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# How do interdisciplinary pathways shape gender diversity in ICT? Evidence from a quantitative study

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ABSTRACT

Despite the growing demand for skilled Information and Communication Technology (ICT) professionals and the many initiatives aimed at broadening participation, women remain markedly underrepresented in computer science and related areas. Identifying and assessing educational interventions, including those implemented in higher education, can inform targeted actions to reduce this barrier.

By observing the significant impact and extensive intersection of computer science with many other disciplines, in the last few years academic institutions have been expanding their offerings to include a variety of interdisciplinary programs and courses. Recognizing this trend, this paper aims to explore the interest of female students in interdisciplinary topics. Our fundamental question is whether novel programs that cross the boundaries of different disciplines have the potential to attract to ICT more women with respect to traditional programs.

To shed light on this issue, we perform a thorough quantitative analysis on extensive data related to students' enrollment in the whole set of Italian academic programs, both at the bachelor and master level, over many academic years. Our analysis reveals that interdisciplinary programs, such as those blending computer science with domains such as economics, management, finance, and governance, exhibit a substantially higher enrollment of female students (plus 16% on average) than traditional programs. Some specific fields, including artificial intelligence and cybersecurity, benefit even more from interdisciplinarity, with an uplift exceeding 25 percentage points. As a by-product of our study, we also characterize interdisciplinary programs in Italy and quantify students' propensity across computer-science subdomains, assessing their appeal through a gender lens.

## 1. Introduction

Technology adoption is a key driver of business and societal transformations and is likely to continue playing this crucial role for many years to come. An extensive analysis by the World Economic Forum (2025) highlights that technological breakthroughs, along with economic disruptions and social and environmental pressures, are expected to drive a profound transformation in the labor market. In this rapidly evolving technological landscape, demand for many STEM (Science, Technology, Engineering, and Mathematics) professionals remains substantial, and computer science has historically been a major contributor to STEM labor-market growth. For instance, based on pre-generative-AI trends, Zilberman and Ice (2021) projected that computer occupations in the United States would grow by 11.5% over 2019–2029, compared with 8.0% for STEM occupations as a whole and 3.7% for all occupations, accounting for roughly two-thirds of all new STEM jobs over the decade. The rapid diffusion of generative artificial intelligence has substantially increased the uncertainty surrounding such projections: AI is reshaping occupational tasks, skill requirements, and workforce needs, potentially creating new opportunities while also transforming or displacing existing roles. This makes longer-term predictions more difficult. At the same time, current labor-market data continue to indicate substantial demand for ICT (Information and Communication Technology) expertise. In the European Union, for instance, 57.5% of enterprises that recruited or attempted to recruit ICT specialists in 2023 reported difficulties filling those vacancies, with national figures ranging from about 30% in Spain to 72% in Germany (Eurostat, 2025b). Moreover, the EU Digital Decade target of 20 million ICT specialists by 2030 remains well above current levels, which stand at slightly more than 10 million (Eurostat, 2025a).

Despite numerous initiatives and increasing efforts to address gender disparities, including within higher education and the computer science community, a substantial gender gap continues to persist in ICT (Powley & Townsend, 2024). While women's participation in science and engineering varies significantly by country, educational level,

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and specific field of study, in many contexts computer science and ICT-related fields are among those with the lowest female participation. For instance, women earn only 21% of bachelor's degrees in computer science in the US (National Center for Science and Engineering Statistics, 2023) and, as of 2023, represent only around 15% of young adults aged 15–34 who hold an ICT degree in the European Union (Eurostat, 2023). The situation may be even more severe in developing countries, where socio-economic constraints can more strongly affect girls' access to ICT education (Dlodlo, 2009). Women's underrepresentation, also stemming from a lack of presence in higher education programs (Harris et al., 2009), leads to missed in-demand and high-paying work opportunities, which are even more significant as many companies now emphasize hiring women and other underrepresented groups as part of their diversity and inclusion programs. Cultivating diversity and inclusivity in the tech workforce is thus not just a matter of gender equality, but can also benefit economy, drive innovation and enhance society in general, resulting in less biased products (Jaccheri et al., 2020).

The need to bridge the gap between the growing demand for CS and ICT experts and the persistent underrepresentation of women in these crucial roles reflects a complex set of factors and calls for action on multiple fronts. Many studies highlight the complex interplay between societal, cultural, and institutional factors (Toti et al., 2025). Many other contributions and initiatives have tried to provide solutions to dismantle the engagement barriers and to support women in following a computer science education, pushing towards gender equality not only in education, but also in the workforce.

Addressing the CS gender gap also calls for a careful examination of how institutional and curricular innovations shape participation in the field. In this paper, we focus on the growing adoption of interdisciplinary computer science programmes and analyze their association with gender patterns. Moving from the deep integration of computing in the modern society, in recent years there has been significant interest in emphasizing its impact and role across various domains. CS students are sometimes involved, as teammates or digital mentors (Pulimood et al., 2024; Rosales et al., 2024), in activities on completely different topics. Specific CS courses have been redesigned with applications in mind (see, e.g., Sedgewick and Wayne (2016)). Even entire bachelor and master programs have been created aimed at exploring the social, legal, and economic implications of computer science, integrating technical training with learning opportunities from other knowledge domains. Interdisciplinarity is regarded as a contemporary movement of curricular change, stemming from the need to study complex problems and hinging upon tools typical of different disciplines (Hannon et al., 2018).

**Our contribution.** Throughout the paper we focus on programs that blend computer science and related disciplines (such as computer engineering, data science, software engineering, artificial intelligence) with non-ICT areas, including economics, management, finance, governance, philosophy, humanities, music, medicine. Our study examines the role of interdisciplinarity in computing education through a gender lens, investigating whether emerging degree programs that combine computing with other disciplinary domains can contribute to broadening women's participation in ICT, compared with more traditional computing programs. Specifically, taking Italian university programs as a case study, we address the following research questions:

- **RQ1.** How widespread are interdisciplinary ICT-related degree programs in the Italian higher-education system, and which non-ICT domains do they most frequently connect with computing?
- **RQ2.** Are interdisciplinary ICT-related programs associated with higher female participation than pure ICT programs?
- **RQ3.** Does the association between interdisciplinarity and female participation vary across ICT subdomains, such as artificial intelligence, cybersecurity, data science, and computer science?

To answer these questions, we conduct an in-depth quantitative analysis of Italian university programs, relying on data provided by MUR, the Italian Ministry of University and Research. Used datasets contain information about more than 7 300 000 students enrolled in 92 Italian universities from academic year 2000/2001 until 2022/2023. We remark that bachelor and master programs are grouped in Italy in several degree classes, where a class refers to a specific group of degree courses within a particular field of study. No cross-discipline classes exist.

We consider in our study 228 bachelor and master programs related to computing. Using MUR degree classes, we first compare the gender gap in CS and ICT programs against STEM courses, quantifying a negative record for computing sciences, with more than 85% of male students. We then delve into pure and interdisciplinary courses. The fact that each program has a unique degree class poses challenges when retrieving information about interdisciplinary courses. Through text processing techniques, we identify over forty programs in Italy that blend Computer Science with non-ICT domains. Our analysis on student enrollment reveals that interdisciplinary programs exhibit a substantially higher enrollment of female students (plus 16% on average) than traditional programs. Interdisciplinarity benefits even more prominently male-dominated fields, where female enrollment rises significantly, by about 25% in artificial intelligence and 27% in cybersecurity. As an additional contribution, we also characterize the attractiveness of various computer science areas, including artificial intelligence, data science, and cybersecurity, from the perspective of students. We believe that our findings on interdisciplinarity and gender point to a promising lever for retaining and supporting more women in computer science, thereby helping to increase the number of female CS graduates entering the workforce.

**Paper organization.** Section 2 reviews related work on gender imbalance and interdisciplinarity with a focus on computing education. Section 3 outlines the methodology and datasets used in our analysis. Section 4 examines interdisciplinarity in ICT-related programs, while Section 5 explores its correlation with gender participation, also across different computing subdomains. Section 6 summarizes our main findings and discusses implications on incentives and policy making.

## 2. Related work

In this section we review the literature on gender imbalance in computer science and ICT education, with particular attention to interdisciplinary pathways and their potential role in broadening participation in computing.

**Gender gap in CS.** The underrepresentation of women in STEM programs, particularly in computer science and related disciplines, has been the subject of extensive research and scholarly inquiry. Except for the biological sciences that attract slightly more women than men, women are underrepresented across all STEM fields, and most notably in physical science, engineering, and computer science. It is thus mandatory to study each discipline separately in order to pinpoint the different students' motivations for pursuing one STEM field versus another, though this is not always the case in previous works, where results are often aggregated.

Computer science often reaches a record low in women's participation compared with other STEM disciplines. The gap in the field is among the largest and this trend is especially concerning, given that ICT is projected to see the strongest employment growth among occupational areas (Yang et al., 2023). Wagner (2016), drawing on data from the Higher Education Statistics Agency (HESA), reports that in 2013 women received fewer than 16% of Computer Science degrees in the United Kingdom. The study then investigates whether a gender-related performance gap exists by comparing student outcomes in Computer Science across 129 UK universities between 2002 and 2013 with those in other disciplines. The analysis reveals a gap in the proportion of first-class CS degrees, but no corresponding gap in the share of "good" degrees.

