Gender and Biomedical Engineering in Higher Education: A Scoping Review

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ABSTRACT

Gender inequalities vary across engineering disciplines. Biomedical engineering (BME), where women are comparatively well represented, offers an opportunity to examine whether numerical representation is accompanied by substantive equality. This scoping review mapped research on gender and BME in higher education, with attention to participation, degree choice, engineering identity, self-efficacy, belonging, specialization, and academic and professional trajectories. Following Joanna Briggs Institute guidance and PRISMA-ScR, searches covered multidisciplinary, education, engineering, and health databases, as well as conference proceedings and doctoral dissertations. Studies had to analyze gender substantively in a BME context; merely reporting sample composition was insufficient. Of 142 records identified, 71 documents representing 68 independent studies met the eligibility criteria. The literature shows that women participate in BME at higher rates than in several other engineering disciplines, but this pattern does not consistently extend to identity, perceived gender–engineering compatibility, belonging, or career expectations. Degree choice reflects interacting family, educational, social, and occupational influences. BME's interdisciplinary character supports identities spanning engineering, science, and medicine, while gendered distinctions may reappear within specializations. Findings across these subjective and professional dimensions are mixed and vary with the construct and setting studied. Evidence is insufficient to conclude that an orientation toward health, care, or social benefit directly explains women's greater participation. The literature is geographically concentrated, predominantly uses binary gender categories, and rarely follows students across educational and professional transitions or examines intersecting inequalities. The review therefore supports an analysis of gender inequality across trajectories rather than enrollment alone. Future research should test explanatory mechanisms in different institutional contexts and assess how educational experiences shape participation, recognition, specialization, and subsequent careers.

Keywords: Gender; Biomedical Engineering; Higher Education; Engineering Identity; Scoping Review.

INTRODUCTION

Persistent gender inequalities in engineering

Women's increasing participation in higher education has not produced an even distribution across STEM disciplines. Engineering remains particularly heterogeneous: representation differs markedly among specialties, which makes aggregate indicators incomplete measures of inequality (Smith, 2011; Suberviola Ovejas et al., 2025). In Colombian graduation data from 2001 to 2018, women accounted for more than half of graduates in biomedical, environmental, and chemical engineering but fewer than 20% in electrical, electronic, and mechanical engineering (Hamid Betancur & Torres-Madronero, 2021). Comparable disciplinary differences have been reported in Canada and the United States (Chesler et al., 2010; Singla et al., 2024).

BME is therefore a useful case for examining horizontal segregation within engineering. Higher enrollment

does not necessarily entail equal recognition, professional identity, or opportunity. Evidence of differences in perceived gender compatibility, self-efficacy, specialization, and career expectations calls for analysis beyond entry into the degree (Miller et al., 2024; Patrick et al., 2021; Szczesny et al., 2023).

The differences among specialties also challenge explanations that locate women's underrepresentation solely in individual interest or aptitude. Fields carry distinct cultural meanings and offer different accounts of what engineers do and who belongs. For example, the Colombian pattern concerns graduates across a national system, whereas evidence from a single Spanish institution describes enrollment in specific programs. These indicators and contexts are not directly interchangeable. Taken together, however, they justify examining both the distribution of students across specialties and the institutional experiences that follow entry. Earlier work on BME also drew attention to differences in representation across undergraduate, graduate, and academic stages (Chesler et al., 2010). These observations warrant analysis of pathways over time without presuming that any movement away from an academic position represents withdrawal from engineering.

The relatively high representation of women in BME does not make it a straightforward exception to gender inequality. On the one hand, the discipline may open routes into engineering for students who would not identify with more narrowly represented specialties. On the other, those students may still encounter cultural definitions of technical competence and occupational legitimacy that circulate throughout engineering. The distinction is important because a discipline can be less segregated in enrollment while maintaining differences in how students imagine their futures. Evidence from BME therefore invites comparisons among specialties at several stages, including first choice, progression, specialization, graduation, and entry into work. The interpretation of any particular percentage depends on the denominator, the educational stage, and the local institutional setting.

Gender, Engineering Identity, Self-Efficacy, and Belonging

Academic and Career Choice In Social Cognitive Career Theory

Social cognitive career theory connects self-efficacy, outcome expectations, interests, and goals with contextual supports and barriers. Gender differences in perceived competence should therefore be examined in relation to socialization and educational experience rather than treated as fixed individual preferences. Studies across STEM report differences in self-efficacy and interest that can persist after accounting for performance (Chan, 2022; Hardin & Longhurst, 2016). For BME, this framework directs attention to how disciplinary meanings and expected career outcomes shape both entry and persistence (Dori et al., 2024).

Self-efficacy describes confidence in carrying out particular tasks, whereas outcome expectations concern the consequences anticipated from pursuing a course of study or career. Both may change as students encounter courses, professional role models, feedback, and barriers. In secondary education, gender differences in STEM self-efficacy have been associated with subsequent differences in interests and aspirations; stronger endorsement of traditional gender roles was associated with larger gaps in one study (Chan, 2022). In higher education, lower self-efficacy or interest among women does not by itself demonstrate lower performance (Hardin & Longhurst, 2016). Applied to BME, this perspective calls for research on the origins of interests and expectations, including how the possibility of working in engineering and medicine is communicated. It also requires attention to differences within groups of women rather than assuming a single pattern of motivation.

Within this account, supports and barriers operate at more than one level. An individual may be encouraged by family members, encounter an accessible professional role model, or learn about routes into medicine and industry. At the same time, stereotyped expectations may affect whether particular skills are attributed to them or whether specific specialties seem socially available. Changes in interests during a degree are consequently compatible with social cognitive career theory rather than a departure from it. A focus on the interaction of beliefs and contexts can help explain why students with similar academic records may develop different ambitions. The review does not use this theory to infer motives from gender alone; it uses the framework to identify relationships that empirical studies could measure and compare.

