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Authentic interdisciplinary online courses for alternative pathways into computer science☆

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ABSTRACT

The field of computer science (CS) is facing a crucial challenge in broadening participation and embracing diversity, especially among underrepresented gender groups. The presented interdisciplinary educational program is an efficient response to this challenge, designed to catalyze diversity in CS through engagement with complex, interest-driven problems. This paper outlines the program's structure, elucidates the pedagogical underpinnings, and reflects on the emergent challenges and opportunities. We delve into how the fusion of CS with other academic disciplines can allure a more varied demographic, emphasizing the engagement of female high school students—a demographic pivotally positioned yet significantly untapped in CS. Through a systematic survey analysis, we measure the program's efficacy in increasing interest in CS and in cultivating an appreciation for its application in addressing real-world, cross-disciplinary challenges. Our findings affirm the program's success in bridging the engagement gap by leveraging students' intrinsic interests, thus charting alternative pathways into the CS field. These insights underscore the critical role of interdisciplinary approaches, establishing a new standard for transformative CS educational methods.

1. Introduction

The field of Computer Science (CS) is at a pivotal juncture, faced with the urgent need to diversify and expand its appeal to a broader audience. Despite its pervasive influence on modern society, CS education has struggled to attract and retain a diverse group of students, particularly from underrepresented gender groups (Vidal et al., 2020). As industries clamour for a workforce that mirrors the multifaceted challenges of the digital age, it is imperative that our educational approaches evolve to meet this demand. The persistent gender gap and the lack of diversity in CS underscore the need for innovative educational strategies that resonate with diverse learners who may feel that their unique interests and non-traditional skills are undervalued in conventional CS settings (Vainionpää et al., 2019; Happe et al., 2021; Wieselmann et al., 2020).

Echoing the sentiments of Dr. Klawe and Dr. Shneiderman, the need for a more interdisciplinary and inclusive approach to CS education is undeniable (Klawe and Shneiderman, 2005). This approach not only addresses the need for diversity but also aligns with the shifting dynamics of CS, which increasingly intersects with various fields, from arts to other sciences. Interdisciplinary courses, by their very nature, offer rich, contextual learning experiences that can demystify CS and present it as an integral part of a wider intellectual landscape, rather than an insular, monolithic domain (Dabu, 2017).

Universities around the world are pioneering the integration of CS with diverse fields such as bioinformatics, cognitive science, and social sciences. These innovative interdisciplinary courses are pivotal in challenging prevailing stereotypes and in demonstrating the multifaceted applications of CS (PhD, 2023; PhD Program, 2023). The subsequent years have only solidified this perspective, with societal advancements and technological innovations indicating an intertwined fate of CS with other fields, setting the stage for the emergence of cross-border sciences (Dabu, 2017). Such interdisciplinary courses are not only enriching but are also becoming crucial for the growth and survival of CS (Margolis and Fisher, 2003). Informatics Europe captures this sentiment well by emphasizing that CS should be studied for both its core value and its applicability to other disciplines (Gander et al., 2013): **The ubiquitous computing-driven progress and innovation in the real world should be mirrored in the experiences our students have while studying CS** Informatics Europe has already recognized this need in their recommendations for CS education (Gander et al., 2013): *"All students should benefit from education in informatics … studied both for its intrinsic intellectual and educational value and for its applications to other disciplines"*

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It is apparent that interdisciplinary programs have the potential to attract not only the most promising students but also the most diverse students, especially women and girls, to CS by providing alternative pathways into the field, simply by building on individual interests (Happe and Buhnova, 2022; Happe et al., 2021). The *interdisciplinary approach* (Millar, 2020) holds strong potential to strengthen women's engagement in CS through authentic interdisciplinary learning experiences. Such courses harness the potential to dispel stereotypes about who can succeed in the field, emphasize the multifaceted nature of CS, and showcase its myriad applications beyond the traditional confines (Happe et al., 2021). Traditional CS education often follows a linear and narrowly focused curriculum, which may inadvertently dissuade a breadth of students from engaging with the field, partly because such curricula do not reflect how diverse interests intersect with CS (Happe and Buhnova, 2022). Through interdisciplinary education, we can foster a learning environment where computing is not only accessible but also meaningful to all students. By tapping into their personal interests, we can create identities and interdisciplinary subcultures that resonate and provide an environment where all students who currently feel left behind can learn CS without feeling trapped by the dominant culture associated with the field today.

Yet, a crucial question remains: **How do interdisciplinary approaches in CS education impact its diversity, especially in terms of gender representation?** This research delves into this pertinent query. We aim to highlight the transformative potential of interdisciplinary CS curricula, especially in high schools, where traditional approaches often fail to captivate female students (Happe and Buhnova, 2022). By exploring the synergies between CS and other fields, we believe that a paradigm shift is possible—one where students, irrespective of their gender or background, find resonance in CS, seeing it not as an isolated field but as a versatile tool that intersects with their diverse interests.

This study introduces an innovative interdisciplinary CS program designed specifically to engage female high school students. The goal is to increase interest and participation in CS by leveraging interdisciplinary expeditions that align with students' personal interests. Our approach is unique in its integration of various academic domains, providing a holistic and engaging learning experience. This approach not only addresses the gender gap but also promotes broader diversity in CS education.

To evaluate the effectiveness of the program, we designed a survey to measure several key indicators: - *Interest in CS:* Changes in students' interest in CS before and after participating in the program. - *Engagement Levels:* Levels of engagement during the program, including participation in activities and interactions with peers and instructors. - *Perceptions of CS:* Students' perceptions of CS as a field, including its relevance and applicability to real-world problems. - *Self-Efficacy:* Students' confidence in their ability to learn and apply CS concepts.

The survey aims to gather insights into how the interdisciplinary program influences these key indicators and to identify evidence of the program's impact on increasing interest and engagement in CS, particularly among female students. By analyzing the survey results, we aim to highlight the effectiveness of interdisciplinary education in addressing gender biases and promoting diversity in CS. These insights will inform educators and policymakers on designing and delivering computer science education that meets the diverse needs of students.

In the subsequent sections, we meticulously examine the benefits of interdisciplinary learning in CS, focusing on its potential to redefine the cultural landscape of the field and make it more inclusive. Through a comprehensive study involving students with diverse backgrounds and predispositions towards CS, this paper demonstrates how tailored interdisciplinary courses can significantly reshape students' attitudes and intentions. Our findings reveal that these authentic interdisciplinary courses not only enhance the enjoyment and curiosity of students towards computer science but also cultivate a greater appreciation for the subject's relevance and applications. We argue that by weaving CS education into a tapestry of varied disciplines, we can attract a more diverse student body, inspire novel applications of computing, and ultimately, contribute to a more equitable and innovative future in technology. The presented findings resonate with the call for educational reformers and policymakers to recognize the urgency of diversifying the field of computer science—not only as a response to the global demand for a skilled workforce but as a fundamental step towards an inclusive and innovative future.

