty in those evaluations and to avoid treating linguistic or incomplete judgments as if they were fully precise.

Physical education has become a particularly active subdomain. One line of work applies 2-tuple linguistic neutrosophic information and generalized aggregation operators to sports-related educational assessment [17, 49]. Other studies use grey relational analysis and taxonomy-based ranking for physical-education teaching quality [18, 19], while EDAS provides an additional group decision-making formulation [20]. Beyond physical education, studies investigate teaching modalities, including blended, flipped, online, and face-to-face learning [59, 65], as well as project-driven immersion teaching in software-engineering education [64]. Collectively, these contributions show that neutrosophic methods are used both for personnel-related decisions and for evaluating the effectiveness of instructional approaches.

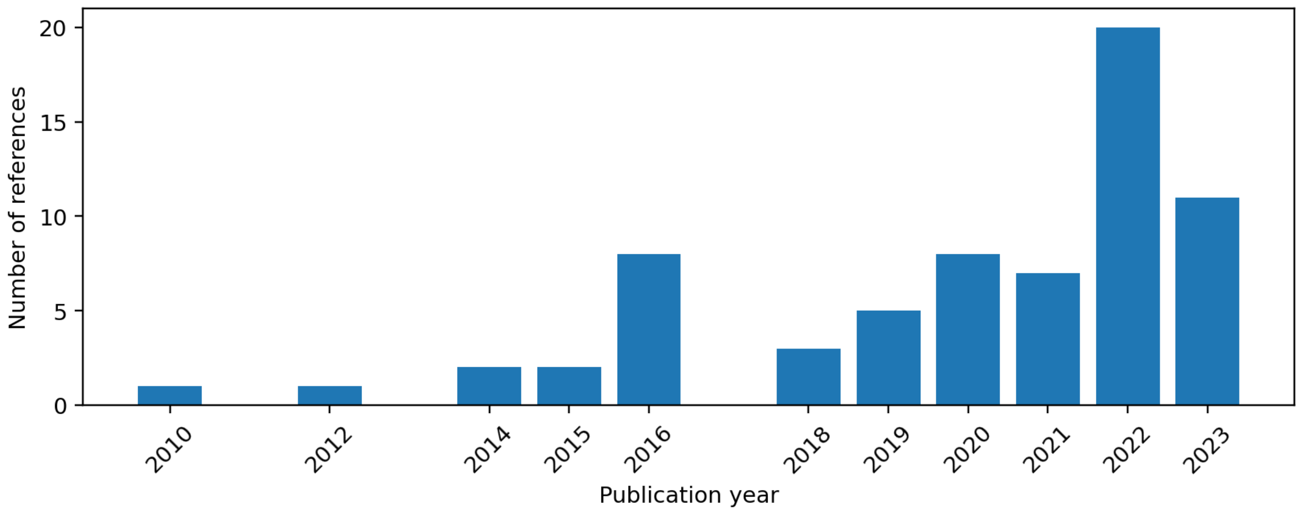

Fig. 1. Distribution of 68 references in the supplied corpus by publication year

5.2 E-Learning, Learning-Management Systems, Distance Education, and Smart Education

A second major cluster concerns technology-mediated education. LMS selection and evaluation were among the earliest sustained applications, particularly through neutrosophic AHP and expert-system models [9, 26, 27]. A related expert-system contribution further developed neutrosophic LMS evaluation [28]. The problem is well suited to neutrosophic analysis because LMS evaluation combines technical features, user perceptions, pedagogical considerations, and uncertain expert assessments. Subsequent work moved beyond platform selection toward intelligent and adaptive e-learning, including microservice-based systems [36], online-learning adequacy assessment [39], and institutional e-learning experiences under uncertain conditions [48].

More recent research treats the learning environment as a dynamic, personalized, and connected system. Sustainable distance education is analyzed from multiple stakeholder perspectives through a neutrosophic AHP-Copeland approach [10]. Personalized exercise recommendation combines cognitive diagnosis with neutrosophic set theory [52], while smart education studies integrate neutrosophic AHP and VIKOR with Internet of Things and Internet of Behavior concepts [55, 56]. Predictive models for future student performance further combine neutrosophic cognitive diagnosis with collaborative-filtering or matrix-factorization ideas [57]. These studies suggest an emerging research direction in which neutrosophic models function as uncertainty-aware components inside larger educational technology architectures.