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Engineering Identity as a Social and Gendered Process

Engineering identity includes both self-identification and recognition by others as a legitimate participant in the profession. It develops through interactions with instructors, peers, curricula, and cultural images of engineering. Historically masculine representations of technical competence can complicate identification even among women already enrolled (Hardtke et al., 2023). BME's links to medicine and life sciences may offer additional forms of identification, but whether these alter gendered recognition requires empirical investigation (Singla et al., 2024).

Studying engineering and identifying as an engineer are distinct processes. A student may meet academic requirements yet still find prevailing images of professional competence difficult to inhabit. Recognition by instructors and peers is therefore analytically important, alongside interest and perceived competence (Patrick et al., 2018). This identity is neither fixed at entry nor independent of educational conditions: encounters with design problems, laboratory work, clinical settings, and interdisciplinary teams may make different versions of engineering visible. The BME case raises a specific question about whether identification with medicine or science supplements an engineering identity, competes with it, or changes the criteria through which students are recognized as engineers. Research in broader STEM populations also links scientific identity with career expectations (Byars-Winston & Rogers, 2019). The BME studies reviewed point to multiple possibilities, so no uniform effect of interdisciplinarity can be inferred.

Social accounts of engineering identity also clarify the difference between formal access and recognition. Admission and successful coursework establish that a student belongs to a program administratively, but everyday interactions may communicate a narrower image of the "typical engineer." Research on women's experiences in engineering describes conflicts between gendered expectations and professional stereotypes, including uncertainty about whether one is seen as competent (Hardtke et al., 2023). BME could provide alternative professional reference points through its connections to health, biology, and medicine, yet these connections might also result in the technical dimension of students' work being undervalued. Determining which outcome predominates requires attention to the language of programs, the distribution of technical roles, and the accounts students give of recognition.

Belonging and the University Experience

Belonging refers to feeling accepted, connected, and recognized within an academic community. It is related to participation and persistence and depends partly on institutional relationships and support (Becerra-Cid et al., 2023; Quezada-Espinoza & Truyol, 2024). In BME, women's responses on several academic dimensions can resemble men's while perceived compatibility between gender and engineering remains lower (Szczesny et al., 2023). Thus, enrollment parity alone cannot establish that students experience the discipline equally.

The experience of belonging is related to the everyday organization of programs, including opportunities for interaction, whose contributions are valued, and which career paths are presented as normal. It should not be treated merely as an individual feeling detached from the learning environment. Research among STEM doctoral students, for instance, connected perceptions of fixed notions of intellectual ability with sexism, lower self-efficacy and belonging, and thoughts about leaving among women (Clark et al., 2021). This broader literature offers a reason to examine institutional culture in BME, while its findings cannot simply be assumed to apply identically to every BME program. Studies within BME are needed to determine how belonging develops in different classrooms, laboratories, and stages of training.

Belonging also helps interpret seemingly contradictory findings. Students may express substantial interest in a discipline while questioning whether their own gender is compatible with the socially dominant image of its practitioners. Conversely, a student who has experienced strong personal support may still observe gendered assumptions elsewhere in the institution. Surveys that measure belonging at a single time point may fail to capture these distinctions. A fuller educational analysis would examine opportunities to participate in discussions and projects, the recognition of academic contributions, relationships with instructors, and access to research and career information. Such variables can identify institutional processes that enrollment numbers alone cannot reveal.

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An Integrated Framework

This review considers two linked phases: choosing BME, shaped by self-efficacy, interests, expectations, and representations of engineering; and studying and continuing in BME, shaped by recognition, identity, belonging, and institutional experience. Together, these dimensions allow gender inequality to be examined across a trajectory instead of at a single point of entry.

The framework does not assume a simple sequence in which choice precedes an otherwise stable educational experience. Students may revise their aims while completing courses, learning about specialties, and meeting professionals. Their sense of belonging may in turn shape the options they regard as attainable. The central empirical issue is whether BME's relatively high representation of women is accompanied by changes in these processes or whether gendered differentiation appears later, within particular technical domains and career routes. The distinction between numerical representation and substantive participation guides the synthesis that follows.

Health, Interdisciplinarity, and Social Benefit in BME

BME combines engineering, life sciences, medicine, and health technologies. This may broaden available professional identities and make the social consequences of technical work more visible (Singla et al., 2024). Other research suggests that communal goals can influence perceptions of STEM careers, but this does not establish that health or care causes women to choose BME (Potvin et al., 2018). Such an explanation also risks treating gendered expectations as innate preferences. Research on women's engineering choices identifies contextual supports and barriers that complicate accounts based solely on individual preference (Mozahem et al., 2019). The review instead examines how institutional contexts and cultural meanings shape choices and subsequent specialization.

Comparative research has shown that engineering specialties may be perceived as more or less appropriate for different genders (Bucak & Kadirgan, 2011). BME's relation to health could make the application of engineering knowledge to human well-being particularly visible, but the perceived purpose of a field is socially constructed and may differ across countries, institutions, and student groups. Some graduates envisage careers in industry, research, medicine, or other health-related settings; the existence of these options also complicates a binary definition of remaining in or leaving engineering (Miller et al., 2024; Singla et al., 2024). The available evidence makes health and social benefit plausible topics for investigation. It does not warrant attributing women's greater enrollment to an intrinsic preference for care.

A Turkish study of 1,163 students found differences in preferences across engineering specialties and in their perceived suitability for women and men: women more often preferred fields including genetic engineering and bioengineering, chemical engineering, environmental engineering, and industrial engineering, while men more often preferred mechanical, civil, and electronic engineering (Bucak & Kadirgan, 2011). These results describe a particular social and educational context and should not be generalized uncritically. They nonetheless illustrate a mechanism that merits study: perceptions of the gender appropriateness of a field can accompany reported preferences. In BME, the coexistence of technical, biological, and health-related meanings may broaden the available descriptions of professional work. Whether this expands opportunity or creates a new form of gender sorting is an empirical question.

