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From Dissection to Simulation: An Exploratory Scientometric and Methodological Analysis of Anatomy Education Literature

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Abstract

Background and Aim: Anatomy education has expanded beyond cadaver-centered teaching toward simulation-based, digital, and hybrid approaches. However, it remains unclear how the literature is distributed across these modalities and whether they differ in methodological profile and bibliometric visibility. This study aimed to map Scopus-indexed anatomy education literature across dissection-based, simulation-based, and hybrid approaches. **Materials and Methods:** We conducted an exploratory scientometric and methodological analysis of Scopus-indexed articles and reviews retrieved on 14 April 2026. The search combined anatomy-related, medical education-related, and modality-related terms referring to dissection or simulation. Records published from 2000 up to the search date were included. Teaching modality, study design, and outcome type were identified through semi-automated lexical coding of title, abstract, author keywords, and index keywords. Logistic regression models were used to examine associations between teaching modality and methodological characteristics, while citation visibility was examined using a multivariable linear regression model of log-transformed citations per year. **Results:** The final corpus comprised 2116 articles and reviews. After excluding records classified as unclear with respect to teaching modality, 2094 records were included in modality-based analyses. Dissection-based studies were the numerically dominant category, followed by hybrid and simulation-based studies. Simulation-based studies showed higher odds of being experimental than dissection-based studies, whereas both simulation-based and hybrid studies showed higher odds of reporting objective and clinical/procedural outcomes. In the bibliometric model, hybrid studies, reviews, international collaboration, and larger author teams were associated with greater citation visibility. **Conclusions:** The transition from dissection-centered anatomy teaching to digital and mixed approaches appears not only thematic, but also methodological and bibliometric. Simulation-oriented studies were more frequently framed through experimental and outcome-based designs, whereas hybrid studies showed the strongest independent citation visibility. These findings should be interpreted as exploratory mapping signals rather than evidence of comparative pedagogical superiority.



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1. Introduction

Anatomy remains a cornerstone of medical education because it underpins structural understanding, spatial reasoning, and the interpretation of clinically relevant relationships across organ systems [1]. At the same time, anatomy teaching has become increasingly heterogeneous [1,2]. While classic reviews emphasize that cadaveric dissection historically dominated anatomy pedagogy and still retains substantial pedagogical value, later critical reviews have argued that modern anatomy education increasingly relies on multimodal combinations of cadaveric, visual, digital, and systems-based resources rather than any single method alone [1,2].

Cadaveric dissection has traditionally been valued not only for transmitting anatomical knowledge, but also for supporting spatial understanding, three-dimensional reasoning, manual engagement with anatomical variation, and early professional formation through direct encounter with the human body [3,4]. At the same time, its role in contemporary curricula has become increasingly debated. Dissection requires substantial institutional resources, donor availability, laboratory infrastructure, trained personnel, curricular time, and ethical governance; it may also impose emotional demands on students and does not always align easily with short-term measurable learning outcomes [3,4]. These advantages and constraints help explain why the future of dissection has become a central issue in anatomy education and why simulation-based and hybrid approaches are increasingly discussed as complementary rather than purely substitutive strategies.

This pedagogical diversification has accelerated with the expansion of simulation-based and digitally mediated educational tools [5]. Recent systematic reviews and contemporary overviews describe substantial use of virtual reality, augmented reality, virtual dissection, and related three-dimensional tools in anatomy education, often reporting favorable student satisfaction and gains in anatomy learning outcomes [6,7]. At the same time, more recent discussions in the field continue to emphasize that full substitution of cadaveric learning remains contested, and that traditional and digital modalities are increasingly being positioned as complementary rather than mutually exclusive [8,9].

This creates an important meta-research question [10–12]. The current debate is often framed around the relative educational value of dissection and simulation, but much less attention has been given to how the literature itself is structured: whether some modalities are more likely to be studied through experimental designs, whether they more often foreground subjective or objective outcomes, and whether certain modalities achieve greater bibliometric visibility than others. These questions matter because publication growth alone does not necessarily indicate evidentiary maturity, and bibliometric studies are particularly useful for describing growth patterns, thematic direction, and structural correlates of visibility in rapidly expanding research areas [10,13].