5.3 Student Assessment, Learning Analytics, and Educational Guidance

Student-centered applications are methodologically diverse. Similarity-based methods have been used to support department or academic-program selection [23, 30, 31], while dynamic neutrosophic TOPSIS models support ranking under changing criteria and alternatives [14, 35]. Neutrosophic statistics have been used to analyze university-student data [32], engagement and attitudes in mathematics [37], educational-program outcomes [47], performance differences between school types [50], and student-performance prediction [42]. These applications show that neutrosophic reasoning is not limited to expert-based decision matrices; it can also be integrated with statistical analysis of educational data.

Other studies address student cognition, affect, and observable behavior. Educational sentiment analysis has been modeled through neutrosophic clustering [38]. Psychological health in sports study has been evaluated with linguistic neutrosophic aggregation [49]. Student competence and ideological or political education quality have been considered through plithogenic and 2-tuple linguistic neutrosophic frameworks [41, 51]. More recent work applies random forests driven by rough neutrosophic representations to infer teaching-learning efficiency from student expressions [58], while neutrosophic assessment is used when teachers are uncertain about the accuracy of student mathematical-skill evaluations [66]. These examples point toward closer integration of neutrosophic modeling with learning analytics and educational AI.

5.4 Curriculum, Institutional Strategy, Sustainability, and Educational Management

At the institutional level, neutrosophic models support decisions that extend beyond individual learners or teachers. Neutrosophic communication and collaboration have been discussed at the university-system level [2], while school-management and educational-system structures have been represented by neutrosophic and interval-valued graph models [8, 33]. Strategy selection in higher education has been formulated as a neutrosophic MCDM problem [40], and university ranking has combined clustering, VIKOR, and interval-valued neutrosophic AHP [62].

Recent contributions add sustainability, risk, curriculum, and efficiency perspectives. University sustainability has been evaluated through FMEA and neutrosophic decision analysis [60]. Curriculum design has integrated text mining, Quality Function Deployment, and single-valued neutrosophic numbers [63]. Plithogenic models have been used for DEA variable selection [67], and Pythagorean/plithogenic extensions have been studied for teaching-method decisions [44, 45]. Together with IoT-based smart-education models [55, 56] and engineering-accreditation evaluation [61], these works demonstrate the potential of neutrosophic reasoning for institutional planning in settings where strategic, technical, pedagogical, and human factors interact.

5.5 Thematic Synthesis

Table 1 summarizes the major application domains and shows that the literature is not homogeneous: the same neutrosophic principle is implemented through different methodological architectures depending on the educational problem.

6. Methodological Patterns

6.1 Neutrosophic Multi-Criteria Decision-Making as the Dominant Family

The strongest methodological pattern is the combination of neutrosophic representations with MCDM. AHP is used for LMS selection, distance-education analysis, and smart-education decision support [9, 10, 55]. Other AHP-based applications address university ranking and teacher-training selection [11, 62]. TOPSIS appears in teaching-modality evaluation, lecturer-performance assessment, and dynamic decision models [13, 14, 21]. It is also used in teaching-quality assessment and project-driven immersion teaching [53, 59, 64]. Other ranking and causal-analysis approaches include VIKOR [56, 62], DEMATEL [16], EDAS [20], and CoCoSo [40, 64]. Grey relational analysis and taxonomy-based ranking provide additional alternatives [18, 19]. Similarity measures and aggregation operators are also widely used to construct educational decision models under uncertainty [12, 23, 30]. Further variants include cosine- and tangent-based similarity, MARCOS, teaching-quality TOPSIS, and multi-attribute formulations [15, 31, 43]. A neutrosophic Q-fuzzy decision setting provides another related extension [68]. Recent work extends these combinations to classroom teaching-quality assessment [17].