2. Leading question

Central to our investigation is the overarching inquiry: How can CS education become more inclusive, especially for underrepresented demographics such as girls and women? At its core, our pursuit seeks to discern the essential ingredients required to make girls and women find more resonance and engagement in CS. The critical question we pose is: *What should a learning experience encompass to genuinely cater to girls, making them feel engaged, find joy, and identify with it?*

While gender inclusivity is a focal point, our exploration extends beyond it. We aspire to develop strategies that resonate with a diverse audience, factoring in other personal attributes like learning types, player profiles, and experience levels. To better understand these facets, we marry insights from both general educational research and CS-specific educational research.

2.1. Background

The realm of CS education is in the midst of a nuanced transformation. The rise of interdisciplinary education stands as a testament to its efficacy in bolstering student engagement and fostering an inclusive ethos. This approach seems especially potent given students' multifaceted expectations of learning environments, facilitating an enriched engagement and tapping into their latent potential (Williams-Pierce, 2011; Boström and Lassen, 2006; Holmes et al., 2018).

The allure of interdisciplinary education lies in its twofold benefits. On one hand, it instils a heightened sense of self-efficacy and motivation, particularly for those tentative about venturing into CS. For example, existing research (Christensen et al., 2021; Grabarczyk et al., 2022) underscores a marked inclination among women and novices in programming towards activities with a more *people*-oriented demeanour as opposed to a strictly *things*-oriented one. This sentiment is echoed in data suggesting that girls are naturally inclined towards learning experiences that are inquiry-driven, open-ended, and have palpable societal ramifications (Buhnova and Happe, 2020; Happe et al., 2021). In the comprehensive literature review (Happe et al., 2021) we identified similar interdisciplinary computer science programs for high school students. Our program is unique in its approach to integrating short-term, domain-specific expeditions that cater to diverse student interests and backgrounds. No other program was found to offer the same combination of accessibility, interdisciplinary focus, and emphasis on gender diversity.

Furthermore, the dichotomy between *dramatists* and *patterners* learning styles elucidate the matter. The former, characterized by a storytelling mode, resonates strongly with girls (Bentz and Standl, 2022; Tarantino and Di Marco, 2021). Efforts aimed at propagating *social good* are instrumental in elevating self-efficacy and reshaping perceptions about CS, especially among marginalized groups (Bryant et al., 2019; Goldweber et al., 2013). Overcoming deep-rooted stereotypes and rectifying prior negative experiences with programming emerges as a crucial step to light the spark of enthusiasm (Beyer, 2014; Happe et al., 2021; Aivaloglou and Hermans, 2019).

Our course frameworks, thus, pivot around these insights, spotlighting the societal contributions of CS. We transcend the mechanics of mere programming, emphasizing its transformative potential. Case in point: "How can we *save* the bees?" Our courses deftly intertwine narrative elements catering to *dramatists* while also presenting a medley of tasks to appeal to the *patterner*-inclined.

By transitioning our courses online, we harness the power of e-learning, providing prompt, customized feedback (Grella et al., 2017), and a conducive learning ambience free from the spectre of competition, allowing learners to flourish at their rhythm (Ejubovic and Puska, 2019).

2.2. Authentic computer science experiences

There exists a pronounced inclination towards genuine experiences in the realm of Computer Science (CS) (Happe and Buhnova, 2022). Even though inquiry-based pedagogy admirably addresses this by fostering scientific methodologies and thought processes, its adoption remains limited. This disconnect between best practices recommended by research and teachers' familiarity with and willingness to employ them is evident. Enhancing teachers' comfort and engagement with these methods necessitates an appreciation of their advantages and incentives.

For women and students with diverse academic backgrounds, understanding CS within the framework of inquiry-based learning is pivotal (Guzdial, 2010). Three distinct benefits are highlighted by authentic CS experiences:

1. **Illuminating the Diverse Landscape of CS Careers:** Girls often lack exposure to the myriad career trajectories within CS, from data scientists to graphic designers (Outlay et al., 2017). Presenting technology in relation to potential vocational or personal applications has been shown to pivot young girls' perceptions of IT professions (Happe et al., 2021). Furthermore, interdisciplinary contexts usher in more holistic learning experiences, emphasizing real-world applications (Raicu and Furst, 2009).
2. **Highlighting the Relevance of CS:** A prevalent sentiment among women is the aspiration to create positive societal change. CS offers myriad avenues for this, especially within interdisciplinary courses that address pressing global challenges, aligning with the "social good" ethos resonating with many women (Goldweber, 2018). Embedding CS within a relevant societal context can notably shift women's perceptions of the field (Happe et al., 2021).
3. **Valuing Diverse Skill Sets:** As technological advancements evolve, there is an increasing emphasis on "transferable" skills. Women, especially, are showcasing their non-traditional skills when operating at the nexus of diverse disciplines (Happe and Buhnova, 2022). Employers in software engineering are now actively seeking talent capable of addressing multifaceted problems within interdisciplinary teams (Carter, 2014).

Authentic interdisciplinary learning, underscored by inquiry-based pedagogy, invigorates curiosity. This curiosity is not just a motivator but an outcome in itself. Such learning approaches accentuate scientific reasoning, problem-solving abilities, and the tangible role of computer scientists in the real world. Leveraging interdisciplinary diversity in teaching approaches refines students' problem-solving capabilities and enhances creativity, communication skills, and understanding.

Various strategies can infuse formal education with interdisciplinary experiences, whether by incorporating CS solutions into non-CS courses or vice-versa. Such immersive experiences can embolden students to delve deeper into CS, identify with relevant challenges, and feel anchored by their existing knowledge.

Interdisciplinary learning modules pave alternative avenues into subjects by harnessing multifaceted perspectives, often anchored in real-world contexts. Such an expansive view fosters a holistic understanding, empowering students to find success and relevance within CS (Tytler et al., 2019). There is ample evidence showcasing the positive impact of interdisciplinary projects on student engagement (Ng and Fergusson, 2020; Tytler et al., 2019). In particular, alternative pathways can illuminate the interconnections between CS and other fields for girls (Happe and Buhnova, 2022), and innovative teaching approaches can bolster girls' confidence in pursuing STEM post-schooling (Ng and Fergusson, 2020).

E-Learning and *Gamification* are potent tools that harness the strengths of digital modalities. Massive Open Online Courses (MOOCs), for instance, empower students to progress at their individual pace, while gamified platforms enhance motivation and engagement (Manzano-León et al., 2021).