Gender disparities in computing cannot be explained solely by differences in individual preferences. Prior research highlights the interplay between social identity, gender stereotypes, institutional signals, and structural barriers in shaping women's entry into and persistence in technology-related fields (Gorbacheva et al., 2019). Similar patterns have also been identified as persistent challenges to women's participation and advancement in the broader engineering literature (Dabić et al., 2024). In particular, experimental evidence suggests that perceptions of identity and belonging can affect women's willingness to pursue technology training (Del Carpio & Guadalupe, 2022), while organizational signals and recruitment practices can further influence who ultimately enters technology-oriented educational pathways (Lane et al., 2024). These mechanisms are consistent with a broader literature documenting multiple and interconnected barriers, including societal stereotypes, environmental and cultural factors, a lack of visible female role models, and women's different interests and experiences. A comprehensive analysis of these factors is provided in Hill et al. (2010). Blickenstaff (2005) focuses on STEM careers and majors, highlighting that there is no unique leading cause for this problem and that individual actions of the educators are crucial to promote a more inclusive gender participation. Beyer (2014), collecting data from first-year college students, observes that gender differences exist in computer self-efficacy, stereotypes, interests, values, interpersonal orientation, and personality. A different approach is taken by Falkner et al. (2015), who analyze the feelings of the few women in computer science. The study highlights the influence of family, exposure, culture, sexism and gendered thought on their perceptions of the field, of themselves and of their peers. Cheryan et al. (2015) point out students' stereotypes: computer science and engineering are believed to involve social isolation, an intense focus on machinery, and inborn brilliance, and appear to students as more compatible with male-qualities. The results reported by Rapoport et al. (2026) further show that women tend to undervalue their technical abilities, with programming languages such as C and Java displaying significant gender disparities in self-assessment.

In contrast, empirical evidence from institutional datasets shows successful experiences for women in computer science programs. Analyses of data from Rutgers University (Babeş-Vroman et al., 2022) indicate strong outcomes for women and document how the gender gap shifts as students advance through the curriculum toward completion of the major. A variety of works emphasize the importance of multi-level interventions to promote an inclusive culture, ranging from curriculum redesign (e.g., inclusive language and representative content) to culturally responsive pedagogies and extracurricular initiatives that foster participation through collaborative game-design activities (Perez-Felkner et al., 2025; Pournaghshband & Medel, 2020).

**Interdisciplinary pathways.** Interdisciplinary education has gained attention as a way to broaden participation (Dabu, 2017; Marquardt & Happe, 2024). Such interdisciplinary ICT programs may play an important role not only because they combine different subject areas, but also because they can reframe computing as a field connected to diverse practices, identities, and forms of knowledge. By embedding computing in domains such as design, media, the social sciences, education, or the humanities, these programs may reduce the association of computing with a narrow technical culture and open alternative pathways into computational education. The importance of expanding the cultural and epistemological frames through which computing is presented has been emphasized in a variety of previous works, including studies on epistemological pluralism in computer culture (Turkle & Papert, 1990), gender and electronic textiles (Searle et al., 2016), and gender and gaming (Kafai et al., 2008). This perspective is further supported by recent work on equity and identity in CS education, which shows how CS learning environments may reproduce exclusion and marginalization (Rankin et al., 2021), and how narrative-driven curricula can engage non-dominant middle-school girls in computational activities by connecting computing with identity, storytelling, and culturally meaningful practices (Pinkard et al., 2017).

Alternative pathways that can be used to inform the computing education research to engage more women are the subject of Zhu et al. (2023), with a focus on women who enter the computing workforce after obtaining an initial undergraduate degree in a non-computing field. Exploring the background of women who enter the field through unconventional or indirect pathways furthers our understanding of potential avenues to attract and retain them in ICT. It has been observed that jobs offering interdisciplinary working areas are appealing to women (Gergis & Kachala, 2021) and that interdisciplinary collaborations could be exploited as a means to attract top talent, stimulate public interest, and broaden available resources (Klawe & Shneiderman, 2005). The emergence of a large number of new interdisciplinary sciences is indeed one of the shaping forces of the scientific landscape and cannot be ignored, especially by computer scientists, resulting in educational curricula being adapted to this trend at different levels (Dabu, 2017). Interdisciplinary courses aligned with students' interests (see, e.g., the RockStartIT initiative (Marquardt & Happe, 2024)) can successfully engage diverse groups of high-school students, making it possible for the participants to discover computer science from different perspectives. Allowing students to integrate computing with other domains in the natural or social sciences, humanities, and the arts, is often referred to as a "CS + X" degree and is quite common in the United States (Toti et al., 2025). Interdisciplinary computing curricula can take different forms, ranging from single introductory courses or short course sequences to full degree programmes that combine foundational coursework in CS and another discipline, often complemented by integrative or synthesis courses and capstone projects. The benefits of such programs from a diversity perspective seems typically dependent on what the "X" is Brodley et al. (2024). Several concrete experiences illustrate this broader trend, including combined computing majors at Northeastern University (Brodley et al., 2022), the Computing in the Arts (CITA) Bachelor's programme (Bares et al., 2018), and CS+Social Science high-school initiatives (Isenegger et al., 2025).

Our study follows the same line of inquiry and asks a fundamental question: can interdisciplinary pathways into computing help reduce the gender gap in computer science? We shed light on this question through a large-scale quantitative analysis of the student population in Italy, assessing not only whether interdisciplinary programmes are associated with higher female participation, but also which interdisciplinary combinations are most prevalent in the national higher-education landscape.

## 3. Methodology

In this section we present our data analytics methodology. After a brief overview of the Italian higher education system provided in Sections 3.1, 3.2 describes the student enrollment datasets used in our study. Section 3.3 presents our classification algorithm for identifying interdisciplinary programs within the Italian academic offer. Finally, Section 3.4 introduces a set of metrics to characterize students' enrollment patterns along the dimensions of gender and interdisciplinarity.

### *3.1. A bird's eye view on the Italian higher education system*

Each university course, i.e., each bachelor and master program offered by public or private universities, is characterized by a title, a degree class, and a field of study. As an example, the bachelor program "Management and Computer Science" at Luiss Guido Carli University is associated with the degree class L-18 "Economics and business management", which is in turn part of the broader field of study dubbed "Economics". The Italian Ministry of University and Research (MUR) defines 15 fields of study: agricultural and veterinary sciences, art and design, computer science and ICT technologies, civil engineering and architecture, economics, education, industrial and information engineering, law, literary and humanistic studies, linguistic studies, medicine and pharmacy, physical education and sports, psychology, mathematics and natural sciences, socio-political sciences and communication. Each bachelor and master degree class is associated with a unique field of study, resulting in a partition of the 146 classes into 15 groups.

It is worth noting that, for historical reasons, computer science and computer engineering programs are part of two different fields of study: computer science and ICT technologies, on one side, and industrial and information engineering, on the other side. The latter field, in addition, also includes courses with a focus on industrial engineering, which are rather different from computer engineering with respect to gender distribution. Hence, an analysis of women participation by just considering the field of study may be not sufficient to provide accurate gender insights, but specific degree classes might be more informative.

Even more importantly for the aims of this study, the existing tree-based classification does not explicitly capture interdisciplinary degrees. Since each program is assigned to a single class, similar interdisciplinary offerings may be placed in different classes, or even in different fields, across universities. For instance, "Data science and business analytics" offered by Bocconi University is a master program in statistics (LM-82, field of study on hard sciences). But "Data science for business informatics" offered by the University of Pisa is a master program in computer science (LM-18, field of study on CS and ICT technologies).

### 3.2. Student enrollment data

Data on student enrollment used in our analysis are provided by MUR, the Italian Ministry of University and Research, on its official Web site. In particular, we consider two main datasets that in total provide information – including gender – on more than 7 300 000 students enrolled in 92 Italian universities. The largest university, Sapienza, counts as many as 421 679 students in the dataset. The datasets feature more than 8 000 different university courses, from which we extracted enrollment information to 228 distinct bachelor or master programs related to computing disciplines. In more details we considered:

- A dataset, dubbed *enrolled-students-per-sector*, which provides information about the students enrolled in each field of study over the last 23 academic years (2000/2001 to 2022/2023).
- A dataset, called *enrolled-students-per-university-program*, which provides more detailed information about the students enrolled in each university, degree class, degree program over four academic years, starting from 2019/2020.

### 3.3. Classifying interdisciplinary and pure programs

As observed in Section 3.1, relying on the MUR field-of-study label to distinguish pure from interdisciplinary ICT-related programs in Italy is unreliable. Each degree program is assigned to a single field, and interdisciplinary programs covering similar content may nevertheless be mapped to different fields (e.g., economics and computer science would be both suitable for a program titled "Data science for market analysis"). Hence, we adopt a different approach, extracting information on interdisciplinarity by carefully processing the *enrolled-students-per-university-program* dataset and analyzing the corresponding program titles. The whole task can be framed as a binary classification problem aimed at distinguishing *interdisciplinary* programs from *pure* ones.

We remark that the term *interdisciplinary ICT-related program* is used in an operational sense throughout the paper, referring to degree programs that combine computing-related topics with at least one non-ICT domain in their title and educational positioning. This usage is close to what is often described as CS+X in the computing-education literature (see Section 2). We do not attempt to distinguish systematically among multidisciplinary, interdisciplinary, and transdisciplinary integration at the curricular-design level, since our data are based on program titles, degree classes, and national enrollment records rather than detailed syllabi. Accordingly, when we use expressions such as cross-disciplinary or boundary-crossing, we only refer to an operational notion of ICT programs that connect computing with non-ICT domains.

The analysis considers programs both in English and in Italian: for all names and words, we always consider their English version as well as their Italian translation. We include in the set of pure courses not just computer science, but also programs focusing on related areas or subdomains: computer engineering, artificial intelligence, cybersecurity, data science, data analytics, software engineering, machine learning, big data. Interdisciplinary courses of interest in our analysis mix these ICT-related keywords with other non-ICT topics. Hence, a program named *Artificial intelligence for finance* is regarded as interdisciplinary, while *Statistics and data science* is rather considered pure, since it mixes two topics, but both of them are domains in the hard sciences. Our classification algorithm proceeds as follows:

**Domain selection via regular expressions.** From the *enrolled-students-per-university-program* dataset we extract degree programs related to computer science and data science using a set of regular expressions built on domain-specific keywords (as listed above).