Table 1
Major application domains of neutrosophic methods in education

Application domain	Typical educational problems	Dominant methodological patterns	Representative references
Teacher and teaching evaluation	Teacher recruitment; lecturer performance; teaching quality; teaching modality selection	Neutrosophic AHP/TOPSIS; DEMATEL; EDAS; aggregation operators; MCDM hybrids	[3, 25, 29]
E-learning and smart education	LMS selection; online-learning adequacy; distance education; adaptive learning; IoT/IoB education	AHP; expert systems; stakeholder MCDM; cognitive diagnosis; recommendation models	[9, 27, 28]
Student assessment and guidance	Program choice; achievement; engagement; psychological assessment; learning analytics	Similarity measures; neutrosophic statistics; dynamic TOPSIS; clustering; regression; ML hybrids	[23, 30, 32]
Institutional and curriculum decisions	School management; university strategy; sustainability; ranking; curriculum; accreditation	Graph models; VIKOR/AHP; FMEA; QFD; DEA/plithogenic models	[2, 8, 33]

This concentration reflects an important characteristic of educational decision problems: they commonly involve multiple criteria and multiple stakeholders, while the inputs are often linguistic or uncertain. Neutrosophic MCDM models therefore offer a natural way to encode uncertain judgments and produce an ordered set of alternatives. However, the methodological diversity also makes direct comparison difficult. Many studies introduce a new operator or hybrid procedure and demonstrate it on a single educational example, but relatively few compare several neutrosophic methods on the same dataset or evaluate whether the final recommendation is stable under changes in model assumptions.

6.2 Neutrosophic Statistics and Quantitative Educational Analysis

A smaller but conceptually important strand uses neutrosophic statistics rather than decision matrices. Neutrosophic ANOVA is proposed for observations that are imprecise or indeterminate [32], while neutrosophic principal-component analysis is applied to explain performance gaps between private- and public-school students [50]. Neutrosophic multiple regression is used for student-performance prediction [42], and neutrosophic statistical reasoning is applied to evaluate educational interventions such as reading stimulation [47]. These studies are important because they extend the field from expert-based ranking into inferential and predictive analysis.

This statistical direction could be developed further. Educational datasets commonly include missing responses, interval-valued measurements, uncertain coding, inconsistent self-reports, and mixed qualitative-quantitative information. Neutrosophic statistics is potentially relevant to such settings, but future work should provide transparent estimation procedures, uncertainty intervals, diagnostics, and comparisons with conventional robust, Bayesian, fuzzy, or interval-based statistical approaches.

6.3 Graph, Soft-Set, Relation, and Structural Models

Another group of studies develops structural representations rather than primarily ranking alternatives. Neutrosophic soft functions [4], complex and Q-neutrosophic relations [5, 6], m-polar graph models [7], interval-valued fuzzy and neutrosophic graph structures [33], and neutrosophic cubic graphs [8] provide mechanisms for representing relationships among educational entities. These approaches are useful when the problem is relational—for example, modeling interactions among criteria, students, teachers, institutional factors, or management components—rather than merely selecting a best alternative.

The main opportunity for this family lies in connecting mathematically rich structural models with empirically observed educational networks. Many educational systems naturally generate graph data through collaboration, course enrollment, communication, social interaction, or learning-platform traces. Stronger integration with real network data could make neutrosophic graph models more directly interpretable and testable.

6.4 Intelligent and Data-Driven Neutrosophic Educational Systems

The most recent methodological tendency is integration with intelligent systems. Adaptive e-learning architectures use neutrosophic theory to support personalization [36], educational sentiment analysis combines neutrosophic clustering with the Artificial Bee Colony algorithm [38], exercise recommendation combines cognitive diagnosis and neutrosophic similarity [52], and student-performance prediction uses neutrosophic cognitive diagnosis together with collaborative filtering and probabilistic matrix factorization [57]. Rough neutrosophic representations have also been combined with random forests for teaching-learning efficiency analysis [58].

These hybrid models are particularly promising because they move beyond static decision tables and connect uncertainty representation with machine learning. The key methodological challenge is to clarify the role played by the neutrosophic component. Future studies should show whether it improves predictive accuracy, calibration, interpretability, robustness to missing information, or decision quality compared with non-neutrosophic baselines. Without such ablation or comparative analysis, it is difficult to determine whether performance gains come from the neutrosophic representation itself or from the accompanying learning algorithm.

7. Discussion

The literature demonstrates that neutrosophic logic has become a flexible modeling framework for educational problems characterized by incomplete, subjective, and conflicting information. Its main contribution is not tied to one particular educational context. Rather, the same conceptual principle—explicit representation of indeterminacy—has been adapted to teacher selection, teaching-quality evaluation, learning-platform assessment, student guidance, curriculum development, institutional planning, sustainability, and learning analytics. This breadth is one of the field's strengths because it shows that neutrosophic reasoning can operate across multiple levels of the educational system.