2.3. Teachers' role in interdisciplinary teaching practice

Teachers straddling multiple subjects grapple with the formidable challenge of mastering content and crafting effective pedagogical strategies across disciplines. The efficacy of a learning environment is invariably tethered to the educator's approach (Hattie, 2008). Beyond the formal curricular mandate, educators shoulder the responsibility of igniting student enthusiasm. Yet, the diverse backgrounds and expectations of students in SE classes present a unique set of challenges.

Interdisciplinary teaching, though promising, is resource-intensive. The very essence of interdisciplinarity – melding knowledge across domains – can be daunting for educators unfamiliar with the associated disciplines (Tytler et al., 2019).

Our initiative seeks to bolster educators by furnishing them with innovative tools that amplify the reach of authentic CS experiences. This not only alleviates the preparatory burden but also refocuses their energy on their true passion—facilitating impactful learning. The positive impact of such a tool was succinctly encapsulated by a teacher who noted its intuitive design and the palpable student engagement it fostered.

3. Organization of the program

In September 2020, the RockStartIT Program secured approval and funding from the Vector Foundation. Subsequently, it was integrated into the suite of educational programs at the Karlsruhe Institute of Technology (KIT) in Germany, catering to high school students. The primary objective of this program is to augment the engagement of a diverse student body in the following research areas:

- Facilitating authentic interdisciplinary experiences in Computer Science (CS) that align with students' daily lives and promote problem-based learning.
- Offering structured guidance through inquiry, complemented by personalized feedback that emphasizes positive reinforcement.
- Equipping educators with user-friendly interdisciplinary resources.

RockStartIT distinguishes itself by structuring its content into unique domain-integrating courses, termed *expeditions* (see Table 1). These expeditions are not merely about knowledge acquisition. Instead, they represent immersive journeys where students delve into problems, explore new methodologies, and drive change. We have designed the program such that engaging scenarios or challenges spark curiosity. Within this context, students naturally navigate their way, posing and addressing questions using CS techniques, tools, and data. The process involves crafting compelling questions or hypotheses that instigate tasks like data collection or analysis. Here, students deploy CS methods and tools to reason, evaluate, and draw conclusions about their inquiries. Hence, the emphasis is on understanding CS through hands-on scientific exploration, presenting a more holistic view than conventional introductory CS courses.

In these expeditions, students learn computational thinking as a tool to address challenges across various fields, rather than as a mere academic subject. Every task in the expeditions is supplemented by constructive feedback. While accurate solutions receive acknowledgment

Table 1
Overview of current interdisciplinary expeditions of RockStartIT.

#	Expedition	CS topic	Keywords	Interdisciplinary Context
	Save the Bees			
1	Know your Mission	Scientific thinking	Science, process, critical thinking, problem solving	Biology, sustainability, writing, math
2	Expedition into the Internet	Web development	Internet, browser, copyright, url, html, tags, css	
3	Journey through Data 1 & 2	Data science	Data, database, sql, visualization, critical thinking	
4	Bee Lore for the AI	Artificial intelligence	Data, ai, machine learning, image recognition	
5	Team-Challenge	Project management	Team work, roles, CS jobs	
	In Search of Other Life			
6	Rocket Launch	Algorithm	Variables, conditions, loops, scratch	Astronomy, physics, photography
7	The Camera Sensor	Signal processing	Signal, analog, digital, discrete	
8	Take a Photo, Save the Photo	Encoding	Binary, pixel, color coding, storage	
9	Sending the Photo back	Error correction		
	Save the Climate			
10	Climate in danger	Computational thinking	Decomposition, pattern matching, abstraction	Geography, sustainability, biology
11	An Ocean of Legumes	Sorting	Bucket sort, scheduling, cache, trees	
12	A Question of the Season	Encoding	Codes, abstraction, binary coding	
	Visual Arts			Arts, color theory
13	Learn the Computer Colors!	Encoding	Pixel, color coding	

highlighting specific achievements, errors are met with explanatory hints or encouragements for reattempts.

A pivotal goal of RockStartIT is to reshape students' perspectives on CS. This involves presenting an expansive, modern understanding of its concepts and their omnipresent applications. A significant focus is on illustrating how computational thinking is underscored by interdisciplinary significance and the potential for transformative impact.

3.1. Course content overview

Crafted to fuel a passion for technology and computer science among girls, this program interweaves multiple disciplines. The RockStartIt initiative introduces a suite of interactive online courses, called expeditions. Each expedition has its primary focus staged in an interdisciplinary context, for example, it could be the understanding and deploying data science techniques in the context of biology. Given its versatile nature, data science serves as a bridge between various disciplines, providing equal opportunities for diverse groups (Burr et al., 2020; Bryant et al., 2019; Allen, 2021; Song and Zhu, 2016).

In a total of six online courses (called *expeditions*), forming the *Save the Bees Expeditions*, students can explore the utility and joy of CS to solve big problems such as bee mortality. This way, the courses support a GROWTH MINDSET, and students can experience CS as an essential tool to make impactful changes for SOCIAL GOOD, both factors that showed potential for addressing underrepresented groups in CS (Boston and Cimpian, 2018; Goldweber, 2018). Additionally, every course is explicitly designed so that no previous knowledge is required at any time. This should make the courses more accessible to a broader audience, especially to those students who could not identify themselves with the subject through prior experiences and thus did not spend as much time with the subject as others. The expeditions then provide a safe space where participants can progress at their own pace and choose their depth and difficulty based on their needs. The duration of one expedition is about 60 to 90 min.

The six expeditions cover CS topics from web development to data science, artificial intelligence (AI), to project management. Each *expedition* starts with a problem statement under the grand goal to *"save the bees"*. The given problem raises food for thought about alternative solutions. Early in the process, students will experience technology as a helpful and fun tool to achieve such big goals. This way, CS is no longer introduced as an end in itself, but with a broader purpose, and in this particular case, with a personal, relevant touch through the higher-ordered goal of saving the bees.

The expeditions, however, do not emphasize thorough content mastery. Instead, they encourage problem-centric exploration, leveraging data science to solve real-world issues. For example, centered around the problem of varying bee mortality rates across Germany, the course immerses students into *detective roles* in order to get to the bottom of the questions with the help of different methods of data science. They are initially exposed to vast bee-related datasets, prompting them to wade through seemingly complex data gradually. Initially, the students should be overwhelmed by the dataset to some degree. In small steps and guided by the interactive elements of the course, they start interacting with the data, which at first seemed far too complex and unmanageable. The process of data storage, analysis, and representation forms the course's backbone (Srikant and Aggarwal, 2017; Saltz and Heckman, 2016). Consequently, students delve into database management using SQL and discover various data visualization techniques.