The concept of social benefit should likewise be separated from the stereotype of care as a feminine trait. The possibility of applying engineering to health challenges may appeal to students of different genders, and other engineering specialties can also contribute substantially to public welfare. A credible explanation for the particular composition of BME must compare programs and measure motives directly. It should also assess whether the curriculum presents social benefit as central or peripheral and whether perceptions change over the course of study. These distinctions prevent a plausible disciplinary narrative from being mistaken for an established cause of enrollment patterns.

Rationale And Research Questions

Research on gender in BME is dispersed across studies of representation, degree choice, identity, belonging, specialization, and career transitions. A scoping review can integrate this heterogeneous evidence and distinguish established findings from unresolved questions. Its central concern is whether relatively high participation by women coincides with broader equality or with new forms of differentiation within BME.

Prior studies have often considered engineering as a single field or have addressed only one moment of an educational trajectory. This creates two problems for interpretation. Aggregate measures can obscure substantial differences across engineering specialties, and a cross-sectional account of enrollment cannot reveal how experiences or opportunities develop after admission. BME is a strategic setting for examining these limits because its comparatively high participation by women permits a more precise question: what forms of gender inequality can remain where access is less visibly unequal? The review therefore brings together descriptive, sociocognitive, educational, and structural perspectives. It maps the range of evidence rather than assuming that any one explanatory theory has already been confirmed.

The review addresses six questions: (1) How does women's participation in BME compare with other engineering fields? (2) Which educational, social, and personal factors are associated with degree choice? (3) How do gender differences appear in self-efficacy, identity, recognition, and belonging? (4) What patterns concern persistence, specialization, and subsequent trajectories? (5) How are interdisciplinarity, health, care, and social impact treated in this literature? (6) Which research gaps remain?

METHODS

Study Design

This scoping review mapped heterogeneous quantitative, qualitative, and mixed-methods evidence rather than estimating a pooled effect. It followed Joanna Briggs Institute guidance (Peters et al., 2020) and was reported with reference to PRISMA-ScR.

The design was chosen because the literature addresses different populations, outcomes, and theoretical questions. It includes enrollment and graduation patterns as well as accounts of experiences, identities, and occupational expectations. A conventional meta-analysis would not adequately represent that breadth. The review instead aimed to describe the distribution of research, identify recurring themes and differences, and specify questions that cannot yet be answered. Reporting the search, screening, and extraction stages makes the scope of the synthesis assessable.

Aim and Research Questions

The aim was to synthesize research on gender and BME in higher education across representation, degree choice, educational experience, and academic and professional trajectories. The six questions are specified in Section 2.

Particular attention was paid to whether a greater presence of women in BME coincides with differences in self-efficacy, engineering identity, recognition, belonging, selection of specialties, and plans after graduation. The analysis also considered whether studies tested explanations involving interdisciplinarity, health, care, or social impact. These dimensions were examined together to avoid equating representation with equality or presuming that the same mechanisms operate across all educational contexts.

3.3. Population, concept, and context

The population comprised university students, graduates, and professionals associated with BME or equivalent programs; relevant faculty studies were also eligible. The concept covered gender inequality in participation, choice, identity, self-efficacy, recognition, belonging, specialization, and careers. The context was higher education and its direct transitions to postgraduate study and employment.

The population criterion allowed studies of instructors and other educational actors when their findings directly illuminated student experience. Equivalent program names included bioengineering and medical engineering where their relationship to BME was explicit. The concept required more than a demographic description: gender had to inform a research aim, comparison, analysis, finding, or interpretation. The contextual boundary included undergraduate education and directly related transitions, rather than studies of clinical practice or technology development without an educational or career component.

Eligibility Criteria

Studies had to analyze gender substantively in relation to BME; reporting sample composition alone was insufficient. Eligible sources included peer-reviewed articles, reviewed full conference papers, and doctoral dissertations in English or Spanish, without a lower date limit. Undergraduate and master's theses, abstracts, posters, editorials, and purely clinical or technical studies without a relevant educational connection were excluded. Multiple reports from one investigation were linked and counted as one independent study.

Quantitative, qualitative, and mixed-methods designs were eligible when they provided evidence relevant to at least one research question. Reviewed conference papers were included because conference proceedings are an important venue for engineering education research; doctoral dissertations broadened coverage of work not yet represented in journal databases. Where a dissertation and a later paper substantially shared a sample, aims, and findings, the fuller account served as the primary source and linked publications were retained for traceability. This distinction between documents and independent investigations was maintained throughout the analysis to avoid double counting.

Information Sources

Scopus, Web of Science Core Collection, ERIC, IEEE Xplore, and PubMed/MEDLINE were searched, along with ASEE PEER and the TESEO, ProQuest Dissertations & Theses Global, and DART-Europe dissertation repositories. Reference and, where relevant, citation searches supplemented database retrieval.

The selected sources covered complementary disciplines: multidisciplinary indexing, education, engineering and technology, and biomedical and health sciences. ASEE PEER provided conference literature particularly relevant to engineering education. Dissertation repositories offered additional institutional and international coverage. Backward reference searching was used for included studies, and forward citation searches were undertaken where useful. This combination was intended to reduce the risk of overlooking work because it appeared outside a conventional journal database.

Search Strategy

Searches combined terms for biomedical engineering, gender and gender inequality, and higher education or educational and professional trajectories. An initial Scopus strategy was adapted to each source, including controlled vocabulary where available. Dates, search fields, filters, exact strings, and retrieval counts were documented for each source; no lower publication-date limit was imposed.