Accordingly, this study aimed to examine how literature on anatomy education is distributed across dissection-based, simulation-based, and hybrid approaches, and to explore whether teaching modality is associated with experimental design, outcome reporting, and bibliometric visibility. Rather than estimating comparative effectiveness, the study was conceived as an exploratory mapping exercise intended to identify structural and methodological patterns in the field [14,15]. Scoping-type evidence mapping is specifically recommended when the goal is to characterize the scope of literature, identify knowledge gaps, and determine whether more focused systematic review questions are warranted [16].

2. Materials and Methods

2.1. Study Design

This was an exploratory scientometric and methodological gap analysis [14] of anatomy education literature indexed in Scopus (Elsevier B.V., Amsterdam, The Nether-

lands). The study was designed to map publication patterns, methodological signals, and bibliometric correlates of visibility rather than to synthesize comparative effectiveness between interventions. This approach is consistent with guidance on scoping-type evidence mapping, which is appropriate when the objective is to examine the extent, nature, and characteristics of a body of literature and to identify broad evidence gaps rather than to answer a narrowly defined effectiveness question [14–16].

2.2. Search Strategy and Eligibility

The literature search was performed in Scopus (Elsevier B.V., Amsterdam, The Netherlands) on 14 April 2026. The search combined three conceptual components: anatomy-related terms, medical education-related terms, and modality-related terms referring to dissection or simulation. The final query was restricted to records in final publication stage, document types “article” and “review,” and publication years from 2000 up to the search date, 14 April 2026. The final retrieval yielded 2116 records. The search architecture followed a domain-based logic comparable to established bibliometric workflows, in which carefully structured concept blocks are combined to maximize conceptual coverage while preserving interpretability of the corpus. Terms within each block were selected because they were associated with the corresponding MeSH-derived conceptual domain or represented related concepts within that domain. The complete search strategy is provided in Supplementary Materials File S1, and the exported Scopus dataset used for analysis is provided in Supplementary Materials File S2.

2.3. Data Source and Semi-Automated Coding

The Scopus export was processed as a structured CSV dataset, and records were analyzed using title, abstract, author keywords, and index keywords. To make the analysis feasible for a large exploratory corpus, study characteristics were identified through semi-automated lexical coding using predefined term dictionaries and a context-sensitive negation detector. The coding workflow operationalized five primary variables: teaching modality (dissection, simulation, hybrid, unclear), study design (experimental vs. non-experimental), subjective outcome reporting (yes/no), objective outcome reporting (yes/no), and clinical/procedural outcome reporting (yes/no). This strategy was intended to capture abstract-level methodological signals rather than to replace full-text study appraisal. The rationale for this choice was pragmatic: large-scale bibliometric and mapping analyses often rely on metadata- and abstract-level processing to identify broad structural patterns in a corpus before more focused appraisal is attempted.

Operationally, a record was classified as dissection-based when non-negated cadaveric or dissection-related terms appeared in the title, abstract, author keywords, or index keywords. These terms included cadaver, cadaveric, dissect, prosect, microdissect, anatomical dissection, anatomy laboratory, gross anatomy laboratory, and plastination-related terms. A record was classified as simulation-based when non-negated simulation or digital-technology terms appeared, including simulation, virtual reality, augmented reality, mixed reality, virtual dissection, three-dimensional models, anatomy tables, haptic tools, digital platforms, interactive tools, computer-assisted resources, virtual anatomy, and digital anatomy. Records were classified as hybrid when both dissection-related and simulation-related term families appeared without negation in the same record. Records without sufficient modality-related evidence were classified as unclear.

Study design was classified as experimental when non-negated terms indicating intervention, allocation, randomization, trial design, pre-test/post-test structure, control groups, or before-and-after comparisons were detected. Reviews were classified as non-experimental. Subjective outcomes were identified through terms related to perception, sat-

isfaction, attitudes, preferences, confidence, feedback, self-report, or Likert-type measures. Objective outcomes were identified through terms related to scores, academic performance, retention, accuracy, examination performance, OSPE/OSCE, task performance, error rates, spatial ability, grades, or other performance indicators. Clinical/procedural outcomes were identified through terms related to clinical skills, procedural accuracy, surgery, operative performance, technical skills, clinical application, or transfer to clinical practice. When a clinical/procedural outcome was identified, the record was also coded as reporting an objective outcome.