**Pattern matching through coordination markers.** We apply on the previously selected pool a pattern-matching step to identify program titles that contain coordination markers, such as conjunctions and prepositions (e.g., "and", "for", "in"), as well as symbols (e.g., "&"). Notice that, in these titles, computer- and data-science keywords may occur either before or after the marker; for instance, we observe names such as *Data Science and Management* and *Economics & Big Data*.

**Semantic analysis of misclassifications.** In the first instance, if any coordination marker is contained in the program's title, we might consider that title as interdisciplinary. This approach, however, may still misclassify some programs. In particular, the presence of a cross-domain pattern detected via a coordination marker is not sufficient to identify interdisciplinarity: we must also examine the program title more closely to avoid labeling as interdisciplinary degrees that combine two or more ICT domains (e.g., *Computing and Data Science*, as mentioned above). Our goal is indeed to capture programs that merge computer- and data-science competencies with other domains, which are often application areas for data analytics and computational techniques. To address this issue, we apply a keyword-based post-processing step to the initial set of candidates, filtering out titles that do not meet this criterion.

**Manual outcome validation.** Owing to the manageable size of the extracted dataset, we finally validate the accuracy of the classification outcome through manual inspection.

The list of interdisciplinary programs identified and subsequently analyzed in our study is reported in Appendix A, together with information on their geographical distribution and course language.

### 3.4. Gender and interdisciplinarity metrics

To characterize the student population, we adopt the conceptual framework illustrated in Fig. 1, which organizes students along two orthogonal dimensions: gender (male/female) and program type (pure/interdisciplinary). This yields four groups: Pure Males (PM), Interdisciplinary Males (IM), Pure Females (PF), and Interdisciplinary Females (IF). Building on this framework, we define the following metrics.

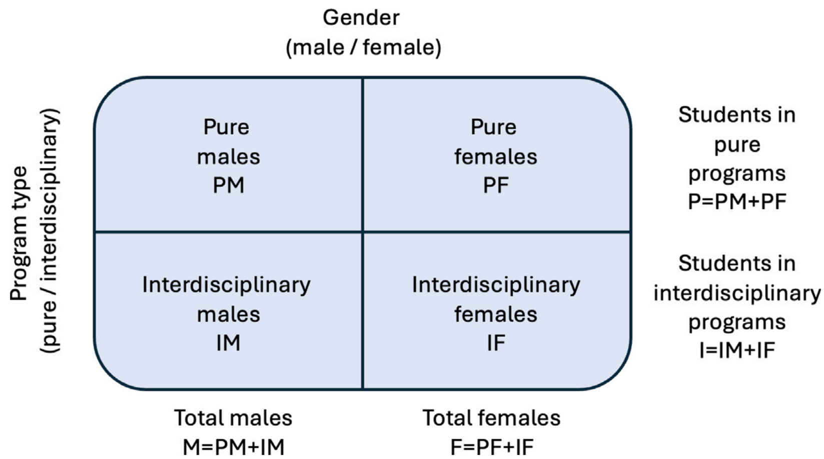


**Fig. 1.** Conceptual framework for analyzing student enrollment by gender and program type, separating pure and interdisciplinary programs and introducing the notation used throughout the analysis.

**Totals:** absolute counts for each group and their aggregates. We consider total males $M = PM + IM$, total females $F = PF + IF$, total pure-program students $P = PM + PF$, total interdisciplinary students $I = IM + IF$, and overall total $T = PM + IM + PF + IF$.

**Normalized proportions:** relative shares (%) with respect to the total student population. We compute both gender shares ($M/T$, $F/T$) and program-type shares ($P/T$, $I/T$). $I/T$ is an *interdisciplinarity index* that measures the overall weight of interdisciplinary programs on the entire student population.

**Conditional shares:** to capture the interaction between gender and interdisciplinarity, we compute (i) the share of interdisciplinary (resp. pure) students within each gender ($IM/M$, $IF/F$, $PM/M$, $PF/F$), and (ii) the gender composition within each program type ($PM/P$, $PF/P$, $IM/I$, $IF/I$).

**Summary indices:** the *gender balance index* (in short, $GBI = 1 - |M - F|/T$) quantifies the degree of gender balance in the overall student population. The same index can be computed separately for pure and interdisciplinary programs by restricting the counts to the corresponding subpopulations, yielding $GBI_P = 1 - |PM - PF|/P$ and $GBI_I = 1 - |IM - IF|/I$, respectively. Higher values of the gender balance index indicate a more balanced gender composition, with the index approaching 1 as parity between male and female students increases.

## 4. Interdisciplinarity in ICT-related academic programs: results and discussion

In this section we provide insights into the landscape of ICT-related academic programs in Italy, both pure and interdisciplinary. In Section 4.1 we present a topic-based analysis, examining topic distributions and frequently occurring patterns of interdisciplinarity. We then examine the geographical distribution of programs in Section 4.2, also in relation to the language of instruction.

### *4.1. Topic analysis and cross-field mixing*

The text analysis approach described in Section 3.3 allowed us to identify 228 ICT-related programs, 184 pure and 44 interdisciplinary, out of more than 5000 bachelor and master programs in Italy across all disciplines. The list of interdisciplinary programs that are the focus of this study is reported in Appendix A.

Fig. 2 summarizes the most frequent components appearing in the English-translated titles of interdisciplinary ICT-related degree programs after decomposing each title into recurring phrases. Box and font sizes are proportional to frequency, providing an immediate view of the dominant themes in the dataset. Unsurprisingly, *Computer science* and *Data science* emerge as the most prevalent computing-related phrases. However, several high-frequency non-computing components, most notably *Economics*, *Business*, *Management*, and *Finance*, also stand out, indicating that interdisciplinarity in the Italian panorama is often realized through combinations of computing and data-analytics skills with socio-economic and managerial application domains. Beyond these core areas, the cloud highlights additional recurring directions (e.g., *Artificial Intelligence*, *Digital*, *Statistics*, and *Humanities*), suggesting a broad spectrum of interdisciplinary positioning.

Fig. 3 supports the qualitative picture provided by the treemap by reporting the frequency of the extracted title components, split into computing-related (top) and non-computing (bottom) terms. The two pie charts reveal two distinct regimes. On the computing side, a small vocabulary (13 components) accounts for most occurrences, resulting in a markedly skewed distribution dominated by a few recurring terms (in particular, *Computer Science* and *Data Science*, as also observed above). Conversely, the non-computing side exhibits substantially higher lexical variety (28 components) and a flatter profile: frequencies are spread across many application and contextual domains, rather than being concentrated on a single area. Overall, the average frequency is higher for computing-related components (3.92) than for non-computing ones (2.36), consistently with the picture of a stable "core" of computing terms combined with a broad range of external domains in interdisciplinary program titles.

Fig. 4 summarizes how ICT-related phrases co-occur with non-ICT components in interdisciplinary program titles. Each cell reports the number of degree programs whose title contains the corresponding pair of keywords (at the row–column intersection), after translation into English of Italian program titles and component extraction. Programs with slightly different coordination patterns (e.g., *Economics and Data Science* vs. *Data Science for Economics*) contribute to the same count. Two main signals emerge. First, besides confirming that interdisciplinarity is largely structured around a small set of ICT anchors (primarily *Computer Science* and *Data Science*), the co-occurrence heatmap highlights that these components repeatedly co-occur with socio-economic domains. The strongest association in the table is between *Data Science* and *Economics* (6 programs), followed by recurrent combinations of *Computer Science* with *Business* and *Management*. Second, many other non-ICT domains appear only sporadically (often with single occurrences), indicating that the long tail of interdisciplinarity is fragmented, while the core of the phenomenon concentrates on

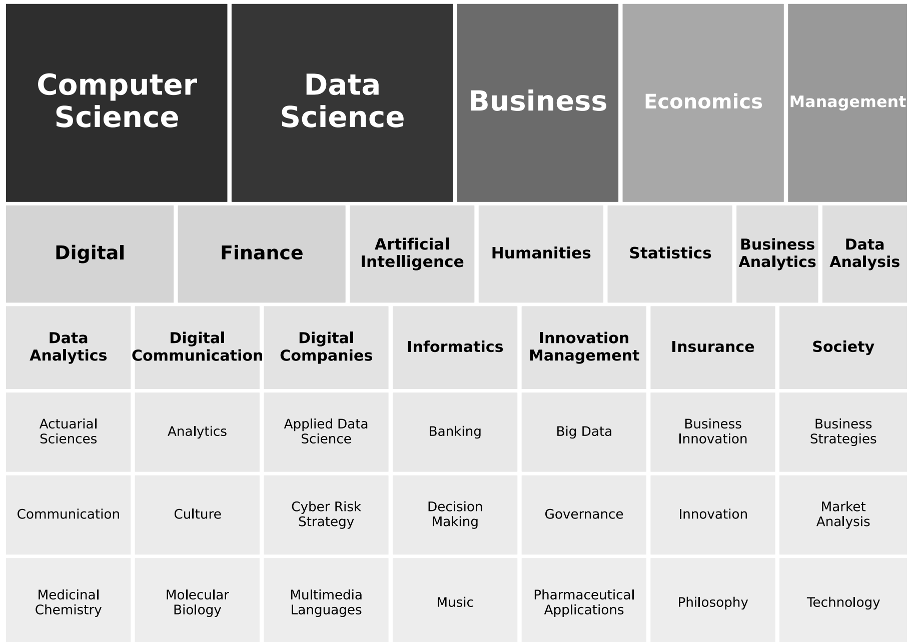


**Fig. 2.** Treemap of 41 recurring patterns extracted from English-translated interdisciplinary program titles. Box and font size reflect frequency.