The BME block included "biomedical engineering," "bioengineering," and "medical engineering" and relevant variants. The gender block included women, sex, gender, segregation, stereotypes, bias, and disparities. The education block incorporated students, university, curriculum, career, profession, and related terms. Boolean combinations were adapted to the syntax and indexing of each source. Medical Subject Headings were considered in PubMed/MEDLINE, ERIC descriptors in ERIC, and platform-specific fields in IEEE Xplore. Simplified combinations were used in ASEE PEER and appropriate Spanish equivalents were incorporated in TESEO. Complete source-specific strategies are intended for the supplementary search record.

Search Piloting

Known relevant publications were used as sentinel studies to assess retrieval sensitivity. A sample of search results was reviewed to refine overly broad or restrictive terms before definitive searches.

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The pilot also examined whether disciplinary terminology produced irrelevant clinical or technical results and whether broader gender terms recovered educational studies that would have been missed by narrowly phrased queries. Revisions to the search syntax were documented before the final search. This stage was especially pertinent because the same BME programs may be labeled differently across institutions and countries.

Study Selection

After deduplication, titles and abstracts were screened, followed by full-text eligibility assessment with reasons for exclusion recorded. Related dissertations, conference papers, and articles were evaluated for overlap in authorship, samples, context, and findings. Reference-derived records underwent the same process. The selection flow is summarized in Figure 1.

When the title or abstract did not provide enough information for a decision, the record advanced to full-text assessment. Potentially related outputs were not removed as simple duplicates at the first screening stage: overlap was assessed from the underlying investigation, including institution, data collection period, participants, objectives, and results. Each eligible document was traceable to an independent study identifier. The flow diagram distinguishes records identified, duplicates removed, records screened, full texts assessed, documented exclusions, included documents, and independent studies.

Data Extraction

A piloted extraction matrix recorded publication details, geography, population, design, methods, theoretical framing, treatment of gender, and findings relevant to the research questions. Linked publications from the same investigation were extracted jointly with one principal source identified.

The matrix also recorded the composition and size of samples, educational stage, measures or interview approaches, and the treatment of representation, choice, identity, self-efficacy, recognition, belonging, curriculum, specialization, and careers. Categories could be refined during initial extraction, as is appropriate for a scoping review (Peters et al., 2020). The distinction between how a study measured gender and how it explained gender inequality was maintained: a comparative numerical result alone is analytically different from an account grounded in institutional, cultural, or social mechanisms.

Evidence Synthesis

Descriptive synthesis characterized the corpus by publication date, country, source type, population, and design. Thematic synthesis addressed representation, choice, identity and belonging, specialization and trajectories, and health and social benefit. The analysis distinguished descriptive comparisons from social or structural explanations and considered differences among educational contexts.

Themes were developed in relation to the research questions and refined as the corpus was examined. The synthesis compared findings within and across topics while retaining the context of each study; results obtained from different national systems or educational stages were not treated as directly equivalent. Particular attention was paid to whether patterns of higher participation were accompanied by differences in subjective experience or later opportunity. The analysis also recorded conceptual, geographic, demographic, and methodological gaps. It did not assign a single direction or magnitude to heterogeneous findings when the underlying constructs or measures differed.

Critical Appraisal

Methodological quality was not an exclusion criterion. Designs, sampling, measures, analytic approaches, gender operationalization, and attention to nonbinary identities and intersecting inequalities were reviewed to contextualize the findings, without assigning aggregate quality scores.

This appraisal allowed the interpretation to distinguish a broad descriptive data source from a small, context-specific qualitative study without placing them on a common numerical quality scale. It also identified when

gender was operationalized only as a binary administrative variable and when the study considered gender as a social process. Limitations of sampling, instruments, and the fit between research questions and results were used to qualify conclusions, particularly about proposed mechanisms and generalizability.

3.12. Ethics and transparency

This review used previously published or archived documents and involved no direct recruitment or collection of personal data; it therefore did not require informed consent or research ethics committee approval. Searches, screening decisions, reasons for exclusion, and extraction decisions were documented to support transparency and reproducibility.

The final extraction matrix and the record of analytic decisions were retained. Reports arising from the same investigation were linked so their contribution could be traced without inflating the number of studies. The distinction between 71 included documents and 68 independent studies is accordingly reported in the abstract, methods, and results. Any accompanying supplementary material should provide the exact searches and the study-level extraction table so that readers can assess coverage and eligibility decisions.

RESULTS

Identification and Selection

Searches identified 142 records; 31 duplicates were removed, leaving 111 unique records. Title and abstract screening excluded 24, and 87 full texts were assessed. Sixteen were excluded: no substantive gender analysis (n = 5), no specific BME connection (n = 4), exclusively clinical or technical focus (n = 2), ineligible population or context (n = 2), BME results inseparable from other disciplines (n = 1), or insufficient information (n = 2). The final corpus comprised 71 documents representing 68 independent studies after overlapping publications were linked.

Figure 1. Identification and Selection of Studies.

142 records identified → 31 duplicates removed → 111 screened → 24 excluded → 87 full texts assessed → 16 excluded → 71 documents included → 68 independent studies.

Characteristics of the Evidence

BME-specific research was concentrated in North America, particularly the United States and Canada. Evidence from Latin America and Europe was less extensive; a Spanish institutional study and Colombian national graduation data offered informative comparisons (Gómez-Rico et al., 2024; Hamid Betancur & Torres-Madronero, 2021). Studies used surveys, institutional records, interviews, and mixed methods. Much of the work on identity, specialization, and educational experience appeared after 2020, and reviewed engineering education conference proceedings were an important publication source. The geographic concentration limits transferability across university systems.