The course design ensures a novice-friendly atmosphere while debunking stereotypes associated with coding (Gürer and Camp, 2002). Coding activities offer varying degrees of complexity, enabling self-regulated learning. This empowers them, aligning with the basic need theory of interest (Krapp, 2005). The course concludes with a comprehensive report that amalgamates their findings.

A pivotal component in bolstering success in STEM, especially for girls, is fostering a "growth mindset" (Boston and Cimpian, 2018). To this end, every task within the expedition incorporates tailored feedback. While accurate responses receive affirmation, incorrect ones are met with either elucidative feedback or an encouraging nudge to revisit the problem. This strategy ensures that every learner feels supported, championing an atmosphere of continuous growth and positivity.

3.2. Technical implementation

Constructed using the WordPress platform, each segment of the course is represented as an individual page. A typical page is architecturally designed to encompass informational text, an associated task, one or multiple interactive modules, and a navigational button leading to the subsequent page.

While progressing through the course, participants are not mandatorily required to complete every task. However, engagement with these tasks is conducive to a more profound comprehension of the subject matter. Even though completion is not a strict prerequisite for progression, it is an instrumental tool for enrichment.

The course incorporates the H5P plugin extensively for its adaptive and interactive features. In addition to H5P modules, the course integrates a myriad of other dynamic elements, such as polls, multimedia videos, charts, and a fluidly responsive database. Emphasizing hands-on involvement, each page is diligently curated to ensure it houses at least one interactive element. This design choice guarantees that participants have the opportunity to engage directly on more than 80% of the course pages, thereby fostering a more immersive learning experience.

A variety of interactive elements (e.g. H5P elements, the interactive database DB Fiddle, the Teachable Machine by Google, …) guide the students on their journey, providing different levels of detail and difficulty to ensure active participation.

In an introductory expedition, a short introduction to the interdisciplinary topic of bee mortality is given with some background from biology. In the *Web Expedition*, students face the question "How can we inform as many people as possible about the problem?" and find homepages as a great solution. They learn essential web technologies and build their own homepage using HTML and CSS. In two *Data Science Expeditions* students first, investigate how bee populations change in different areas and second, how they can help local beekeepers find an optimal location for their bee hives. They learn about suitable storage strategies and how to use database technologies such as SQL to find new knowledge in big datasets. The starting point for the *AI Expedition* is whether all bees leaving the bee hive will also return. The students experience that counting bees alone is very dull. They learn about possibilities to train the computer with machine learning to recognize and count bees. Therefore they experiment with models in the Teachable Machine by Google (TM) and are encouraged to train their own AI. The last expedition *Team Expedition* is about requirements for starting an own initiative. First, they learn about the basic principles of project work. Then they go through a hiring process where they choose fictive people for their initiative on provided characteristics. At the same time, this is a recap illustrating that big problems involve interdisciplinary collaboration, often including many very different fields of CS, highlighting the broad spectrum of CS.

3.3. Selected expeditions

Every expedition we curate stems from subjects that, while initially appearing anchored in distinct domains, possess the intrinsic potential to illuminate the vast capabilities and universal applicability of computer science (CS). Our overarching aim is to curate a diverse palette of expeditions, ensuring every student can embark on a CS journey intertwined with their individual passions and curiosities.

To amplify the diversity in CS education, we meticulously craft each expedition with an interdisciplinary lens, presenting problems that beckon solutions through computational thinking and tools. A few exemplars from our repertoire are delineated below.

3.3.1. Beyond biology - Save the bees

This expedition series elucidates the symbiotic relationship between biology and computer science, highlighting how leveraging technology can address pressing biological challenges like the colony collapse disorder. At its core, the expedition series immerses students into the world of STEM, shedding light on the interplay between biological phenomena and computational techniques. This culminates in an experiential learning journey, fostering an inquiry-based learning approach. Throughout six expeditions, students venture into uncharted territories, harnessing STEM methodologies and tools to devise solutions.

The Expedition Journey:

1. *The Mission*: Commencing their journey, students are introduced to the fundamental biology of bees and the central problem statement - *"How can we assist the bees?"*. This sets the stage for the ensuing adventures.
2. *Web Warriors*: The second expedition empowers students with the basics of web development. Using HTML and CSS, they craft their own websites, aiming to amplify awareness about the bee crisis. These student-created sites can even be showcased on the RockStartIT platform, allowing them to share their creations with loved ones.
3. *Data Diving*: Venturing further, the third expedition pivots to data science. Here, students grapple with data storage solutions like databases and become acquainted with SQL, enabling them to mine datasets for insights. Additionally, they delve into data visualization, fortifying their critical thinking abilities, particularly in interpreting these visualizations. Their primary quest here is to discern patterns regarding bee health and strategize on using such data to aid bees in locating sustenance.
4. *AI Bee-counters*: In the subsequent expedition, students confront a fresh challenge: gauging whether every bee venturing out of the hive returns. To streamline this, they harness the power of artificial intelligence, leveraging it to count bees, thereby eliminating the tedium of manual counting.
5. *Commanding the Swarm*: As the journey progresses, students step into the shoes of a project manager in the penultimate expedition. They are introduced to the merits of team collaborations to tackle monumental challenges. The primary learning outcome here revolves around assembling a dream team dedicated to "saving the bees". As they scout for potential teammates, students gain insights into the multifaceted expertise required, with a special emphasis on the pivotal role of CS. They simulate the hiring process by reviewing applications from fictitious candidates, each encapsulating the gamut of skills they have traversed, ranging from web design to data science and AI specializations.

In essence, this expedition series furnishes students with a holistic overview, spanning from web development foundations to leveraging AI for biological insights. Through this journey, students not only grasp the instrumental role of CS in diverse domains but also experience the exhilaration of solving real-world problems with interdisciplinary prowess.

3.3.2. Beyond physics - In search of other life

Harnessing the intriguing allure of outer space, this expedition series bridges the realms of physics and computer science, guiding students on a captivating quest to uncover extraterrestrial life.

The Expedition Journey:

1. *Lift-Off Logistics*: Before any cosmic voyage, one must first break free from Earth's gravitational pull. Hence, the maiden expedition introduces students to the intricate world of rocket science. They unravel the nuances of propelling a rocket to space, realizing that manual navigation is not only cumbersome but practically unfeasible. The reliance on control systems governed by adept software comes to the fore. Diving into the realm of programming, students engage with a Scratch project, incrementally addressing challenges. Through this immersive exercise, they acquaint themselves with foundational control structures and variable management, culminating in a successful rocket launch.
2. *Sight Beyond Sight*: Once in space, visual documentation is paramount. The ensuing expedition immerses students in the intricacies of camera sensors, which become their eyes in the vastness of space. Delving deeper, they juxtapose analog and digital signal processing, leveraging historical time-lapse visuals to solidify their understanding (#7).
3. *Pixels and Pictures*: As they grasp the mechanics of camera sensors, the subsequent challenge lies in image digitization. Venturing into the digital realm, students unravel how photos transition into pixel representations, facilitating their storage and transmission across vast cosmic distances (#8).
4. *Error-Free Extraterrestrial Transmission*: With images digitized, the next hurdle is their secure transmission back to Earth. Outer space, with its myriad interferences, poses threats to the integrity of these images. Students are introduced to the enigma of signal

interference and embark on a mission to circumvent it. By mastering primary error correction mechanisms (#9), they ensure the pristine transfer of their space-captured visuals, paving the way for future exploratory expeditions.