No standardized questionnaire or participant-reported instrument was used, because the study did not collect primary data from students, teachers, or institutions. All variables were derived from bibliographic metadata and semi-automated lexical coding of Scopus records.

2.4. Variables

Scientometric variables included publication year, document type, number of citations, citations per year, number of authors, open access status, and international collaboration. Citations per year were calculated from total Scopus citations divided by years since publication. Number of authors was derived from author fields in the export. International collaboration was operationalized from affiliation-country diversity within each record. Methodological variables included modality, design, and the three outcome categories defined by the semi-automated coding strategy. Hybrid studies were defined as records in which both dissection-related and simulation-related term families appeared without negation in the title, abstract, author keywords, or index keywords. Therefore, hybrid classification should be interpreted as lexical co-occurrence of both modality signals within the available metadata, rather than as full-text confirmation of equal curricular emphasis.

2.5. Statistical Analysis

Descriptive analyses examined annual publication output overall and by modality, as well as modality-specific distributions of methodological characteristics. Pearson's chi-squared tests were used to compare the proportion of experimental studies and the proportion of studies reporting subjective, objective, and clinical/procedural outcomes across modalities.

Binary logistic regression models with a logit link were fitted to estimate whether teaching modality was associated with experimental design, objective outcome reporting, and clinical/procedural outcome reporting. Dissection-based studies were used as the reference category for teaching modality. Publication year was centered to the first included year and entered as a covariate in all logistic regression models. For the models of objective and clinical/procedural outcome reporting, experimental design was included as an additional covariate because outcome reporting may differ between experimental and non-experimental studies. Predictors were entered simultaneously, and no automated stepwise selection procedure was used.

Bibliometric visibility was examined using an ordinary least-squares linear regression model with $\log(1 + \text{citations per year})$ as the dependent variable. Predictors were entered simultaneously and included teaching modality, document type, open access status, international collaboration, number of authors, and centered publication year. The purpose of this model was to identify structural correlates of citation visibility, not to infer educational effectiveness or pedagogical value.

The term "exploratory" refers to the hypothesis-generating purpose of the analyses and not to a distinct statistical procedure. Because this was an exploratory mapping study, no single confirmatory primary hypothesis was prespecified. Therefore, no formal

correction for multiple comparisons was applied. Chi-squared tests and regression models were interpreted descriptively and in relation to effect sizes, confidence intervals, and consistency across analyses rather than as confirmatory hypothesis tests. Accordingly, *p*-values should be interpreted as exploratory signals.

All analyses were conducted in R version 4.4.2 (R Foundation for Statistical Computing, Vienna, Austria) [17]. The full analytic code, including the lexical dictionaries and keyword-based rules used for semi-automated article classification, is available in a Zenodo repository (<https://doi.org/10.5281/zenodo.19690320>). This analytic structure is consistent with standard bibliometric guidance, which recommends combining descriptive performance analysis with explanatory multivariable models when the goal is to move from simple counting toward interpretation of structural correlates of visibility [15,18].

2.6. Reporting Considerations

Because this study relied on a single database and semi-automated abstract-level coding, it should be interpreted as an exploratory mapping of evidence patterns rather than a definitive synthesis of educational effectiveness. In that sense, the study aligns more closely with the objectives of scoping-oriented evidence mapping than with a conventional intervention review, and the full search strategy and raw export were therefore retained as Supplementary Materials to improve transparency and reproducibility.

3. Results

3.1. Baseline Characteristics of Research Output

A total of 2116 Scopus-indexed records met the eligibility criteria. Of these, 22 were classified as unclear with respect to teaching modality and were excluded from modality-based comparative analyses, leaving 2094 records in the analytical corpus. Among these, 1440 (68.8%) were classified as dissection-based, 531 (25.4%) as hybrid, and 123 (5.9%) as simulation-based. Overall, 18.0% of the analytical corpus was classified as experimental, 56.0% reported subjective outcomes, 72.2% reported objective outcomes, and 62.6% reported clinical/procedural outcomes. Median citation count was 7, median citations per year were 1.0, median number of authors was 4, 48.4% of records were published as open access, and 18.6% involved international collaboration (Table 1).