The U.S. studies covered representation, academic and professional identity, self-efficacy, choice of specialization, curriculum, belonging, and plans after graduation (Cardador et al., 2023; Chan et al., 2025; Chesler et al., 2010; Miller et al., 2024; Patrick et al., 2021). Canadian work included comparisons among engineering programs and qualitative accounts of entry, persistence, and possible movement between engineering and medicine (Harandi et al., 2024; Singla et al., 2024). The Colombian study offered national graduation indicators across specialties, while the Spanish study offered an institutional comparison. These sources differ in population, outcome, and scale and therefore should be read as complementary evidence rather than pooled estimates.

Within Europe, a broader literature addresses gender in engineering or STEM, but relatively few studies isolate BME outcomes. Such work can frame questions about stereotypes, educational support, or persistence without becoming direct evidence about BME. In Spain, the University of Alicante comparison supplies a concrete

indication of relative parity in BME at one institution (Gómez-Rico et al., 2024). Spanish research on engineering persistence, career choice, gendered representations, and STEM role models supplies contextual interpretation, without establishing BME-specific outcomes (González-Pérez et al., 2022; Pablo-Lerchundi et al., 2015; Sáinz et al., 2019, 2020; Verdugo-Castro et al., 2021, 2025). In Latin America, the Colombian graduation analysis provides an important specialty comparison, whereas other regional studies are largely contextual unless their BME findings can be separated (Costa et al., 2024). Keeping this distinction explicit prevents evidence about engineering in general from being presented as evidence about BME in particular.

The methodological mix reflects a field still developing its questions. Surveys and administrative records are useful for comparisons in representation and measured constructs; interviews illuminate how family, disciplinary identities, and anticipated careers are understood by participants. Conference proceedings were retained because several relevant engineering education studies appeared in that format, including work on BME students' educational motivations (Handley et al., 2018). Conversely, general research on gender in STEM or engineering was used as context rather than treated as BME-specific evidence (Cannaerts et al., 2025; Feijóo et al., 2018; Rodríguez-Rodríguez et al., 2019). The uneven geographical coverage remains a major constraint on claims about the field as a whole.

Another feature of the corpus is the relative recency of work on subjective and educational dimensions. Earlier studies addressed participation and the movement of women across educational stages, while studies from approximately 2020 onward investigated postgraduation expectations, disciplinary identity, computing experiences, specialization decisions, and entry and exit narratives (Patrick et al., 2021; Shoaib et al., 2023; Miller et al., 2024; Singla et al., 2024; Springer & Huang-Saad, 2020). This shift broadens the questions that can be asked but has not yet produced a large body of comparable designs. Consequently, even where several studies address "identity" or "belonging," their populations and measures may differ substantially.

Gender composition across engineering specialties

BME consistently showed a higher proportion of women than several traditionally male-dominated engineering fields. In Colombian graduation data, women exceeded 50% in biomedical, environmental, and chemical engineering but remained below 20% in electrical, electronic, and mechanical engineering (Hamid Betancur & Torres-Madronero, 2021). At one Spanish university, women represented approximately 52% of BME students in 2023–2024, compared with 16% in both computer engineering and robotics; these institutional figures should not be generalized nationally (Gómez-Rico et al., 2024). U.S. and Canadian evidence also points to different preferences across specialties (Harandi et al., 2024; Potvin et al., 2018). The pattern indicates horizontal segregation within engineering, even where one program approaches parity.

Differences also appear before the final distribution of graduates. In a U.S. study involving four universities, women reported greater interest in bioengineering or BME than in electrical engineering and computer science and more strongly associated BME with helping others (Potvin et al., 2018). A longitudinal analysis of program preferences at the University of British Columbia found BME among specialties with high participation by women; the introduction of the program coincided with a change in the proportion selecting electrical engineering (Harandi et al., 2024). These findings cannot by themselves establish why preferences arise or whether one program draws students away from another. They do indicate that discipline-specific comparisons are essential.

Interpretation should also consider the cultural meaning attached to specialties. Some engineering fields are presented as more compatible with masculinity or femininity, and faculty interpretations can reproduce these distinctions (Blosser, 2017). Consequently, apparent parity in one program may coexist with pronounced imbalance elsewhere and with gendered differentiation inside the more balanced specialty. The descriptive finding is robust enough to motivate investigation; its causal explanation remains open.

A further analytical distinction concerns horizontal and vertical processes. Horizontal segregation refers here to differences among specialties or subfields at a similar educational level; vertical differences concern representation across stages and positions. Comparative research has documented horizontal differentiation across engineering specialties (Hartman et al., 2007; Litzler, 2010). The observed BME patterns primarily

demonstrate this form of differentiation. Earlier accounts of changing representation across undergraduate study and later academic stages raise a separate question about vertical pathways (Chesler et al., 2010; Frize et al., 2022). Both processes can occur simultaneously, but a cross-sectional comparison of programs does not establish how students move between stages or why. This distinction is relevant to the design of future comparative and longitudinal studies.

Choosing BME

Choice was associated with family and social influences, perceived career flexibility and security, interest in combining engineering and medicine, and educational experience (Singla et al., 2024). Decisions continued to develop after enrollment: instructors and courses were prominent influences on specialization, with some gender differences in reported influences and expectations (Miller et al., 2024). The available studies do not isolate the factors that explain why women choose BME more often than several other engineering specialties.

In qualitative interviews, Singla et al. (2024) identified positive and negative family influences, the perception that BME preserves occupational options, concurrent identification with engineering and medicine, perceptions of academic requirements for particular routes, and the role of a student's social environment. The themes interacted rather than forming a single explanatory pathway. Students could value the possibility of retaining several future options even when their immediate reasons for enrollment differed. Research on motivation and anticipated futures similarly suggests that imagined professional roles can influence how current coursework is interpreted (Benson et al., 2014).