This series takes students on a stellar journey, intertwining the wonders of space exploration with computational techniques. From launching rockets to ensuring the safe transfer of invaluable space images, students experience firsthand the symbiotic relationship between physics and computer science, reiterating the limitless possibilities when disciplines converge.

3.3.3. Beyond geography - Save the climate

Marrying the critical subject of climate change from the domain of geography with computational concepts, this expedition series provides a rich, relevant context for students to explore and apply computer science principles. Leveraging the omnipresence of climate-related discourse in students' lives, this course seeks to illuminate how computational thinking can be a potent weapon in the arsenal against environmental challenges. Guiding this expedition is Ida, an animated young computer scientist brimming with curiosity. Representing more than just an avatar, Ida embodies the spirit of innovation, serving as an inspiration for students, and underlining the everyday significance of computer science.

The Expedition Journey:

1. *Climate Conundrums and Computational Concepts* (#10): Commencing their journey, students wade into the vast ocean of computational thinking, acquainting themselves with its foundational pillars: decomposition, pattern recognition, abstraction, and algorithms. Contextualizing these principles, they explore their potential to distil complex issues into actionable solutions. By constructing a model elucidating the causal relationships behind the greenhouse effect, they experience the power of computational tools in dissecting macro-level environmental problems.
2. *Legumes, Logistics, and Logic* (#11): The next challenge finds Ida swamped with legumes, potent symbols of sustainable nutrition. To assist her, students employ the principle of decomposition, segmenting the overarching task into manageable chunks. This expedition introduces them to the logic of bucket sorting, allowing them to systematically categorize legumes, an exercise that mirrors the larger theme of sustainable resource management.
3. *Barcode Breakdowns and Seasonal Sustainability* (#12): Venturing into the domain of information coding, students decipher the enigmatic barcodes that grace supermarket items. These seemingly innocuous stripes serve as reservoirs of information, including data about produce seasons. Through coding theory, students conceptualize a labeling system for fruits and vegetables. This system not only informs them about the optimal seasonal consumption of these items but also underscores the broader theme of sustainable consumption.

Interweaving computational concepts with pressing environmental issues, this course not only fosters a deeper understanding of computer science but also instils in students a sense of responsibility and empowerment, positioning them as change-makers in the fight against climate change.

4. Research method

In this article, we shed light on findings from summarized data of one year of workshops where secondary school students participated in courses part of the RockStartIT project. In every workshop, students choose courses (called *expeditions*) from the *Save the Bees Expeditions*. The courses connect topics from biology and geoecology about *bee mortality* with CS in such a way that students explore how CS can help solve big problems and make impactful contributions. All courses are freely available online (rockstartit.com). To capture changes throughout the workshops and the potential of our interdisciplinary online courses to impact students' perception and interest in CS positively, we used an experimental pre-test-post-test study design (Dimitrov and Rumrill Jr., 2003). Therefore, students were asked to complete a survey at the workshop's beginning and end.

Table 2
Overview of student participation in RockStartIT courses from January 2022 to September 2022.

Program	Type	Participants	
		Female	Male
Gender Equity (KIT)	Research project	14	32
IT Mission (KIT)	Research project	50	51
Girls Day (KIT)	Workshop	14	0
Science Camp (KIT)	Workshop	12	0
MINT Feriencamp (Cyberforum)	Workshop	14	10
Burg Liebenzell (ZLB)	Workshop	28	0
Secondary schools	Lessons	65	62
Total		197	155

4.1. Context

Since the workshops were conducted in Germany, we will shortly illustrate the CSEd situation in the study area. The KIT has, with more than 2700 active students in the CS degree program, one of the largest programs in Germany. Still, just less than 13% of the students are female, illustrating the diversity problem. Since the ratio of females under new registrations is also just roughly 15%, CSEd in secondary school might be an important set screw. In the study area, CS is a mandatory subject in grade 7 (ages 12–13) of secondary school (the *gymnasium*), but only in that grade and only since 2016. For grades 8, 9, and 10 there is no dedicated subject for CS. CS is then only selectable in a trade-off with a second foreign language as part of the subject IMP, a combination of informatics (the more common term for CS in Germany), maths, and physics. This drives CS in a challenging situation. CS in this educational level has big pressure to glance at a high stage to attract as many students as possible so that they are not lost here. This highlights the need for innovative approaches in computer science education.

4.2. Program implementation

The RockStartIT initiative has effectively integrated its courses across various programs, as detailed in Table 2. With more than 300 secondary school students participating in these courses, the reach and influence of RockStartIT are demonstrably significant. This broad student engagement has enabled the collection of rich evaluation data and diverse feedback. By analyzing these insights, RockStartIT continually refines and optimizes its offerings to better suit both informal and formal educational settings.

This proactive feedback loop ensures that RockStartIT remains relevant and effective in its mission to introduce computational thinking and computer science concepts to a broad spectrum of students. The course offerings, encompassing both research projects and workshops, reflect a deliberate design to cater to diverse learner profiles, ensuring that every participant, regardless of gender, finds a fitting and engaging platform to delve into computer science.

4.3. Workshops

For the current case study, we collected data from 16 different workshops from January to December 2022. All workshops were in German and conducted by scientific staff familiar with the project. The

Fig. 1. Students working on online courses of the *Save the Bees Expeditions* by *RockStartIT* in a computer lab at the KIT.

workshops were conducted in either one of the following setting types: a face-to-face (F2F) setting in a computer lab at the KIT (see Fig. 1) or an online setting via conference tools (*Zoom*, *BigBlueButton*). In both settings, participants enrolled in online courses of the *Save the Bees Expeditions* and could ask for support at any time during the workshop. In the online setting, the scientific staff was always present with video and voice turned on. The duration of the workshops varied from 2-to −3-hour day workshops to 6-hour day workshops, to repeating 2-hour workshops for six weeks. In the day workshops, students usually completed one or two expeditions (excluding the introductory expedition). Student groups of the six-week program usually went through all expeditions (except for the *Team Expedition*).