Table 1. General scientometric and methodological characteristics of the corpus according to teaching modality.

Modality	n	Experimental Design (%)	Subjective Outcome (%)	Objective Outcome (%)	Clinical/Procedural Outcome (%)	Median Citations	Median Citations per Year	Median Authors	Open Access Rate (%)	International Collaboration Rate (%)
Dissection	1440	16.2	50.9	67.3	57.4	6	1.00	4	46.5	16.3
Hybrid	531	17.7	67.4	81.7	71.9	9	1.83	5	53.3	24.7
Simulation	123	39.0	65.9	87.8	82.9	5	1.00	5	50.4	18.7
Total	2094	18.0	56.0	72.2	62.6	7	1.00	4	48.4	18.6

When stratified by modality, simulation-based studies showed the highest proportion of experimental designs (39.0%), followed by hybrid (17.7%) and dissection-based studies (16.2%). Hybrid and simulation-based studies also showed higher proportions of subjective outcomes (67.4% and 65.9%, respectively) than dissection-based studies (50.9%). A similar gradient was observed for objective outcomes, which were reported in 87.8% of simulation-based studies, 81.7% of hybrid studies, and 67.3% of dissection-based studies. Clinical/procedural outcomes followed the same pattern, with the highest proportion in simulation-based studies (82.9%), followed by hybrid (71.9%) and dissection-based studies

(57.4%). Hybrid studies also showed the highest median citation count [9] and median citations per year (1.83), whereas simulation-based studies showed the lowest median citation count [5]. Median team size was slightly larger in hybrid and simulation-based studies (5 authors) than in dissection-based studies (4 authors) (Table 1).

3.2. Temporal Growth of the Literature

Annual publication output showed a clear long-term increase across the full corpus, rising from 8 publications in 2000 and 16–17 publications per year in 2001–2003 to 115 in 2019, 130 in 2020, 149 in 2021, 151 in 2022, 163 in 2023, 191 in 2024, and 211 in 2025. This pattern indicates a marked acceleration in publication activity from approximately 2019 onward, following a more gradual but sustained growth phase during the preceding years. Because the search was conducted on 14 April 2026, records from 2026 represent only partial-year output and were not interpreted as a complete annual estimate (Figure 1a).

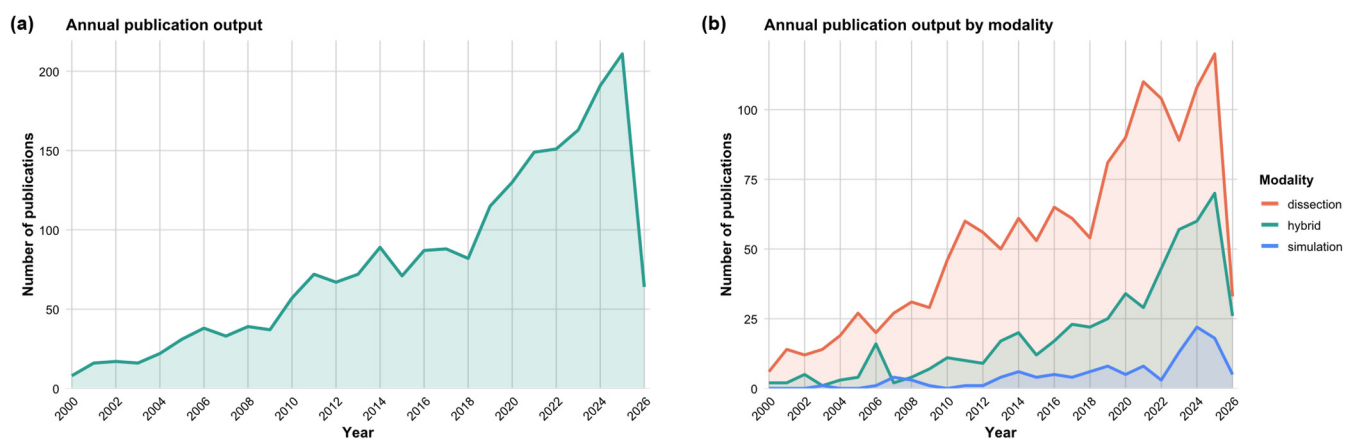


Figure 1. Temporal structure of the corpus. (a) Annual publication output of the full corpus. (b) Annual publication output by modality. Publications from 2026 represent partial-year output up to the search date, 14 April 2026.