Choice should therefore be understood as an evolving process. Exposure to instructors, classes, projects, and co-curricular experiences can clarify or revise career plans. Miller et al. (2024) found that instructors and courses were especially influential in specialization choice and documented some differences by gender in how influences and expected outcomes were assessed. Other educational activities can help students identify possible sectors and roles (Scott et al., 2024; Woodcock et al., 2020). Nonetheless, the BME-specific evidence remains too limited to identify the relative contribution of health orientation, family influence, perceived career security, or institutional context to women's higher participation across specialties.

The distinction between the decision to enter BME and the decision to specialize within it deserves attention. The first may reflect information available in secondary education, family networks, and public images of the discipline. The second occurs after students have encountered faculty, technical methods, clinical applications, and the constraints of available courses or placements. An explanation based solely on initial preferences would overlook this subsequent educational work. Likewise, the existence of varied career routes could make BME attractive because it allows students to keep options open, without implying that all students understand those options in the same way. The reviewed studies illustrate these possibilities but do not yet provide a comparative model capable of estimating their relative importance.

Identity, Self-Efficacy, and Gender Compatibility

Findings were mixed rather than uniformly disadvantageous for women. Among 716 BME students, Patrick et al. (2021) found no overall concentration of women in particular postgraduation plan profiles, but some women reported lower self-efficacy, interest, or engineering identity within profiles. Other work found strong engineering and science identities without a significant gender effect on professional identity (Springer & Huang-Saad, 2020). Szczesny et al. (2023) reported similar scores across many dimensions but lower perceived compatibility between being a woman and being an engineer. Thus, high representation does not establish equivalent experiences of recognition or identity.

Engineering identity comprises interest and perceptions of competence, but recognition by significant others is also central to its development (Patrick et al., 2018). Measures of identity and self-efficacy consequently answer different questions from enrollment statistics (Cech et al., 2011; Eddy & Brownell, 2016). In the Patrick et al. (2021) analysis, a lack of overall gender concentration across future-plan profiles coexisted with within-profile differences in selected psychosocial measures. This distinction matters: evidence about where students intend to go after graduation does not establish that they have experienced the degree in the same way.

Springer and Huang-Saad (2020), surveying 150 undergraduate students, graduate students, and professionals, found strong identification with both engineering and science and did not observe gender as a significant predictor of the professional identity measures analyzed. Szczesny et al. (2023) likewise reported similarity on several scales of interest, belonging, and intention but a difference in perceived gender–engineering compatibility. The results should not be collapsed into a single claim about women's confidence or identity. They vary with the construct, sample, educational stage, and institutional setting. Together, they make clear why greater numerical representation is an incomplete indicator of substantive equality.

The interpretation of apparently inconsistent results depends on construct validity. Professional identity can refer to interest, competence, recognition, identification with a scientific field, or expectations of practicing engineering; self-efficacy may be academic, technical, or career-related. A gender difference on one measure and similarity on another need not be contradictory. Moreover, a program with many women can still operate within a wider engineering culture in which technical authority is associated with masculinity. The difference in perceived compatibility found by Szczesny et al. (2023) is meaningful for that reason, even though other measures showed little difference. Broader engineering research also connects belonging and identification with educational conditions (Bahnson et al., 2024; Cannaerts et al., 2025). Studies that specify precisely how constructs are defined and measured will allow stronger comparisons.

Interdisciplinarity and Hybrid Identities

Students' definitions of BME increasingly incorporated medicine and biology as they progressed (Ramo et al., 2019). Interviews also identified combined engineering and medical identities (Singla et al., 2024). These multiple affiliations may broaden professional possibilities; they can also create tensions when particular subfields, such as computing, retain gendered meanings (Shoaib et al., 2023).

The disciplinary boundaries of BME are unusually permeable. Students encounter engineering methods alongside biological knowledge, clinical problems, medical technology, and health-related applications. Ramo et al. (2019) observed that students' definitions of the field drew more frequently on areas outside engineering as they advanced in their programs. Research on core BME competencies, tissue engineering, clinical design, and collaboration with medicine similarly reflects the coexistence of distinct disciplinary practices (Erath et al., 2024; Maloney et al., 2022; White et al., 2020; Woodcock et al., 2019). Such findings support the idea that an individual can construct a professional identity that combines engineering, science, and medicine without treating these categories as mutually exclusive.

The meaning of this hybridity for gender remains unsettled. Multiple identities could challenge a narrow, traditionally masculine conception of engineering, but students may still encounter gendered expectations in particular tasks or specialties. Work in a computing-intensive course identified tensions around the development of computational identity among BME and other engineering students (Shoaib et al., 2023). The case suggests that parity at program level may coexist with unequal identification in particular technical domains. More comparative research across subfields is needed to assess this possibility.

A hybrid identity should not be treated as automatically inclusive. It may provide language through which students articulate interests in medicine, biology, and technology, but its effect depends on which forms of expertise are valued in a particular program. If medical or caring applications are framed as peripheral to "real" engineering, students may face pressure to prove technical legitimacy. If clinical problems are integrated into design and research, a different understanding of engineering competence may be possible. The present corpus indicates that BME students can identify with more than one discipline; it does not resolve how these identities are recognized by instructors, employers, or peers or whether recognition differs by gender.

Specialization and Subsequent Trajectories

Some gender differences were identified in specialization interests and the value assigned to instructors and courses (Miller et al., 2024). Yet available evidence does not support a general pattern in which women leave engineering after BME graduation: postgraduation plans encompass industry, research, postgraduate study,

medicine, and related fields (Ortiz-Rosario et al., 2019; Patrick et al., 2021). Longitudinal studies are needed to establish whether differences emerge, persist, or change across these transitions.