4.4. Participants

Over 160 students participated in the workshops. We had 164 valid responses in the pre-test and 131 in the post-test. Invalid cases were responses with 5-star (or 1-star) ratings only, identified through negatively formulated control questions in the survey. For validity purposes, we excluded all cases from our analysis without transparent allocation between the pre-test and post-test data. The final dataset included responses from 130 students (79 female, 50 male, and one non-binary) from German secondary schools. The mean age is 13.14, ranging from 10 to 16 years. All participants were informed about their rights to participate in the survey study and confirmed a written declaration of consent. Participation in the survey was voluntary.

4.5. Survey instrument

We asked the participants to complete a survey at the beginning and end of the workshop. In the case of the six-week program, this was done only once at the beginning of the first workshop session and once at the end of the last workshop session. We used a previous study questionnaire to assess our courses' enthusiasm potential (Marquardt et al., 2023). The questionnaire consists of 28 items, most scaled on a Likert scale from (1)-*"Strongly disagree"* to (5)-*"Strongly agree"*. The full questionnaire is represented in Table 3. The questionnaire is used to measure enthusiasm potential based on the cognitive constructs *interest*, *positive feelings*, and *future intents* from the person-object theory of interest (POI) (Krapp, 2007).

- *Positive Feelings* relates to the extent to which an activity is connected to positive emotions such as fun. In the best case, this results in a *flow* momentum (Csikszentmihalyi and Csikzentmihaly, 1990) in which "time flies by".
- *Interest* represents the self-intentionality and self-identification expressed by the extent to which "goals and volitionally realized intentions related to the area of an interest are compatible with the attitudes, expectations, values and other aspects of the person's self-system" (Krapp, 2007, p. 11).
- *Future Intents* is reflected in a person's desire, or development of such a desire, to expand their competencies concerning the subject of interest, to increase their knowledge, and to improve their skills.

The value for one construct is then calculated for responses to multiple items related to the specific construct.

The questionnaire also includes items to perception such as students' *interdisciplinary preferences* and *self-efficacy*. In addition, we collected sociodemographic data for gender (choices: *"female"*, *"male"*, *"not listed"*), age, grade level, and average time spent on a computer daily.

4.6. Analysis

First, we performed an exploratory analysis with descriptive statistics (means and effect sizes) to estimate the potential impact of our approach on different groups (Haden, 2019a). Then, we used paired t-test and independent t-test analyses with 95% confidence intervals (CIs) and Cohen's d for effect sizes to compare pre-test and post-test results (within-subject analysis) as well as differences between different groups (between-subject analysis) (Haden, 2019b; Lakens, 2013). We used the Welch test instead of the independent t-test if Lavene's test for equality of variances performed at $p < .05$ (Rasch et al., 2011). Statistical significance is a measure used to determine if the results of a study are likely to be true and not due to chance. In this context, a result is considered statistically significant if the probability of it occurring by chance is less than 5% ($p < 0.05$).

5. Findings

This section delves into the outcomes derived from the implementation of our interdisciplinary online courses. These insights contribute to a nuanced understanding of gender dynamics within educational settings in STEM. Previous publication of some findings can be found in Marquardt et al. (2023) and Marquardt and Happe (2023).

5.1. How do girls experience interdisciplinary online courses?

As depicted in Fig. 2, the interdisciplinary online courses by RockStartIT were enthusiastically received by female students. A majority of the girls, surpassing 90%, reported that it was fun to engage with the topics of the course and more than 80% indicated, that the course has aroused their curiosity, that school would be more fun if they would do things as they did in the course more often, and that they would recommend the course to others. About 80% of the participating girls showed also interest in doing a similar course again and even about 70% of the girls acknowledged an increased interest in computer science subsequent to their participation.

These outcomes underscore the capacity of interdisciplinary courses to reshape girls' attitudes towards computer science positively. While direct effects are not immediately evident from the pre-post study results shown in Table 5 (see rows positive feelings, future intents, and interest for girls), the general trend is upward across these various dimensions of engagement and interest. This trend was especially highlighted by the survey item *"Coding is fun for me"* $t(75) = -2.76$, $d = -0.32$, $p = .007$ (see Fig. 3(a)) that yielded a statistically significant result, where the post-intervention data showed an uptick in 'tend to agree' and 'strongly agree' categories. Notably, the 'strongly agree' responses post-intervention have seen a considerable increase, suggesting a significant impact on the respondents' strong agreement with the statement in question.

Table 3
Items from the questionnaire used in the survey study to interest, positive feelings, future intents, and perception of students towards computer science.

	Construct	No.	Item	Source
Pre-test and post-test	Positive feelings	Q3	I enjoy solving problems with computers	Chipman et al. (2018)
		Q4	Learning about what computers can do is fun	Friend (2017)
		Q10	Coding is fun for me	Müller et al. (2007)
	$\alpha_{pre} = .750$ $(n = 123)$, $\alpha_{post} = .771$ $(n = 127)$			
	Interest	Q5	I am interested in computer science	Beumann (2017)
		Q9	Computing jobs are boring	Ericson and McKlin (2012)
		Q13	Computer scientists deal with interesting topics	Katterfeldt et al. (2019)
		Q16	What I learn in computer science I know I can put to good use later on	Müller et al. (2007)
		Q17	Coding skills can help me in my everyday life	Theodoropoulos et al. (2018)
	$\alpha_{pre} = .785$ $(n = 126)$, $\alpha_{post} = .829$ $(n = 128)$			
	Future intents	Q2	I do not want to deal with coding in my life	Theodoropoulos et al. (2018)
		Q7	I would be interested in learning more about computer science than I need for school	Palmer et al. (2017)
		Q18	I can see myself doing something in the field of computer science later on after school	
	$\alpha_{pre} = .781$ $(n = 128)$, $\alpha_{post} = .639$ $(n = 127)$			
	Perception	Q1	I like to combine knowledge from different fields to solve problems	Ng and Fergusson (2020)
		Q6	I know I can do well in computer science	Unfried et al. (2015)
		Q8	I know what computer science is and what computer scientists do	Chipman et al. (2018)
		Q11	What spontaneously comes to your mind about computer science? Name up to 3 keywords.	Katterfeldt et al. (2019)
		Q12	Computer scientists mainly deal with programming	Katterfeldt et al. (2019)
		Q14	Computer science is... rather a very specialized field or just everywhere?	Katterfeldt et al. (2019)
		Q15	Computer science is an appropriate subject for both boys and girls	Jenson and Black (2017)
Post-test only	Positive Feelings	Q19	School would be more fun if we would cover things like this more often	Häussler (2007)
		Q22	It was fun to engage with the topics covered in the course	Beumann (2017)
		Q23	The course has aroused my curiosity	Beumann (2017)
		Q27	During the course time flew by	Zehren (2009)
	$\alpha = 0.765$ $(n = 130)$			
	Interest	Q20	My interest in computer science has increased since I took the course	Häussler (2007)
		Q21	I felt like I had learned something for myself	Häussler (2007)
		Q26	I would recommend such a course to others	
	$\alpha = 0.801$ $(n = 128)$			
	Future intents	Q24	I would love to do a course like this again	
		Q25	During the course I had an aha moment	Beumann (2017)
		Q28	I will talk to friends, parents, or siblings about things I experienced in the course	Engeln (2004)
	$\alpha = 0.633$ $(n = 130)$			