When examined by modality, growth was driven primarily by dissection-based and hybrid studies. Dissection-based publications increased from 6 in 2000 to 120 in 2025, remaining the numerically dominant modality throughout the study period. Hybrid studies also showed substantial growth, increasing from 2 in 2000 to 70 in 2025, with a particularly visible expansion after 2019. Simulation-based studies remained less frequent in absolute terms across the whole period, but they also showed an upward trajectory, increasing from 0–1 records per year in the early 2000s to 22 in 2024 and 18 in 2025. Overall, the temporal structure of the corpus suggests that the recent expansion of anatomy education literature has been accompanied not only by continued growth in dissection-based publications, but also by increasing representation of hybrid and simulation-oriented studies (Figure 1b).

3.3. Modality Was Significantly Associated with Methodological Profile

Pearson's chi-squared tests showed that the distribution of methodological characteristics differed significantly according to teaching modality. Significant associations were observed between modality and study design ($\chi^2 = 39.93$, $df = 2$, $p < 0.001$), subjective outcome reporting ($\chi^2 = 48.13$, $df = 2$, $p < 0.001$), objective outcome reporting ($\chi^2 = 56.19$, $df = 2$, $p < 0.001$), and clinical/procedural outcome reporting ($\chi^2 = 58.35$, $df = 2$, $p < 0.001$). These findings indicate that dissection-based, simulation-based, and hybrid studies do not share the same methodological profile.

In proportional terms, simulation-based studies were more likely to be experimental than both hybrid and dissection-based studies (39.0% vs. 17.7% and 16.2%, respectively).

Hybrid and simulation-based studies were also more likely than dissection-based studies to report subjective outcomes (67.4% and 65.9% vs. 50.9%), objective outcomes (81.7% and 87.8% vs. 67.3%), and clinical/procedural outcomes (71.9% and 82.9% vs. 57.4%).

3.4. Simulation-Based Studies Showed Higher Odds of Experimental Design

In exploratory logistic regression, simulation-based studies showed significantly higher odds of being experimental than dissection-based studies (OR 3.15, 95% CI 2.12–4.64, $p < 0.001$), whereas hybrid studies did not differ significantly from dissection-based studies (OR 1.07, 95% CI 0.81–1.39, $p = 0.633$). Publication year showed a small positive association with experimental design in the main model (OR 1.02 per year, 95% CI 1.00–1.04, $p = 0.049$) (Table 2).

Table 2. Exploratory logistic regression models of methodological characteristics according to teaching modality.

Outcome	Predictor	OR	95% CI	<i>p</i> -Value
Experimental design	Simulation vs. dissection	3.15	2.12–4.64	<0.001
Experimental design	Hybrid vs. dissection	1.07	0.81–1.39	0.633
Experimental design	Year	1.02	1.00–1.04	0.049
Objective outcome	Simulation vs. dissection	2.67	1.57–4.86	<0.001
Objective outcome	Hybrid vs. dissection	2.02	1.58–2.60	<0.001
Objective outcome	Experimental vs. non-experimental	2.45	1.81–3.37	<0.001
Objective outcome	Year	1.04	1.03–1.06	<0.001
Clinical/procedural outcome	Simulation vs. dissection	3.03	1.90–5.06	<0.001
Clinical/procedural outcome	Hybrid vs. dissection	1.78	1.43–2.21	<0.001
Clinical/procedural outcome	Experimental vs. non-experimental	1.51	1.18–1.94	0.001
Clinical/procedural outcome	Year	1.04	1.02–1.05	<0.001

Note: Logistic regression models were fitted as binary logistic models with simultaneous entry of predictors. Dissection-based studies were the reference category for teaching modality. Odds ratios and 95% confidence intervals are shown. Full model coefficients are provided in the Supplementary Materials.