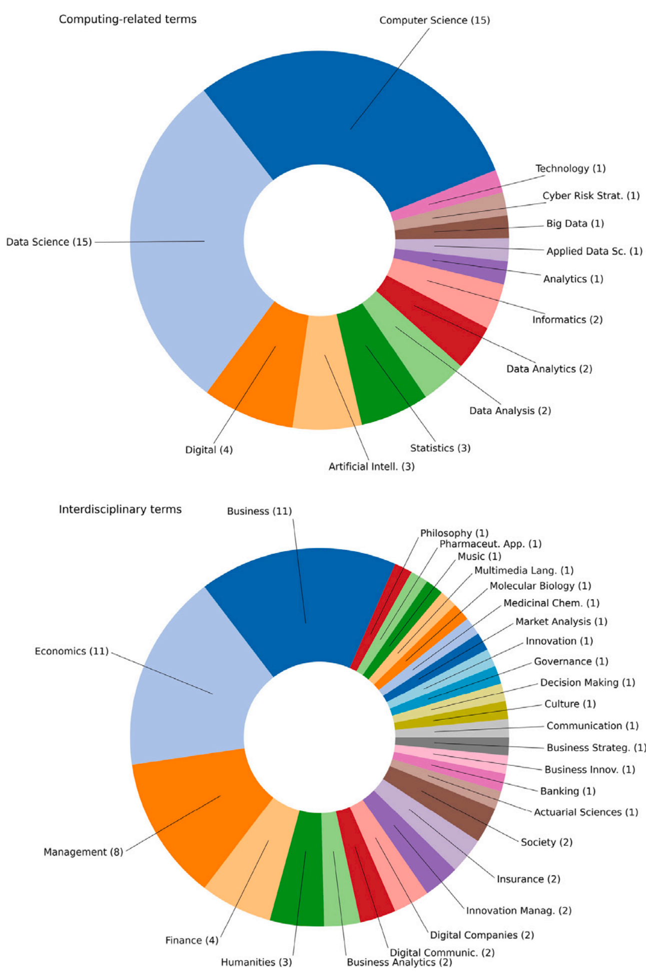


**Fig. 3.** Component frequencies by type: computing-related terms (13, top) are fewer and more concentrated, while non-computing terms (28, bottom) are more numerous and more evenly distributed.

business-, management-, and economics-oriented applications of data analytics and computational techniques.

Overall, the heatmap accounts for 71 ICT and non-ICT co-occurrences across interdisciplinary program titles. This total exceeds 44 because a single interdisciplinary title may contain multiple keywords and therefore contribute to multiple cells. For instance, *Data Analytics for Business and Society* is counted twice in the *Data Analytics* column, at the intersections with the *Business* and *Society* rows, respectively. Similarly, *Economics, Management and Computer Science* contributes to two cells in the *Computer Science* column, at the intersections with *Economics* and *Management*.

### 4.2. Geographical analysis and language distribution

Fig. 5 compares the geographical distribution of pure ICT programs (left) and interdisciplinary ICT-related programs (right) across Italian regions. Pure programs are widely distributed throughout the country, with relatively high concentrations in several regions across the North, Center, and South. This pattern is consistent with the consolidated and widespread presence of traditional computer science education within the Italian higher-education system. In contrast, interdisciplinary programs are markedly less numerous and display a more uneven geographical distribution. They are concentrated in a limited number of regions, with pronounced clusters in Northern and Central Italy, while several regions, especially in the South, host few or no interdisciplinary offerings. Overall, this spatial asymmetry suggests that interdisciplinarity in ICT education still remains an emerging and regionally uneven phenomenon in Italy, potentially reflecting differences in institutional capacity, strategic orientation, or regional demand.

Fig. 6 complements the geographical maps by providing a region-level comparison of pure and interdisciplinary programs. While pure programs dominate in all regions, the relative weight of interdisciplinary offerings varies substantially across the country. Lombardy stands out both in absolute terms and in relative share, with interdisciplinary programs accounting for more than 45% of the regional ICT offer. Other regions with a notable interdisciplinary presence include Campania, Tuscany, Emilia-Romagna, and Lazio, although with markedly lower shares ranging from 18% to 27%. In most regions, interdisciplinary programs represent a minority of the overall ICT

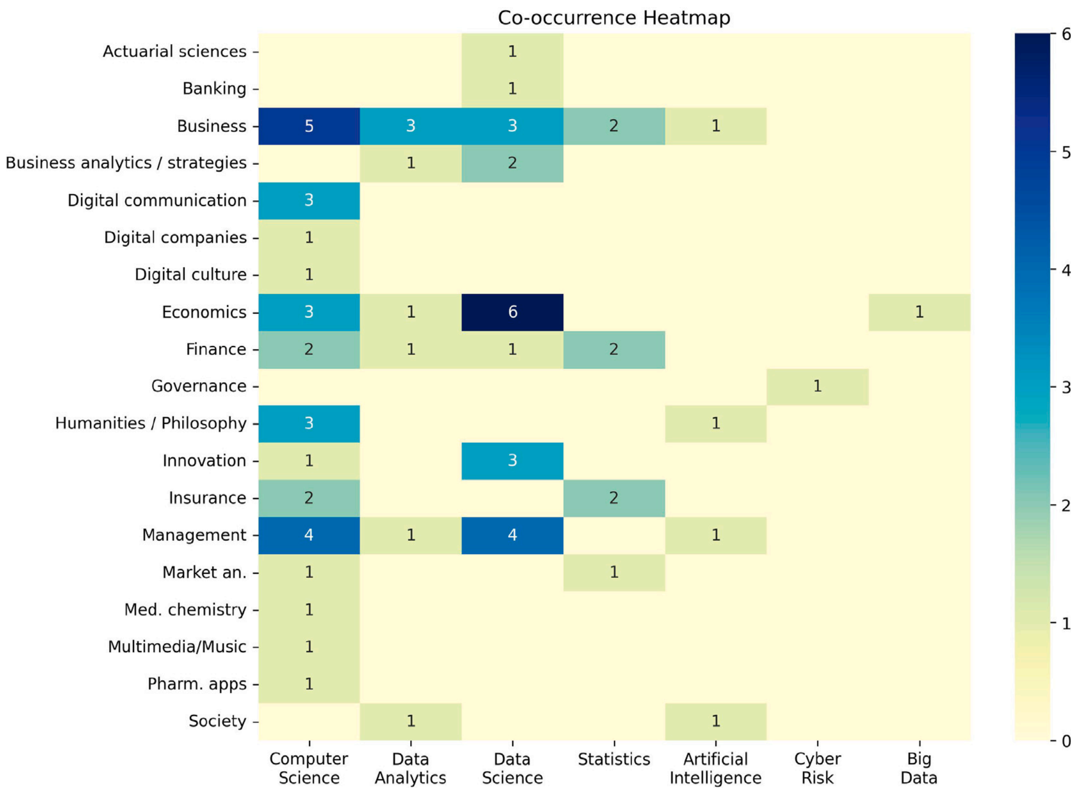


**Fig. 4.** Co-occurrence heatmap in interdisciplinary program titles: each cell reports the number of degree programs combining an ICT keyword (column) with a non-ICT component (row). Names of Italian programs have been translated in English.

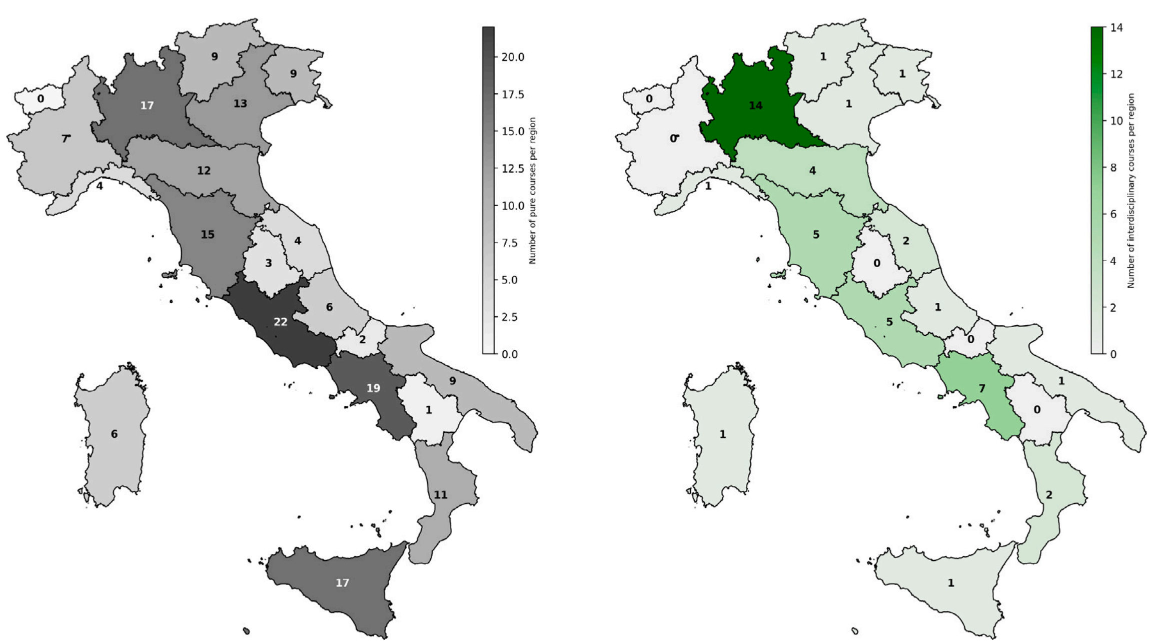


**Fig. 5.** Geographical distribution of pure courses (map on the left) and interdisciplinary courses (map on the right) over Italian regions.

supply, often below 25% and in several cases below 10%. Smaller regions typically host few ICT programs overall and frequently lack interdisciplinary offerings altogether. These patterns reinforce the picture emerging from the maps: uneven distribution and concentration in regions with larger, more diversified higher-education systems, where institutional scale and strategic orientation may better support cross-disciplinary program design.