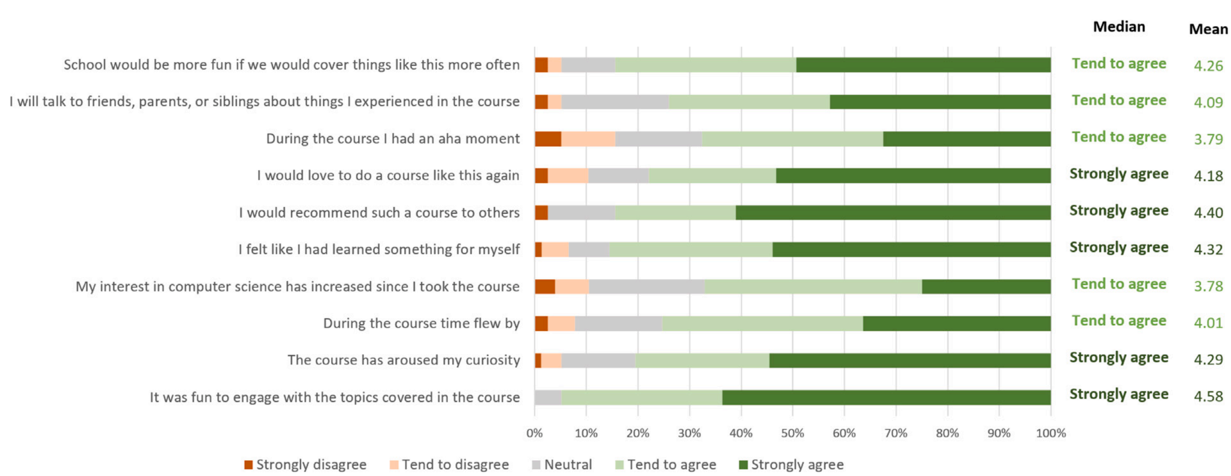
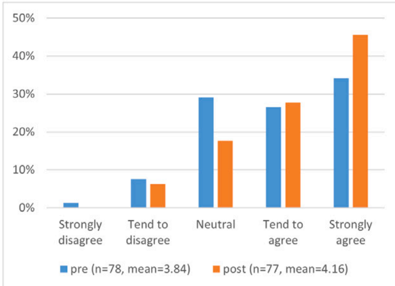


Fig. 2. Positive reception of activities by female students (n = 77) in the courses.

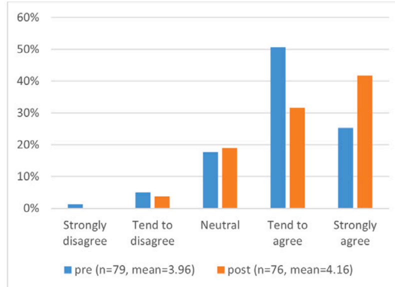
Similarly, the survey item *"Computer scientists deal with interesting topics"* t(75) = −2.11, d = −0.24, p = .039 (see Fig. 3(b)), where the most significant change is observed in the 'neutral' category, where post-intervention responses have declined, while both agreement categories ('tend to agree' and 'strongly agree') have seen a rise. This suggests a stronger conviction in the respondents' opinions following the intervention.

While already in the beginning the girls showed a high affinity for interdisciplinary learning, participating in courses of RockStartIT did even further increase their preference for interdisciplinary learning t(76) = −3.28, d = −0.37, p = .002 (see Fig. 3(c)). A majority of respondents tend to agree or strongly agree with the statement post-intervention, indicating a positive shift in attitudes. The percentage of 'neutral' responses has decreased in the post category, suggesting a reduction in uncertainty or ambivalence regarding the statement. The increase in the mean value also supports a positive change in the consensus.

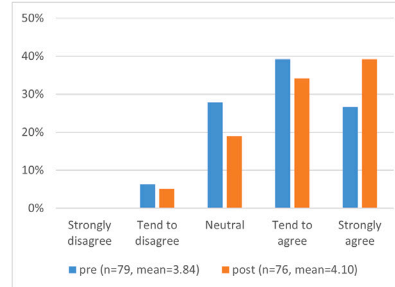
The course was also effective in fostering their self-efficacy in computer science t(76) = −1.68, d = −0.19, p = .096 (see Table 5). Despite a statistically insignificant t-test result, which suggests that the increase in self-efficacy was not strong enough to be considered statistically significant, the qualitative data suggest substantial subjective



(a) Increased perception of coding as enjoyable (Item: *Coding is fun for me*, t(75)=-2.76, d=-0.32, p=.007)



(b) Greater interest in topics dealt with by computer scientists (Item: *Computer scientists deal with interesting topics*, t(75)=-2.11, d=-0.24, p=.039)



(c) Preference for interdisciplinary problem-solving (Item: *I like to combine knowledge from different domains to solve problems* t(76)=-3.28, d=-0.37, p=.002)

Fig. 3. Female participants' responses to selected survey items.

Table 4
Analyzed groups of students determined by rating conditions of selected grouping variables (items from the questionnaire).

Group		Students			Grouping variable	Ratings	Scale
		n	f	f/n			
CA	Coding Aversion	18	14	78%	I do not want to deal with coding in my life	4, 5	A
LS	Low Self-efficacy	12	9	75%	I know I can do well in computer science	1, 2	A
CU	CS Career Unlikely	31	22	71%	I can see myself doing something in the field of computer science later on after school	1, 2	A
NF	CS Narrow Field	14	6	43%	Computer science is... rather a very specialized field or just everywhere?	1, 2	B
LC	Low Computer Affinity	40	26	65%	On average, I spend ... hours on the computer	1	C
LI	Low Interdisciplinary Preference	39	27	69%	I like to combine knowledge from different domains to solve problems	1, 2, 3	A

Scale A: Strongly disagree (1), Tend to disagree (2), Neutral (3), Tend to agree (4), Strongly agree (5).
Scale B: Very specialized (1) to Just everywhere (5).
Scale C: Less than 1 h (1), 1 to 2 h (2), 2 to 3 h (3), 3 to 4 h (4), more than 4 h (5).

improvements. The effect size (d = −0.19) is small, and the *p*-value is marginally above the conventional threshold for significance (p < .05), indicating a trend that could be explored with a larger sample size or additional data.