3.5. Objective and Clinical/Procedural Outcomes Were More Frequent in Simulation-Based and Hybrid Studies

For objective outcomes, both simulation-based and hybrid studies showed higher adjusted odds than dissection-based studies. Simulation-based studies were associated with 2.67-fold higher odds of reporting objective outcomes (OR 2.67, 95% CI 1.57–4.86, $p < 0.001$), while hybrid studies showed 2.02-fold higher odds (OR 2.02, 95% CI 1.58–2.60, $p < 0.001$). Experimental studies were also more likely to report objective outcomes than non-experimental studies (OR 2.45, 95% CI 1.81–3.37, $p < 0.001$), and publication year was positively associated with objective outcome reporting (OR 1.04 per year, 95% CI 1.03–1.06, $p < 0.001$) (Table 2).

A similar pattern was observed for clinical/procedural outcomes. Simulation-based studies showed the highest odds relative to dissection-based studies (OR 3.03, 95% CI 1.90–5.06, $p < 0.001$), followed by hybrid studies (OR 1.78, 95% CI 1.43–2.21, $p < 0.001$). Experimental design was also positively associated with clinical/procedural outcome reporting (OR 1.51, 95% CI 1.18–1.94, $p = 0.001$), as was publication year (OR 1.04 per year, 95% CI 1.02–1.05, $p < 0.001$).

Sensitivity analyses restricted to original articles yielded directionally similar results (Supplementary Materials File S3). In this restricted analysis, simulation-based studies remained more likely to be experimental than dissection-based studies (OR 3.98, 95%

CI 2.61–6.05, $p < 0.001$), and both simulation-based and hybrid studies remained more likely to report objective outcomes (OR 2.54 and 2.06, respectively) and clinical/procedural outcomes (OR 2.81 and 1.82, respectively) than dissection-based studies (Supplementary Materials File S3).

Bibliometric Visibility Favored Hybrid Studies, Reviews, and Collaborative Teams

In the exploratory bibliometric model, hybrid studies showed significantly greater citation visibility than dissection-based studies ($\beta = 0.281$, 95% CI 0.208 to 0.354, $p < 0.001$), whereas simulation-based studies did not differ significantly from dissection-based studies ($\beta = 0.059$, 95% CI -0.075 to 0.194 , $p = 0.387$). Reviews were more visible than original articles ($\beta = 0.324$, 95% CI 0.228 to 0.419, $p < 0.001$). International collaboration was positively associated with citation visibility ($\beta = 0.154$, 95% CI 0.071 to 0.237, $p < 0.001$), as was the number of authors ($\beta = 0.023$, 95% CI 0.013 to 0.032, $p < 0.001$). By contrast, a more recent publication year was negatively associated with citations per year ($\beta = -0.018$, 95% CI -0.024 to -0.013 , $p < 0.001$). Open access status was not independently associated with citation visibility ($\beta = 0.042$, 95% CI -0.026 to 0.110 , $p = 0.222$) (Table 3).

Table 3. Exploratory multivariable model of factors associated with bibliometric visibility.

Predictor	Beta (β)	95% CI	<i>p</i> -Value
Simulation vs. dissection	0.059	-0.075 – 0.194	0.387
Hybrid vs. dissection	0.281	0.208–0.354	<0.001
Review vs. article	0.324	0.228–0.419	<0.001
Open access vs. non-open access	0.042	-0.026 – 0.110	0.222
International collaboration vs. single-country publication	0.154	0.071–0.237	<0.001
Number of authors	0.023	0.013–0.032	<0.001
Publication year (centered)	-0.018	-0.024 – -0.013	<0.001

Note: The dependent variable was log-transformed citations per year, computed as $\log(1 + \text{citations per year})$. Predictors were entered simultaneously. Beta coefficients, 95% confidence intervals, and p values are shown. Dissection-based studies, original articles, non-open access publications, and single-country publications were used as reference categories where applicable. Citation visibility should not be interpreted as direct evidence of educational value or pedagogical superiority.