At the same time, the synthesis reveals an imbalance between methodological innovation and empirical validation. A substantial portion of the literature is application-driven and demonstrates a newly proposed operator, aggregation rule, similarity measure, or hybrid MCDM model through one illustrative case. Such studies are valuable for showing feasibility, but they do not by themselves establish general superiority. Claims of improved decision quality require stronger evidence through repeated datasets, sensitivity analysis, benchmarking, external validation, or prospective use in real educational decision processes.

A second issue concerns interpretability. Neutrosophic models are often justified because they explicitly model truth, indeterminacy, and falsity, yet the empirical meaning of these components is not always explained in educational terms. For example, indeterminacy may arise from missing data, evaluator disagreement, ambiguous linguistic judgments, uncertain measurement, temporal variability, or conflicting evidence. These sources are not equivalent. Future work should distinguish them and explain how the selected neutrosophic representation corresponds to the actual data-generating or judgment process.

A third issue is the growing complexity of hybrid models. Combining neutrosophic sets with AHP, TOPSIS, VIKOR, DEMATEL, EDAS, graph models, clustering, recommendation systems, or machine learning can increase modeling flexibility, but it can also introduce many parameters and transformation stages. The value of these hybrids should therefore be demonstrated through transparent workflows, reproducible calculations, robustness checks, and comparison with simpler alternatives. Methodological complexity is justified only when it produces a measurable improvement in decision reliability, predictive performance, interpretability, or practical usefulness.

8. Research Gaps and Future Directions

The reviewed literature suggests several priorities for the next stage of research. First, validation should become more rigorous. Studies should report sensitivity analysis for criterion weights and neutrosophic parameters, robustness of rankings, inter-rater variation, and out-of-sample or cross-institutional validation when data permit. Second, comparative benchmarking should be routine. New neutrosophic models should be compared not only with other neutrosophic variants but also with conventional MCDM, fuzzy/intuitionistic-fuzzy models, probabilistic methods, and modern machine-learning baselines where relevant.

Third, the field needs more longitudinal and real-world deployment studies. Many educational phenomena are dynamic, yet the evidence is often based on a single evaluation exercise. Longitudinal data could test whether neutrosophic models remain stable as student performance, course delivery, technology use, or institutional priorities change. Dynamic neutrosophic approaches already provide a methodological basis for this direction [14, 35], but broader empirical use is needed.

Fourth, integration with educational AI should emphasize interpretability and responsible use. Hybrid systems already demonstrate the potential of neutrosophic modeling for sentiment analysis, recommendation, and prediction [38, 52, 57]. Rough-neutrosophic learning combined with random forests further illustrates its use in behavioral assessment [58]. However, educational decisions can affect learners and staff directly. Future work should therefore report how uncertainty is communicated to users, how algorithmic recommendations are reviewed by humans, and whether the model performs consistently across different learner groups and educational contexts.

Fifth, review methodology itself should become more systematic. As the literature grows, future reviews should use reproducible database search strategies, explicit inclusion and exclusion criteria, duplicate screening, bibliometric mapping, and transparent thematic coding. Such work would complement the present structured narrative synthesis and provide a stronger basis for identifying publication trends, methodological clusters, and underexplored educational domains.

9. Conclusions

Neutrosophic logic has developed into a broad uncertainty-modeling framework for educational decision-making and analytics. Across the 68 references reviewed here, the most prominent applications concern teacher and teaching-quality evaluation, e-learning and learning-management systems, student assessment and guidance, and institutional or curriculum-level decision support. Neutrosophic MCDM is the dominant methodological family, but the literature also includes neutrosophic statistics, graph and relation models, adaptive systems, recommendation approaches, and machine-learning hybrids.

The field has progressed from early conceptual and decision-support applications toward increasingly hybrid and intelligent educational systems. Its future development, however, should be driven less by the introduction of additional mathematical variants alone and more by evidence that neutrosophic modeling improves real educational decisions. Stronger validation, benchmarking, reproducibility, interpretability, and longitudinal testing will be essential for moving from methodological possibility to demonstrable educational value.

Acknowledgement
This research was not funded by any grant.

Conflicts of Interest
The authors declare no conflicts of interest.

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