BME offers multiple routes through industry, postgraduate study, research, medicine, and health-related sectors. In a study of specialization decisions, instructors and coursework were reported as influential, while some gender differences appeared in the evaluation of particular influences and anticipated outcomes (Miller et al., 2024). This means that the gendered organization of opportunity may arise after admission, when students gain access to information, mentors, and experiences that make different routes imaginable. The existing evidence does not establish a consistent overall sorting of women and men across all subsequent pathways.

Patrick et al. (2021) found that women were not generally concentrated in particular profiles of postgraduation plans. Comparisons of professional outcomes have also complicated the assumption that movement into medicine or other sectors is simply a loss of engineering talent (Ortiz-Rosario et al., 2019). A student may choose a role that draws on BME training outside a narrowly defined engineering occupation. Because most studies observe a single educational stage, however, the review cannot determine whether gender differences change across entry, degree completion, early employment, and later career development. Longitudinal designs are especially important here.

A further issue is whether the choice of specialization reproduces gender divisions inside a program that appears balanced overall. Available studies identify differences in some expectations and influences but do not establish a stable pattern across institutions or cohorts. The pathways after graduation are similarly plural: industry, research, postgraduate study, medicine, and other sectors cannot be placed on one linear continuum from persistence to departure. Future research should describe the content and conditions of these destinations and examine whether graduates experience equal access to technical responsibilities, recognition, and advancement. Such evidence is necessary before inferring that higher enrollment in BME translates into comparable professional opportunity.

Curriculum and Educational Experience

Courses, authentic problems, and relationships with faculty may shape specialization and belonging (Chan et al., 2025; Miller et al., 2024). Findings from diversity, equity, and inclusion interventions are not uniformly positive: one curricular study reported no immediate improvement in women's belonging or intention to remain (Szczesny et al., 2023). A translational research laboratory course has also reported gender-differentiated educational outcomes (Chen et al., 2023). The small and varied evidence base precludes a general claim about intervention effectiveness.

Curricular experience matters because interests and aspirations can be revised through learning activities, feedback, and contact with possible professional futures. Faculty and courses were among the strongest reported influences on specialization choice in one study (Miller et al., 2024). Educational relationships may also affect whether students see themselves as legitimate members of BME. An intervention built around informal student–faculty meetings was associated with improvements in dimensions of belonging and a more balanced pattern among participants after the intervention (Chan et al., 2025). The design and context of each intervention must be considered before attributing broader effects.

Equity-oriented content does not necessarily produce immediate changes in the outcomes measured. Szczesny et al. (2023) found no improvement in women's belonging or intention to remain after diversity, equity, and inclusion material was introduced into required BME courses. The result does not show that curricular change is futile; it indicates that a specific intervention and short-term measures cannot alone address all aspects of institutional culture. Recent discussion of inclusive BME education calls for attention to learning environments and professional development more broadly (Leight et al., 2025). The small number of comparable studies, varied interventions, and different measures currently limit any general conclusion about which educational practices reduce gender inequality in BME.

The distinction between curricular content and the organization of educational relationships is especially relevant. Teaching about diversity may raise awareness, while belonging is also shaped by repeated

experiences of interaction, recognition, and opportunity. An intervention can therefore plausibly affect one outcome without immediately changing another. Course design, authentic problem solving, mentoring, faculty availability, and access to different professional settings represent potentially distinct mechanisms. The current evidence is too fragmented to rank these approaches or to identify which works for particular groups. Evaluation should use clearly defined outcomes and attend to unintended effects and variation among participants.

Health, Care, and Social Benefit

The association of BME with medicine and health may make its social purpose more visible. Research on communal goals offers an indirect rationale for studying this possibility, and engineering students may connect BME with helping others (Potvin et al., 2018). However, the included BME studies do not directly establish that health, care, or social benefit explains the field's relatively high participation by women. These mechanisms require explicit comparative study rather than inference from enrollment patterns.

Broader STEM literature suggests that some professions are perceived as less compatible with communal goals, such as helping other people or contributing to collective well-being (Diekman et al., 2010, 2011, 2017). Gendered socialization may influence the importance and perceived accessibility of these goals; studies of engineering perceptions offer an additional reason to examine how a field's social purpose is presented (Batz-Barbarich et al., 2024). BME could make the link between technical work and human health more apparent than other specialties, and its educational and professional identities do frequently include medicine. These points make a plausible hypothesis, but plausibility is not the same as direct evidence about why different students select specific engineering degrees.

Within the reviewed BME literature, care is less developed as an analytic concept than identity, self-efficacy, belonging, or career plans. Few studies systematically compare students' valuations of health, care, and social benefit by gender or examine whether these perceptions predict enrollment after accounting for other influences. Motivations for social contribution may also matter across engineering fields rather than being unique to BME (Rulifson & Bielefeldt, 2017). The present review therefore identifies this proposed explanation as a research gap and rejects any inference that an assumed natural disposition toward care accounts for women's participation.

An adequate test of this hypothesis would need to distinguish students' reasons for entering a field from the images of that field circulated by institutions and wider society. It would compare BME with other engineering specialties, assess how social impact is represented in each curriculum, and examine whether these meanings are associated with choice after considering other influences. Such a design would also allow researchers to ask whether perceived usefulness is important to men, women, and students with other gender identities in similar or different ways. Until this evidence is available, health and care should remain carefully formulated hypotheses rather than conclusions of the review.

Research Gaps

The evidence is geographically concentrated in North America and rarely follows students from entry through employment. Binary comparisons predominate, while nonbinary and trans experiences and intersections of gender with race, class, disability, or sexuality remain underexamined. Broader STEM research on gendered racism provides relevant context for this gap (Salmon, 2022). Research also rarely compares proposed mechanisms, including health orientation, interdisciplinarity, social benefit, and disciplinary stereotypes, across engineering specialties.