With respect to the language, among the 44 interdisciplinary programs, three are offered in both Italian and English and therefore appear twice in our list, which comprises 47 titles in total (44 unique programs plus three language duplicates). Of these, 27 titles are in Italian and 20 in English, corresponding to 57% and 43%, respectively (see Appendix A for details). Notably, the share of English-taught programs is relatively high in the Italian higher-education context, suggesting a

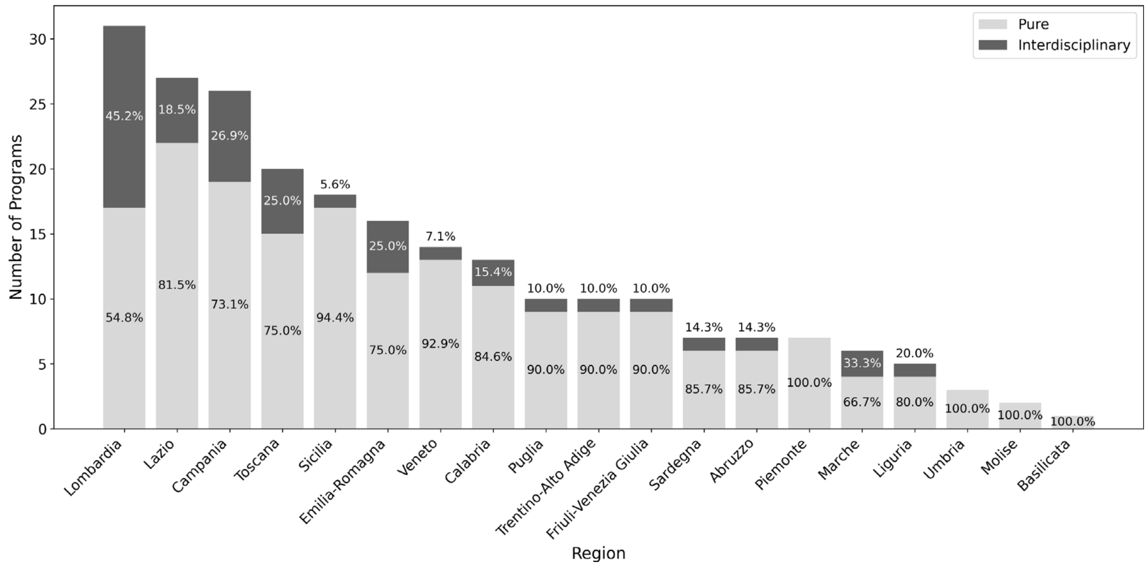


**Fig. 6.** Distribution of pure and interdisciplinary ICT programs by region. Bars report absolute counts of the number of programs, with percentages indicating the regional share of interdisciplinary programs. For the sake of completeness, a map of Italian regions is shown in Appendix B.

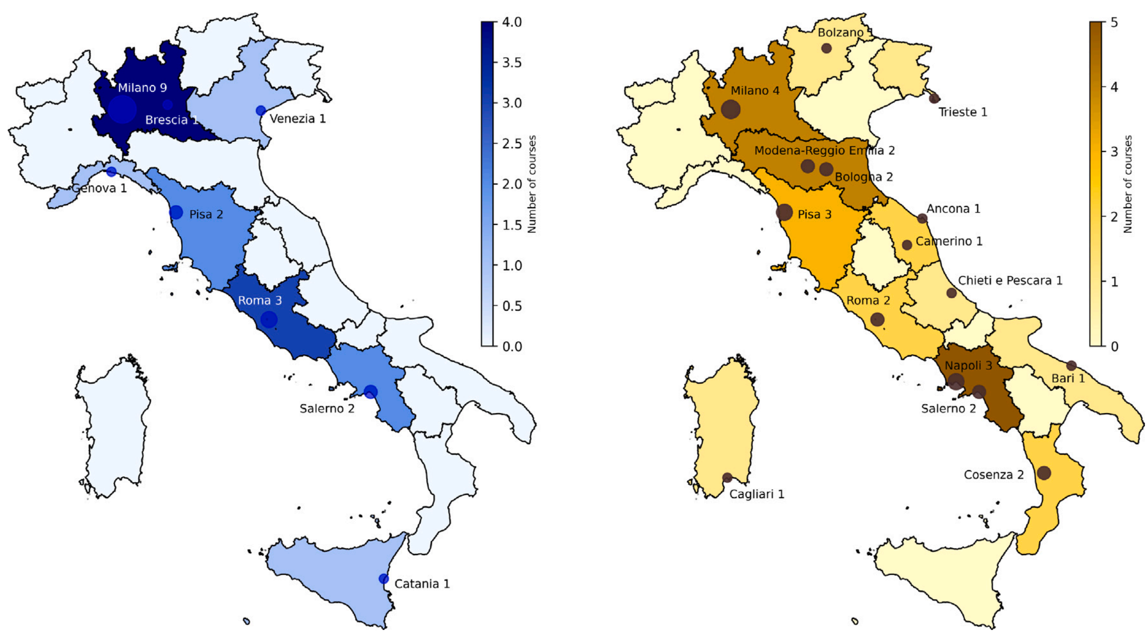


**Fig. 7.** Geographical distribution of interdisciplinary courses taught in English (map on the left) and interdisciplinary courses taught in Italian (map on right).

strong international orientation of ICT-related interdisciplinary offerings. The geographical distribution of programs by language, however, is uneven, as highlighted in Fig. 7. English-taught interdisciplinary programs are strongly concentrated in a limited number of academic hubs, most notably in Milan, followed by Rome and Pisa, with only isolated offerings in other cities. By contrast, Italian-taught interdisciplinary programs exhibit a broader spatial distribution, spanning a wider set of regions and urban centers across the country. This divergence suggests that English-taught interdisciplinary ICT programs tend to be associated with large, internationally oriented universities and metropolitan areas, whereas Italian-taught programs are more diffusely embedded in the national higher-education system. Overall, Fig. 7 reinforces the idea that internationalization and interdisciplinarity in ICT education often co-evolve, but remain geographically concentrated rather than uniformly distributed.

## 5. Interdisciplinarity and gender dynamics: results and discussion

In this section we examine the impact of interdisciplinarity on gender dynamics. In Section 5.1 we provide an overview of gender distribution across fields relevant to the interdisciplinary programs considered in this study, drawing on data spanning more than twenty years. In Section 5.2 we delve into a focused analysis, examining the relationship between interdisciplinarity and gender patterns in computing education.

### *5.1. Computer science in context: a comparative perspective*

The majority of students enrolled in Italian university programs is composed by females (56%), but the percentage decreases to 36.7% if we focus on STEM fields. Computer science and ICT technologies and industrial and information engineering, among the 15 MUR fields

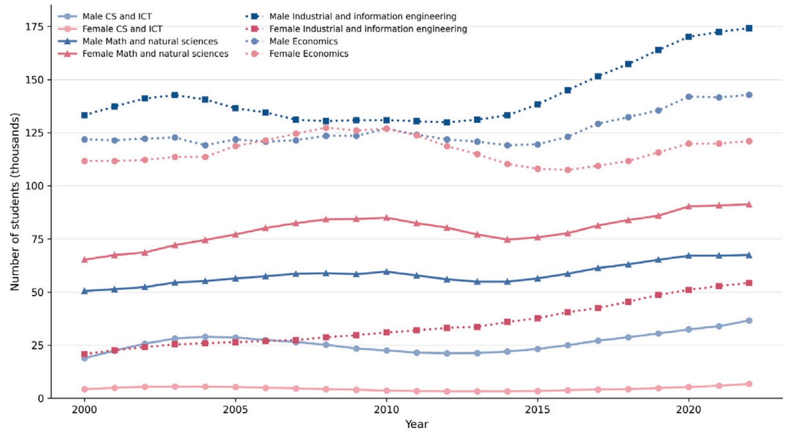


**Fig. 8.** Longitudinal trends in gender-disaggregated student enrollment across four fields of study: Computer science and ICT technologies, Industrial and information engineering, Mathematics and natural sciences, Economics.

of study, are the worst in terms of gender gap, with percentages of men that are respectively 84% and 76%. Data about enrolled students per field of study over the last 23 academic years, obtained from the *Enrolled-students-per-sector* dataset, are charted in Fig. 8 focusing on four fields of study that are relevant to our analysis: computer science and ICT technologies, economics, industrial and information engineering, mathematics and natural sciences. For simplicity, the graphs' x-axes do not show the full academic year (e.g., 2000/2001) but only the starting year (e.g., 2000).

The charts highlight different phenomena. First, fields have rather different sizes, with industrial and information engineering being the largest. A more detailed analysis not reported in this paper reveals that, in the two domains contained in this field, the industrial part involves the largest majority of students. This is also confirmed by the fact that Computer Science and ICT, which is a field strictly related to information engineering, is the smallest of the four domains. Its growth is however impressive: with respect to academic year 2012–13, the number of male students increased by almost 50%.

Mathematics and natural sciences show a prevalence of female students: upon closer inspection, this is especially due to domains such as biology. The gender gap in economics – quite surprisingly – got worse in the last ten years, starting from an almost perfectly balanced situation in 2010. Both industrial and information engineering and CS and ICT technologies show improvements in terms of gender gap, but are still far from obtaining a balanced situation. Moreover, while the number of enrolled female students in ICT has been rising in recent years, this increase has occurred at a markedly slower pace than for their male counterparts.