4. Discussion

This exploratory analysis suggests that the anatomy education literature is no longer organized around a simple opposition between cadaveric teaching and digital innovation [1]. Instead, it appears to be structured across three partially overlapping spaces: a numerically dominant dissection-based literature, a smaller but methodologically more intervention-oriented simulation literature, and a hybrid literature that may occupy a particularly visible position in the field. This pattern is broadly consistent with the wider evolution of anatomy education, which has progressively moved from a predominantly dissection-centered model toward multimodal and blended formats [1,2,19]. Earlier reviews already argued that no single anatomy teaching tool is sufficient for modern curricula, and more recent analyses have emphasized that the current debate is less about absolute replacement than about how traditional and digital approaches can be pedagogically integrated [2,20–22].

One of the clearest findings in the present study is that simulation-based papers were more likely to be framed as experimental and more likely to report objective and clinical/procedural outcomes than dissection-based papers. This should not be interpreted as evidence that simulation is inherently superior to dissection. A more cautious interpretation is that simulation-oriented interventions are often introduced as discrete educational tools,

and are therefore more easily evaluated through comparative, pre-post, or performance-based designs. Recent reviews and meta-analyses of immersive virtual reality, augmented reality, and broader digital anatomy tools similarly show that this literature is frequently organized around measurable learning outcomes, usability, and learner perception, even while methodological heterogeneity remains substantial [19,21–23]. Studies of blended anatomy curricula also suggest that technology-enhanced formats can improve satisfaction and selected learning outcomes, but often function best as complements within multimodal teaching rather than as complete substitutes for cadaveric instruction [24,25].

At the same time, the present findings should not obscure the continuing educational value attributed to cadaveric dissection. A growing literature continues to argue that dissection contributes to dimensions of anatomy learning that are not always well captured by short-term performance metrics alone, including professional identity formation, reflection, emotional processing, and embodied understanding of the human body [23,26,27]. Recent empirical work has also shown that even in contemporary environments where virtual resources are widely available, many students still value cadaveric dissection and often prefer integrated or blended formats that preserve hands-on anatomical experience while incorporating digital support [24,26,28]. In that sense, the lower experimental profile of dissection-based studies in the present corpus may reflect differences in how these studies are framed and evaluated, rather than diminished educational relevance.

The hybrid category was particularly informative. In the present corpus, hybrid studies showed substantially higher odds of reporting objective and clinical/procedural outcomes than dissection-based studies, and they also demonstrated the strongest independent bibliometric visibility. One plausible interpretation is that hybrid studies occupy a strategically advantageous middle ground: they preserve the pedagogical legitimacy of cadaveric teaching while simultaneously aligning with demands for curricular modernization, technological integration, and explicit evaluation of educational effects. This positioning may make hybrid studies more citable across both traditionalist and innovation-oriented segments of the anatomy education literature [21,22,24,25]. It may also explain why hybrid studies, rather than simulation-only studies, emerged as the most visible category in the bibliometric model.

The bibliometric results also reinforce the idea that visibility in anatomy education depends on more than thematic novelty. In the adjusted model, simulation-based studies were not independently more visible than dissection-based studies, whereas hybrid studies were. Reviews, international collaboration, and larger author teams were also positively associated with citation visibility. These findings are compatible with broader bibliometric evidence showing that review articles often attract disproportionate citation attention and that collaborative, internationally connected, and larger-team publications tend to achieve wider reach [29–31]. From this perspective, citation visibility in anatomy education appears to depend not only on what modality is studied, but also on how that work is positioned within networks of synthesis, collaboration, and dissemination.

4.1. A Meta-Research Perspective

These findings can also be interpreted from a meta-research standpoint. Research on research is essential because the credibility, efficiency, and usefulness of science depend not only on producing studies, but also on understanding how those studies are designed, reported, cited, and incentivized [11,12]. In the present context, the uneven distribution of design types and outcomes across modalities suggests that the anatomy education literature is not just pedagogically heterogeneous, but also methodologically uneven. Recent contributions have similarly emphasized that scientometrics and meta-research are necessary to identify structural distortions in biomedical fields, especially in contexts characterized

by rapid growth, variable rigor, and potentially inflated visibility signals [13,32–34]. From that perspective, the present study does not simply describe a pedagogical transition from dissection toward simulation and hybrid teaching; it also reveals how certain segments of the field may be more likely to generate evidence that appears decision-ready because it is framed through experimental logic and explicit outcome reporting.