These gaps affect both the reach and the meaning of existing findings. Programs in Spain, other European systems, Latin America, Asia, and Oceania operate within different curricula and labor markets, yet BME-specific evidence from these settings remains sparse. Many studies compare women with men without examining the diversity of gender identities or the conditions that shape experiences at the intersection of gender and race, ethnicity, social class, disability, or sexuality. Cross-sectional measures cannot show how an early difference in belonging or self-efficacy relates to later specialization or employment. Finally, descriptive

comparisons across specialties rarely test competing explanations for why BME's composition differs from that of electrical, mechanical, or computer engineering.

The conceptual gap is equally consequential. In some publications gender functions only as a variable for comparing groups; in others it is used to examine cultural expectations, institutional structures, and unequal recognition. These approaches can generate different questions even when they analyze similar enrollment figures. More explicit theoretical frameworks could connect socialization, professional stereotypes, educational practices, and occupational opportunity without assuming that a single explanation fits every context. Intersections with race, class, disability, and sexuality should be integrated into research designs rather than appended as demographic controls where sample sizes permit. The findings from this review indicate where these developments are needed but cannot substitute for the new empirical studies they require.

Results Synthesis

The corpus shows higher representation of women in BME alongside context-dependent differences in identity, perceived compatibility, educational experience, and specialization. Findings do not support either uniform disadvantage or the assumption that parity removes inequality. The evidence is more consistent with partial change and possible reconfiguration of gendered processes across educational and professional trajectories.

Some studies report differences in identity or self-efficacy in particular subgroups, whereas others find little or no gender association with professional identity or overall postgraduation plans (Patrick et al., 2021; Springer & Huang-Saad, 2020). Perceived incompatibility between gender and engineering can nevertheless persist in a field with comparatively high participation by women (Szczesny et al., 2023). The evidence thus supports a differentiated interpretation: opportunities for participation may expand while particular expectations, experiences, and routes remain gendered. The scope and direction of these processes depend on what is measured and where and when the study is conducted.

DISCUSSION

BME demonstrates why engineering should not be treated as a homogeneous field: relatively high participation by women coexists with strong gender differences among specialties (Chesler et al., 2010; Hamid Betancur & Torres-Madronero, 2021). Yet enrollment is only one aspect of equality. Recognition, self-efficacy, belonging, and professional identity may differ even where participation approaches parity (Patrick et al., 2021; Szczesny et al., 2023).

This distinction between access and substantive equality is the review's central contribution. Representation matters because unequal access restricts opportunities, but a balanced intake is not evidence that students receive equivalent recognition or that they encounter the same range of possible futures. The BME findings are particularly instructive because they expose the limits of an aggregate account of engineering's gender gap. Horizontal segregation appears not only between STEM and other areas or between engineering and other disciplines but among engineering specialties. Depending on program design and local culture, it may also appear between concentrations within BME itself. Future work should therefore connect institutional participation data with measures of educational experience and longer-term outcomes.

A trajectory perspective connects entry to experiences during the degree, selection of specializations, and transitions into work or further education. BME's interdisciplinary position can expand identification with engineering, science, and medicine (Singla et al., 2024; Springer & Huang-Saad, 2020), but it may also relocate gendered differentiation within subfields. Movement into medicine, research, or related employment should not automatically be coded as departure from engineering; the meaning of each path depends on students' goals and occupational context.

This observation qualifies a simple "leaky pipeline" interpretation. Earlier work has used successive declines in women's representation to highlight consequential inequalities across stages (Chesler et al., 2010), but the metaphor can obscure the plurality of careers for which a BME degree prepares graduates. It may classify

movement across disciplines as loss even where individuals continue to apply engineering knowledge in medical, research, or industrial settings. A trajectory approach asks when transitions reflect expanded opportunity, institutional barriers, or constrained choice. The current literature cannot reliably distinguish among these possibilities because longitudinal follow-up is uncommon. It also rarely assesses whether women and men have comparable access to mentors, technically prestigious subfields, and employment options within those varied trajectories.

The findings do not justify essentialist claims that women are inherently oriented toward care. Future studies should compare institutional conditions, socialization, stereotypes, and the perceived purposes of engineering specialties with designs capable of testing those relationships. Universities should assess access alongside recognition, belonging, learning opportunities, specialization, and subsequent outcomes. The review is limited by the corpus's geographic concentration, heterogeneous measures, binary treatment of gender, and scarcity of longitudinal and intersectional research. Because this is a scoping review, the synthesis maps evidence and gaps rather than estimating effects or establishing causation.

Educational responses should therefore encompass both curriculum and institutional relationships. Relevant questions include who is recognized as technically capable, how students encounter possible specializations, whether role models reflect varied professional paths, and how opportunities are distributed in courses, projects, and placements. Evidence that belonging may respond to student–faculty interaction is encouraging (Chan et al., 2025), but individual interventions require careful evaluation within their own settings. A broader research agenda should compare BME with other engineering specialties across institutions, incorporate nonbinary and intersectional perspectives, and follow cohorts into postgraduate education and employment. Such work could establish when a numerical change reflects more equal participation and when gendered inequalities have taken another form.

CONCLUSIONS

Biomedical engineering provides a useful setting for examining gender inequality beyond admission figures. The reviewed literature documents comparatively high participation by women alongside context-dependent differences in identity, perceived compatibility, belonging, specialization, and expectations after graduation. These findings do not establish a single causal explanation for the field's gender composition. In particular, the proposed role of health, care, and social benefit requires direct comparative testing. Longitudinal and intersectional research across a wider range of countries is needed to assess how educational experiences affect recognition, opportunity, and subsequent trajectories.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Data Availability

The publications analyzed in this review are identified in the references. A public repository link for the search records, screening decisions, and extraction matrix is not supplied with this manuscript.

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