### 5.2. Gender dynamics in interdisciplinary programs

Since non-computing fields typically exhibit higher female enrollment than ICT domains (see, e.g., Economics in Fig. 8), it is natural to ask whether blending computer science with such disciplines can make ICT topics more appealing to women, thereby increasing female enrollment shares. In this section we aim to shed light on this question. Beyond computer science as a whole, we also examine several specific subdomains, namely artificial intelligence, big data, cybersecurity, data analytics, and data science. As noted in Section 3.3, a variety of interdisciplinary programs in Italy, at both the Bachelor's and Master's levels, explicitly target these areas. Moreover, as observed in Demetrescu et al. (2022), different topics and application areas within computer science may vary in their appeal, indicating that gender participation patterns can differ substantially across computing subdomains.

Our numerical results are summarized in Tables 1 and 2, respectively. The first four rows of Table 1 report raw counts of enrolled students by gender and program type (pure vs. interdisciplinary). The remaining rows present the aggregate and normalized metrics introduced in Section 3.4. Conditional metrics are given in Table 2. As noted above, students are assigned to six subdomains based on ICT-related keywords extracted from program titles. Column totals across subdomains may not sum to the overall total, since a given student may be associated with multiple subdomains. This overlap may also occur within pure programs, as some degree titles explicitly mention more than one computing area (e.g., *Computer Engineering, Cybersecurity and Artificial Intelligence* or *Applied Computer Science and Artificial Intelligence*). The final "Total" column reports only unique students.

*Interdisciplinarity in the student population.* We first examine interdisciplinary enrollment. The absolute counts $P$ and $I$ of students in pure and interdisciplinary programs confirm that traditional ICT programs dominate enrollment across all subdomains (see Table 1). Computer science accounts for the vast majority of students (318 642 out of 340 276, i.e., more than 93%), both in pure and interdisciplinary variants, while interdisciplinary tracks remain comparatively limited in size. Nonetheless, interdisciplinarity is already non-negligible, especially in data-related areas. In particular, the share $I/T$ of students enrolled in interdisciplinary programs varies widely, ranging from about 4%–6% in areas such as computer science and cybersecurity to more than 25% in big data and over 30% in data science. This indicates that interdisciplinarity is unevenly distributed across ICT domains and is particularly concentrated in data-centric fields, which nevertheless account for a smaller fraction of overall enrollment.

*Gender shares.* Turning to gender distribution and relative shares, the metrics in Table 1 reveal substantial differences across ICT subdomains. Overall female representation remains low, with women accounting for only 15% of the total ICT student population ($F/T$), confirming the persistence of a pronounced gender gap. At the same time, marked variation emerges across areas: female representation is lowest in cybersecurity, while data-related domains exhibit the highest shares of female students.

Conditional shares in Table 2 reveal systematic and highly informative gender differences associated with interdisciplinarity. Across all subdomains, the share of interdisciplinary enrollment is consistently higher among female students than among male students. In the overall student population, $IF/F$ equals 12%, whereas $IM/M$ is much lower at 5%. This gap is particularly pronounced in data science and data analytics, where roughly one third of female students are enrolled in interdisciplinary programs. Moreover, within interdisciplinary programs, female representation is substantially higher than in pure programs, often approaching or exceeding 40%, whereas pure ICT programs remain heavily male dominated. Overall, the female share is on average more

**Table 1**
Raw number of students per gender in each ICT-related area, together with aggregate totals and normalized proportions capturing the overall distribution by gender and interdisciplinarity. Percentages are rounded to the nearest integer.

| | | Artificial intelligence | Big data | Computer science | Cyber-security | Data analytics | Data science | Total |
|---|---|---|---|---|---|---|---|---|
| Pure males | $PM$ | 4185 | 2011 | 262 344 | 5798 | 1551 | 4874 | 275 037 |
| Interdisciplinary males | $IM$ | 154 | 594 | 11 031 | 169 | 350 | 1965 | 14 263 |
| Pure females | $PF$ | 1195 | 477 | 40 826 | 749 | 581 | 1848 | 44 787 |
| Interdisciplinary females | $IF$ | 136 | 244 | 4441 | 104 | 255 | 1009 | 6189 |
| Totals | | | | | | | | |
| Total | $T$ | 5670 | 3326 | 318 642 | 6820 | 2737 | 9696 | 340 276 |
| Pure/Interdisciplinary distr. | $P$ | 5380 | 2488 | 303 170 | 6547 | 2132 | 6722 | 319 824 |
| | $I$ | 290 | 838 | 15 472 | 273 | 605 | 2974 | 20 452 |
| Gender distribution | $M$ | 4339 | 2605 | 273 375 | 5967 | 1901 | 6839 | 289 300 |
| | $F$ | 1331 | 721 | 45 267 | 853 | 836 | 2857 | 50 976 |
| Normalized proportions | | | | | | | | |
| Interdisciplinarity shares | $P/T$ | 95% | 75% | 95% | 96% | 78% | 69% | 94% |
| | $I/T$ | 5% | 25% | 5% | 4% | 22% | 31% | 6% |
| Gender shares | $M/T$ | 77% | 78% | 86% | 88% | 70% | 70% | 85% |
| | $F/T$ | 23% | 22% | 14% | 12% | 30% | 30% | 15% |

**Table 2**
Conditional shares and summary indices capturing the relationship between gender composition and interdisciplinarity across ICT-related areas. Percentages are rounded to the nearest integer.

| | | Artificial intelligence | Big data | Computer science | Cyber-security | Data analytics | Data science | Total |
|---|---|---|---|---|---|---|---|---|
| Conditional shares | | | | | | | | |
| Interdisc. share among males | $IM/M$ | 3% | 23% | 4% | 3% | 18% | 29% | 5% |
| | $PM/M$ | 97% | 77% | 96% | 97% | 82% | 71% | 95% |
| Interdisc. share among females | $IF/F$ | 10% | 34% | 10% | 12% | 31% | 35% | 12% |
| | $PF/F$ | 90% | 66% | 90% | 88% | 70% | 65% | 88% |
| Gender share among pure | $PM/P$ | 78% | 81% | 87% | 89% | 73% | 73% | 86% |
| | $PF/P$ | 22% | 19% | 13% | 11% | 27% | 27% | 14% |
| Gender share among interdisc. | $IM/I$ | 53% | 71% | 71% | 62% | 58% | 66% | 70% |
| | $IF/I$ | 47% | 29% | 29% | 38% | 42% | 34% | 30% |
| Summary indices | | | | | | | | |
| Gender balance index | $GBI$ | 0.47 | 0.43 | 0.28 | 0.25 | 0.61 | 0.59 | 0.30 |
| Gender balance index pure | $GBI_P$ | 0.44 | 0.38 | 0.27 | 0.23 | 0.55 | 0.55 | 0.28 |
| Gender balance index interdisc. | $GBI_I$ | **0.94** | **0.58** | **0.57** | **0.76** | **0.84** | **0.68** | **0.61** |

than 16 percentage points higher in interdisciplinary programs than in pure ones: $IF/I$ is 30%, while $PF/P$ is only 14%.

Gender shares in pure and interdisciplinary programs are also illustrated in Fig. 9. The figure shows that some domains benefit particularly strongly from interdisciplinarity, especially those that are traditionally more male dominated. Notably, female enrollment increases by about 25% in artificial intelligence and by 27% in cybersecurity when these areas are offered within interdisciplinary programs. It should be noted, however, that the student populations in these fields are substantially smaller than that of computer science as a whole, which alone accounts for more than 318 000 students. By contrast, data-related programs appear to benefit less from combinations with non-ICT topics in terms of female participation. We conjecture that this may be due to the intrinsically broader and more application-oriented nature of data science disciplines, which often encompass a variety of topics even in pure programs. Indeed, pure data-related programs already exhibit a lower proportion of male students (73%) compared to pure computer science programs (87%).

*Gender balance: summary indices.* The patterns discussed above are synthesized in Table 2 by the gender balance indices. While the GBI remains uniformly low for pure ICT programs, reflecting strong gender imbalance, it increases markedly for interdisciplinary programs across all subdomains. In a few cases, such as artificial intelligence and data analytics, the index $GBI_I$ approaches values close to 1, corresponding to near gender parity. This contrast indicates that interdisciplinarity is associated with more balanced gender compositions, a feature that is not observed in traditional ICT curricula.

Overall, Table 2 provides consistent quantitative evidence that interdisciplinarity is beneficial from a gender perspective: interdisciplinary ICT-related programs, although still limited in absolute size, are substantially more gender-balanced than their pure counterparts and are associated with higher female participation across all considered subdomains.

## 6. Discussion and conclusions

This article examined the relationship between interdisciplinarity and gender patterns in computing education, using the Italian higher-education system as a large-scale case study. Combining national enrollment data with a systematic classification of ICT-related degree programs, we show that interdisciplinary curricula are consistently associated with more gender-balanced participation than pure computing programs. Overall, women account for only 15% of ICT students, but their share rises from 14% in pure programs to 30% in interdisciplinary programs. This pattern is also reflected in the gender balance index, which increases from 0.28 for pure ICT programs to 0.61 for interdisciplinary ones.