This meta-research lens is particularly relevant for interpreting the apparent advantage of simulation-based studies in methodological terms. A field can look more mature not necessarily because its evidence is stronger in absolute terms, but because its studies are more frequently designed in ways that facilitate measurable effects, clearer endpoints, and greater uptake in the literature [11–13,32–34]. In anatomy education, this may mean that simulation-oriented evidence is more likely to be framed as intervention research [35], while cadaveric or tradition-oriented evidence may continue to capture educational value and broader forms of learning (including humanism, empathy, professionalism, and professional identity formation) that is less easily operationalized in short-term or performance-based metrics [27,36]. This distinction matters for curriculum design: if educational decisions are guided mainly by what is most measurable or most visible, rather than by the full range of educational functions each modality serves, they may be at risk of conflating methodological visibility with pedagogical superiority.

These findings should be interpreted in light of the exploratory design of the study. The corpus was derived from a single database, and modality, design, and outcome categories were identified through semi-automated lexical coding of title, abstract, and keywords rather than through full-text validation. Accordingly, the results should be understood as a mapping of structural and methodological signals in the literature rather than as a definitive appraisal of educational effectiveness or study quality. Nonetheless, this type of exploratory mapping is consistent with the aims of meta-research, which seeks to identify broad evidentiary patterns, structural asymmetries, and reproducibility-relevant signals that can guide more focused future syntheses [11,13,32].

Overall, the main implication of this study is that the transition from dissection-centered anatomy teaching to digital and mixed approaches is not merely technological. It is also methodological and bibliometric. Simulation-oriented studies appear more likely to be produced through experimental frameworks and explicit outcome reporting, whereas hybrid studies appear to achieve the strongest independent citation visibility. Future work should therefore move beyond the question of whether digital tools can replace traditional anatomy teaching and instead ask how different modalities contribute to distinct educational goals, how those goals should be measured, and which combinations of methods generate the most educationally meaningful and methodologically credible evidence.

4.2. Limitations

This study has several limitations. First, the corpus was derived from Scopus only, and therefore does not capture all anatomy education literature, including non-indexed journals, conference proceedings, local educational outputs, or institutional reports. Second, classification was based on title, abstract, author keywords, and index keywords rather than full-text review. As a result, modality, design, and outcome categories should be interpreted as metadata-level methodological signals rather than definitive classifications of the full educational intervention. Third, although negation-sensitive lexical rules were used to reduce false positives, semi-automated coding may still misclassify records, particularly when abstracts use ambiguous terminology or mention dissection or simulation only peripherally. Fourth, citation visibility was measured using citations per year, which partially accounts for publication age but does not fully capture citation half-life, journal visibility, topic popularity, author networks, accessibility, or field-specific citation practices. Therefore,

citation visibility should not be interpreted as equivalent to pedagogical importance or educational effectiveness. Finally, because the analyses were exploratory and involved multiple statistical comparisons, the findings should be interpreted as hypothesis-generating rather than confirmatory.

5. Conclusions

Within this exploratory corpus, anatomy education literature appeared unevenly distributed across dissection-based, simulation-based, and hybrid modalities. Dissection-based studies remained the numerically dominant component of the field, whereas simulation-based studies were more strongly associated with experimental framing and with the reporting of objective and clinical/procedural outcomes. Hybrid studies, in turn, showed the highest independent bibliometric visibility. Taken together, these exploratory findings suggest that the transition from dissection-centered anatomy teaching to digital and mixed approaches may be not only thematic, but also methodological and bibliometric in how evidence is produced, reported, and recognized. Future research should move beyond the question of replacement and instead clarify how different modalities contribute to distinct educational goals and which combinations of methods generate the most meaningful and credible evidence for anatomy education. However, these patterns should be interpreted as structural signals in the literature rather than evidence that any modality is pedagogically superior.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/metrics3030012/s1>, File S1: Complete search strategy. File S2: Scopus export used for the present analyses. File S3: Sensitivity analysis restricted to original articles.

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