These findings directly address the research questions posed in the introduction. With respect to RQ1, we show that interdisciplinary ICT programs in Italy remain limited in number and geographically uneven, but they form a recognizable segment of the national academic

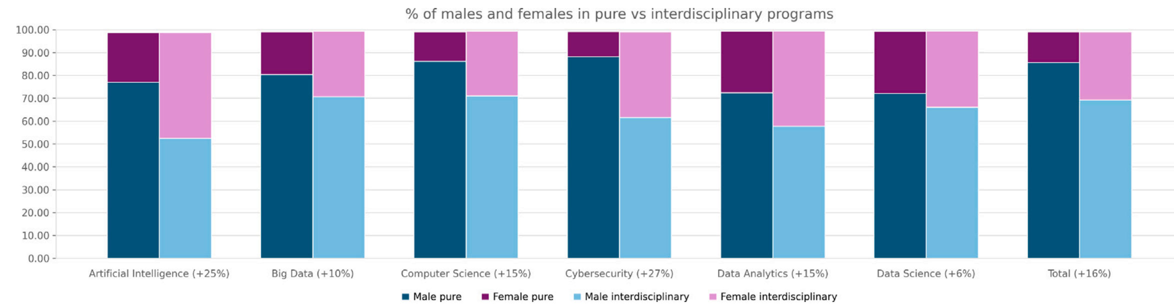


**Fig. 9.** Female vs. male enrollment in pure and interdisciplinary ICT-related programs across different domains.

offer. They most frequently connect computing and data-science topics with socio-economic and managerial domains, including economics, management, finance, business, and governance. With respect to RQ2, we find a systematic association between interdisciplinarity and higher female participation. With respect to RQ3, we highlight that this association is not uniform across subdomains: it is particularly strong in highly male-dominated areas such as artificial intelligence and cybersecurity, while it is smaller in data-related areas, where pure programs are already comparatively more gender-balanced.

Beyond the Italian case, our findings contribute to the literature on broadening participation in computing. The higher female shares observed in interdisciplinary programs are consistent with the view that computing participation is shaped not only by access to technical content, but also by the cultural and epistemological frames through which computing is presented. Programs that connect computing with other domains may make computing visible as a tool for addressing broader problems, rather than as a narrowly technical or isolated discipline. From this perspective, interdisciplinarity should not be interpreted only as a curricular response to labor-market demand or to the growing pervasiveness of computing, but also as a potential broadening-participation strategy. From a policy perspective, universities and policymakers could thus consider interdisciplinary ICT programs as part of a broader portfolio of interventions aimed at reducing gender disparities in computing. Such programs should not replace efforts to make traditional computer science curricula more inclusive. Rather, they can complement these efforts by creating additional entry points into computing, especially for students attracted by application-oriented, socio-economic, creative, or socially grounded contexts.

Finally, we note that these results should be interpreted in light of the observational nature of our analysis, which does not allow us to establish causal mechanisms underlying students' choices. Moreover, our operational definition of interdisciplinarity is based on program titles, degree classes, and national enrollment records, rather than on fine-grained curricular content or students' motivations. Future work may therefore extend this analysis through cross-country comparisons, more detailed curricular studies, and longitudinal analyses of student trajectories. Complementary qualitative studies, such as surveys or interviews with students enrolled in interdisciplinary programs, could shed light on motivations, expectations, and perceived barriers. Tracking retention and post-graduation outcomes would also help assess whether interdisciplinary pathways not only attract more women to computing, but also sustain their long-term participation and success in the field.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Catalogue of interdisciplinary ICT-related programs available in Italian universities at the time of the study

We list in this appendix the interdisciplinary programs considered in our study. For programs offered in Italian, the English translation used in the analysis is provided in parentheses. We remark that such English translations do not correspond to official program names. The lists include 47 entries in total, corresponding to 44 distinct programs. Three programs are offered in both Italian and English and therefore appear twice.

*Interdisciplinary programs offered in English*

| City | Region | Name |
|---|---|---|
| Brescia | Lombardia | Analytics and Data Science for Economics and Management |
| Catania | Sicilia | Data Science for Management |
| Genova | Liguria | Economics & Data Science |
| Milano | Lombardia | Data Science for Economics |
| Milano | Lombardia | Data Science and Economics |
| Milano | Lombardia | Artificial Intelligence for Science and Technology |
| Milano | Lombardia | Economics, Management and Computer Science |
| Milano | Lombardia | Cyber Risk Strategy and Governance |
| Milano | Lombardia | Data Science and Business Analytics |
| Milano | Lombardia | Applied Data Science for Banking and Finance |
| Milano | Lombardia | Data Analytics for Business |
| Milano | Lombardia | Data Science and Actuarial Sciences |

| City | Region | Name |
|---|---|---|
| Pisa | Toscana | Data Science and Business Informatics |
| Pisa | Toscana | Business Informatics |
| Roma | Lazio | Molecular Biology, Medicinal Chemistry and Computer Science for Pharmaceutical Applications |
| Roma | Lazio | Data Science and Management |
| Roma | Lazio | Management and Computer Science |
| Salerno | Campania | Data Science and Innovation Management |
| Salerno | Campania | Business Innovation and Informatics |
| Venezia | Veneto | Data Analytics for Business and Society |

*Interdisciplinary programs offered in Italian*

| City | Region | Name |
|---|---|---|
| Chieti e Pescara | Abruzzo | Economia e Informatica per l'Impresa (Economics and Computer Science for Business) |
| Bari | Puglia | Informatica e Comunicazione Digitale (Computer Science and Digital Communication) |
| Bologna | Emilia-Romagna | Informatica Umanistica e Cultura Digitale (Digital Humanities and Digital Culture) |
| Bologna | Emilia-Romagna | Informatica per il Management (Computer Science for Management) |
| Modena e Reggio Emilia | Emilia-Romagna | Analisi dei Dati per l'Economia e il Management (Data Analysis for Economics and Management) |
| Modena e Reggio Emilia | Emilia-Romagna | Analisi dei Dati per l'Impresa e la Finanza (Data Analysis for Business and Finance) |
| Cagliari | Sardegna | Data Science, Business Analytics e Innovazione (Data Science, Business Analytics and Innovation) |
| Cosenza | Calabria | Data Science per le Strategie Aziendali (Data Science for Business Strategies) |
| Cosenza | Calabria | Statistica ed Informatica per le Decisioni e le Analisi di Mercato (Statistics and Computer Science for Decision Making and Market Analysis) |
| Napoli | Campania | Linguaggi Multimediali e Informatica Umanistica (Multimedia Languages and Digital Humanities) |
| Napoli | Campania | Statistica e Informatica per l'Azienda, la Finanza e le Assicurazioni (Statistics and Computer Science for Business, Finance and Insurance) |
| Napoli - telematica | Campania | Informatica per le Aziende Digitali (Computer Science for Digital Companies) |
| Salerno | Campania | Business, Innovazione ed Informatica (Business, Innovation and Informatics) |
| Salerno | Campania | Data Science e Gestione dell'Innovazione (Data Science and Innovation Management) |
| Camerino | Marche | Informatica per la Comunicazione Digitale (Computer Science for Digital Communication) |
| Ancona | Marche | Data Science per l'Economia e le Imprese (Data Science for Economics and Business) |
| Pisa | Toscana | Informatica per l'Economia e per l'Azienda (Computer Science for Economics and Business) |
| Pisa | Toscana | Informatica umanistica (Digital Humanities) |
| Pisa | Toscana | Scienza dei Dati per l'Economia e per l'Azienda (Data Science for Economics and Business) |
| Roma | Lazio | Filosofia e Intelligenza Artificiale (Philosophy and Artificial Intelligence) |
| Roma | Lazio | Economia e Big Data (Economics and Big Data) |
| Trieste | Friuli Venezia Giulia | Statistica e Informatica per l'Azienda, la Finanza e l'Assicurazione (Statistics and Computer Science for Business, Finance and Insurance) |
| Milano | Lombardia | Scienza dei Dati e Economia (Data Science and Economics) |
| Milano | Lombardia | Informatica musicale (Computer Science for Music) |
| Milano | Lombardia | Informatica per la Comunicazione Digitale (Computer Science for Digital Communication) |
| Milano | Lombardia | Intelligenza Artificiale, Impresa e Società (Artificial Intelligence, Business and Society) |

| City | Region | Name |
|---|---|---|
| Bolzano | Trentino-Alto Adige | Informatica e Management delle Aziende Digitali (Computer Science and Management of Digital Companies) |

## Appendix B. Map of Italian regions


## Data availability

Data will be made available on request.

## References


Babeş-Vroman, M., Nguyen, T. N., & Nguyen, T. D. (2022). Gender diversity in computer science at a large public R1 research university: Reporting on a self-study. *ACM Transactions on Computing Education*, *22*(2), http://dx.doi.org/10.1145/3471572.

Bares, W., Manaris, B., & McCauley, R. (2018). Gender equity in computer science through computing in the arts: A six-year longitudinal study. *Computer Science Education*, *28*(3), 191–210. http://dx.doi.org/10.1080/08993408.2018.1519322.

Beyer, S. (2014). Why are women underrepresented in computer science? Gender differences in stereotypes, self-efficacy, values, and interests and predictors of future CS course-taking and grades. *Computer Science Education*, *24*(2–3), 153–192. http://dx.doi.org/10.1080/08993408.2014.963363.

Blickenstaff, J. C. (2005). Women and science careers: Leaky pipeline or gender filter? *Gender and Education*, *17*(4), 369–386. http://dx.doi.org/10.1080/09540250500145072.

Brodley, C. E., Barr, V., Gunter, E. L., Guzdial, M., Libeskind-Hadas, R., & Manaris, B. Z. (2024). ACM 2023: CS + X - Challenges and opportunities in developing interdisciplinary-computing curricula. *Inroads*, *15*(3), 42–50. http://dx.doi.org/10.1145/3687131.

Brodley, C. E., Hescott, B. J., Biron, J., Ressing, A., Peiken, M., Maravetz, S., & Mislove, A. (2022). Broadening participation in computing via ubiquitous combined majors (CS+X). In *Proceedings of the 53rd ACM technical symposium on computer science education* (pp. 544–550). ACM, http://dx.doi.org/10.1145/3478431.3499352.

Cheryan, S., Master, A., & Meltzoff, A. N. (2015). Cultural stereotypes as gatekeepers: Increasing girls' interest in computer science and engineering by diversifying stereotypes. *Frontiers in Psychology*, *6*, http://dx.doi.org/10.3389/fpsyg.2015.00049.

Dabić, M., Posinković, T. O., Maley, J. F., Vlačić, B., Marzi, G., & Kraus, S. (2024). Exploring the multifaceted challenges of women in engineering: A comprehensive literature review. *IEEE Transactions on Engineering Management*, *71*, 3325–3339. http://dx.doi.org/10.1109/TEM.2023.3342980.

Dabu, C.-M. (2017). Computer science education and interdisciplinarity. In A. V. Dos Santos, & J. C. Krause (Eds.), *Science education - research and new technologies*. IntechOpen, http://dx.doi.org/10.5772/intechopen.68580, https://www.intechopen.com/chapters/55209.

Del Carpio, L., & Guadalupe, M. (2022). More women in tech? Evidence from a field experiment addressing social identity. *Management Science*, *68*(5), 3196–3218. http://dx.doi.org/10.1287/mnsc.2021.4035.

Demetrescu, C., Finocchi, I., Ribichini, A., & Schaerf, M. (2022). On computer science research and its temporal evolution. *Scientometrics*, *127*(8), 4913–4938. http://dx.doi.org/10.1007/s11192-022-04445-z.

Dlodlo, N. (2009). Access to ICT education for girls and women in rural South Africa: A case study. *Technology in Society*, *31*(2), 168–175. http://dx.doi.org/10.1016/j.techsoc.2009.03.003.

Eurostat (2023). Men represented 84% of people employed with an ICT education. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20231016-1.

Eurostat (2025a). Digitalisation in Europe – 2025 edition. https://ec.europa.eu/eurostat/web/interactive-publications/digitalisation-2025.

Eurostat (2025b). ICT specialists – statistics on hard-to-fill vacancies in enterprises. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=ICT_specialists_-_statistics_on_hard-to-fill_vacancies_in_enterprises.

Falkner, K. E., Szabo, C., Michell, D., Szorenyi, A., & Thyer, S. (2015). Gender gap in academia: Perceptions of female computer science academics. In *Proceedings of the 2015 ACM conference on innovation and technology in computer science education* (pp. 111–116). ACM, http://dx.doi.org/10.1145/2729094.2742595.

Gergis, D., & Kachala, M. (2021). Two ways to improve gender balance in tech. *Harvard Business Review*, https://hbr.org/2021/12/two-ways-to-improve-gender-balance-in-tech.

Gorbacheva, E., Beekhuyzen, J., vom Brocke, J., & Becker, J. (2019). Directions for research on gender imbalance in the IT profession. *European Journal of Information Systems*, *28*(1), 43–67. http://dx.doi.org/10.1080/0960085X.2018.1495893.

Hannon, J., Hocking, C., Legge, K., & Lugg, A. (2018). Sustaining interdisciplinary education: Developing boundary crossing governance. *Higher Education Research & Development*, *37*(7), 1424–1438. http://dx.doi.org/10.1080/07294360.2018.1484706.

Harris, N., Kruck, S. E., Cushman, P., & Anderson, R. D. (2009). Technology majors: Why are women absent? *Journal of Computer Information Systems*, *50*(2), 23–30. http://dx.doi.org/10.1080/08874417.2009.11645381.

Hill, C., Corbett, C., & Rose, A. S. (2010). *Why So few? Women in science, technology, engineering, and mathematics*. American Association of University Women.

Isenegger, K., Fowler, M., Hammer, D., Leff, B., Gertner, Y., Hegeman-Davis, R., & Pitt, L. (2025). Integrating a CS+Social Science project into STEM and non-STEM high school courses. In *Proceedings of the 56th ACM technical symposium on computer science education* (pp. 540–546). ACM, http://dx.doi.org/10.1145/3641554.3701818.

Jaccheri, L., Pereira, C., & Fast, S. (2020). Gender issues in computer science: Lessons learnt and reflections for the future. In *2020 22nd international symposium on symbolic and numeric algorithms for scientific computing* (pp. 9–16). IEEE, http://dx.doi.org/10.1109/SYNASC51798.2020.00014.

Kafai, Y. B., Heeter, C., Denner, J., & Sun, J. Y. (Eds.), (2008). *Beyond Barbie and Mortal Kombat: New Perspectives on Gender and Gaming*. MIT Press.

Klawe, M., & Shneiderman, B. (2005). Crisis and opportunity in computer science. *Communications of the ACM*, *48*(11), 27–28. http://dx.doi.org/10.1145/1096000.1096024.

Lane, J. N., Lakhani, K. R., & Fernandez, R. M. (2024). Setting gendered expectations? Recruiter outreach bias in online tech training programs. *Organization Science*, *35*(3), 911–927. http://dx.doi.org/10.1287/orsc.2022.16499.

Marquardt, K., & Happe, L. (2024). Crossing borders: The beauty of computer science beyond disciplinary borders. In *11th ACM celebration of women in computing*. http://dx.doi.org/10.5445/IR/1000172166, https://publikationen.bibliothek.kit.edu/1000172166. Poster.

National Center for Science and Engineering Statistics (2023). *Diversity and STEM: Women, minorities, and persons with disabilities 2023: Special report no. NSF 23-315*, National Science Foundation.

Perez-Felkner, L., Erichsen, K., Li, Y., Chen, J., Hu, S., Surmeier, L. R., & Shore, C. (2025). Computing education interventions to increase gender equity from 2000 to 2020: A systematic literature review. *Review of Educational Research*, *95*(3), 536–580. http://dx.doi.org/10.3102/00346543241241536.

Pinkard, N., Erete, S., Martin, C. K., & McKinney de Royston, M. (2017). Digital youth divas: Exploring narrative-driven curriculum to spark middle school girls' interest in computational activities. *Journal of the Learning Sciences*, *26*(3), 477–516. http://dx.doi.org/10.1080/10508406.2017.1307199.

Pournaghshband, V., & Medel, P. (2020). Promoting diversity-inclusive computer science pedagogies: A multidimensional perspective. In *Proceedings of the 2020 ACM conference on innovation and technology in computer science education* (pp. 219–224). Association for Computing Machinery, http://dx.doi.org/10.1145/3341525.3387360.

Powley, W., & Townsend, G. C. (2024). A town meeting: SIGCSE committee on expanding the women-in-computing community. *vol. 2*, In *Proceedings of the 55th ACM technical symposium on computer science education* (p. 1920). ACM, http://dx.doi.org/10.1145/3626253.3635367.

Pulimood, S. M., Bates, D. C., & Pearson, K. (2024). Immersing undergraduates in interdisciplinary course collaborations. In *Proc. 55th ACM technical symposium on computer science education* (pp. 1782–1783). ACM, http://dx.doi.org/10.1145/3626253.3635598.

Rankin, Y. A., Thomas, J. O., & Erete, S. (2021). Real talk: Saturated sites of violence in CS education. In *Proceedings of the 52nd ACM technical symposium on computer science education* (pp. 802–808). ACM, http://dx.doi.org/10.1145/3408877.3432432.

Rapoport, E., Volkova, N. V., & Barajas, A. (2026). Women and men in tech: Invisible barriers, gendered self-perception, and the social reshaping of work. *Technology in Society*, *84*, http://dx.doi.org/10.1016/j.techsoc.2025.103116.

Rosales, J., Melville, E., Wright, M. A., Akhtar, S., & Wright, R. N. (2024). The experience of near-peer computing mentors: Strengthening and expanding women's computing identities in undergraduate interdisciplinary contexts. In *Proceedings of the 55th ACM technical symposium on computer science education* (pp. 1154–1160). ACM, http://dx.doi.org/10.1145/3626252.3630946.

Searle, K. A., Fields, D. A., & Kafai, Y. B. (2016). Is sewing a "girl's sport"? Addressing gender issues in making with electronic textiles. In K. A. Peppler, E. R. Halverson, & Y. B. Kafai (Eds.), *vol. 2*, *Makeology: Makers as learners* (1st ed.). (pp. 72–84). New York: Routledge, http://dx.doi.org/10.4324/9781315726496-5.

Sedgewick, R., & Wayne, K. (2016). *Computer science: An interdisciplinary approach*. Pearson.

Toti, G., Lindner, P., Gao, A., Baghban Karimi, O., Engineer, R., Hur, J., McNeill, F., Reckinger, S., Robinson, R., Sollazzo, A., & Wicentowski, R. (2025). Diversity, equity, and inclusion in computing science: Culture is the key, curriculum contributes. In L. Barker (Ed.), *Annual conference on innovation and technology in computer science education, iTiCSE*, *Publication of the 2024 working group reports on innovation and technology in computer science education* (pp. 175–225). Association for Computing Machinery, http://dx.doi.org/10.1145/3689187.3709611.

Turkle, S., & Papert, S. (1990). Epistemological pluralism: Styles and voices within the computer culture. *Signs: Journal of Women in Culture and Society*, *16*(1), 128–157. http://dx.doi.org/10.1086/494648.

Wagner, I. (2016). Gender and performance in computer science. *ACM Transactions on Computing Education*, *16*(3), http://dx.doi.org/10.1145/2920173.

World Economic Forum (2025). The future of jobs report 2025. https://www.weforum.org/publications/the-future-of-jobs-report-2025/.

Yang, G., Yao, S., & Dong, X. (2023). Digital economy and wage gap between high- and low-skilled workers. *Digital Economy and Sustainable Development*, *1*, http://dx.doi.org/10.1007/s44265-023-00009-y.

Zhu, J., Lunn, S. J., & Ross, M. (2023). Characterizing women's alternative pathways to a computing career using content analysis. In *Proceedings of the 54th ACM technical symposium on computer science education* (pp. 158–164). ACM, http://dx.doi.org/10.1145/3545945.3569798.

Zilberman, A., & Ice, L. (2021). Why computer occupations are behind strong STEM employment growth in the 2019–29 decade. *Beyond the Numbers: Employment & Unemployment*, *10*(1), https://www.bls.gov/opub/btn/volume-10/why-computer-occupations-are-behind-strong-stem-employment-growth.htm.