So the courses might be an excellent opportunity to enrich traditional school lessons, giving new possible connection points to identify with the subject and get curious about what one can do with CS. This is also reflected in the survey feedback we get from students. The course content's relevance to real-world applications, as evidenced by student feedback, likely contributes to heightened interest in CS. The positive comments reflect a strong appreciation for the course's interactive and user-friendly approach. For instance, one student reflected *"It's always fun and it's nice to learn here"*., emphasizing the engaging and enjoyable nature of the learning experience. This sentiment is crucial as it indicates that the program successfully fosters a positive attitude towards learning computer science, which is often perceived as a challenging subject. Another student mentioned, *"I love the website. You learn a lot of new things. It is very interesting and great design"*. This feedback underscores the importance of a well-designed digital learning platform that not only delivers educational content but also keeps students engaged and motivated.

Participants also appreciate the free space the courses give them to progress at their own speed, as this feedback illustrates: *"I liked that we could work very freely"*. This self-directed approach not only caters to the varied learning speeds of students but also empowers them to take charge of their own learning process, which is a crucial element in fostering self-efficacy.

The study of the *Save the Bess Expeditions* highlights the course's interdisciplinary approach and its capacity to engage a broad and diverse audience. The inclusive nature of the course design shows promise in not only attracting girls and underrepresented groups in CS but also in appealing to students who may have previously experienced an aversion to programming or who lack confidence in their CS abilities, which we will have a closer look at in the next section. This is an encouraging sign that the course is breaking down barriers to entry in the field of CS and is promoting a more inclusive environment for all students.

5.2. Embracing diversity through interdisciplinarity

In this section, we further investigate the effect of our interdisciplinary online courses on various student sub-groups. The analyzed subgroups and the grouping conditions are outlined in Table 4. Students were included in one group if their response to a specific questionnaire item (grouping variable) fell into one category defined by rating. What becomes clear at first glance is that the proportion of female students among all groups is higher than the proportion in the overall study sample (61%). This is especially evident for the groups *Coding Aversion* where the proportion of female students is 78% and *Low Self-efficacy* where it is 75%. Only in the group of students who think that computer science is a very specialized subject (*CS Narrow Field*), the share of female students is significantly lower compared to their overall share, which indicates, that many girls do assume computer science as a relevant subject with broad field of applications. Next, we will analyze the effect of the interdisciplinary courses of RockStartIT on students of these groups. Parts of the findings presented in this section were originally published in Marquardt and Happe (2023).

5.2.1. Exploring the impact on students with coding aversion

We turn our attention to students initially reluctant towards coding (N = 18, f = 14), as evident from their agreement (ratings of 4 or 5) with the statement, *"I do not want to deal with coding in my life"*(see Fig. 4(a)), where they rated it with a four or five. After participating in interdisciplinary courses, significant improvements were observed in various aspects for this group.

Table 5
Paired t-tests for pre-test (1) to post-test (2) results by group.

Construct	Group	N	M_1	M_2	SD_1	SD_2	Cohen's d	95% CI Lower	95% CI Upper	p
Interdisciplinary preferences	all	126	3.91	4.13	0.85	0.85	−0.32***	−0.50	−0.14	.000
	girls	77	3.84	4.10	0.89	0.90	−0.37**	−0.60	−0.14	.002
	boys	48	4.00	4.15	0.77	0.77	−0.24	−0.52	0.05	.109
	CA	16	3.56	3.88	0.89	0.89	−0.44[1]	−0.95	0.08	.096
	LS	12	3.50	3.58	1.00	1.08	−0.16	−0.73	0.41	.586
	LC	40	3.73	3.85	0.99	0.98	−0.19	−0.51	0.12	.230
	CU	31	3.52	3.84	0.85	1.04	−0.41*	−0.77	−0.04	.031
	NF	13	3.77	3.92	1.09	1.19	−0.22	−0.77	0.33	.436
	LI	39	2.85	3.36	0.37	0.81	−0.68**	−1.02	−0.33	.000
Self-efficacy	all	125	3.64	3.77	0.98	0.99	−0.16	−0.34	0.02	.074
	girls	77	3.49	3.65	0.96	0.94	−0.19[1]	−0.42	0.03	.096
	boys	47	3.89	3.96	0.98	1.04	−0.08	−0.37	0.20	.569
	CA	15	3.07	3.73	1.44	0.96	−0.74*	−1.31	−0.16	.012
	LS	12	1.67	2.83	0.49	0.94	−1.05**	−1.74	−0.32	.004
	LC	40	3.40	3.43	1.00	0.99	−0.07	−0.38	0.24	.653
	CU	31	2.90	3.23	1.08	1.02	−0.31	−0.67	0.10	.096
	NF	13	3.46	3.77	0.97	1.01	−0.30	−0.85	0.26	.303
	LI	39	3.15	3.33	1.11	0.93	−0.16	−0.48	0.15	.313
Positive feelings	all	123	3.77	3.80	0.86	0.82	−0.05	−0.23	0.12	.281
	girls	73	4.08	4.16	0.79	0.76	−0.13	−0.36	0.10	.269
	boys	44	4.50	4.53	0.59	0.52	−0.06	−0.35	0.24	.713
	CA	15	3.84	4.18	0.97	0.75	−0.59*	−1.13	−0.03	.038
	LS	11	3.27	3.61	0.65	0.83	−0.44	−1.05	0.19	.176
	LC	35	3.97	4.22	0.79	0.80	−0.38*	−0.72	−0.03	.032
	CU	28	3.65	3.92	0.91	0.81	−0.36[1]	−0.74	0.03	.070
	NF	12	4.44	4.30	0.43	0.74	0.34	−0.25	0.91	.269
	LI	36	3.81	3.97	0.93	0.83	−0.21	−0.54	0.13	.224
Future intents	all	118	4.24	4.30	0.74	0.70	−0.10	−0.23	0.12	.557
	girls	75	3.66	3.70	0.79	0.76	−0.07	−0.29	0.16	.572
	boys	47	3.94	3.95	0.89	0.78	−0.02	−0.31	0.26	.878
	CA	15	2.69	3.31	0.67	0.95	−0.94**	−1.54	−0.31	.003
	LS	10	2.90	3.03	0.82	0.51	−0.16	−0.78	0.47	.631
	LC	39	3.61	3.61	0.82	0.85	0.00	−0.31	0.31	–
	CU	29	2.78	3.10	0.58	0.49	−0.57**	−0.96	−0.17	.005
	NF	12	3.75	3.83	0.84	0.78	−0.14	−0.70	0.43	.643
	LI	37	3.27	3.41	0.75	0.72	−0.30	−0.56	0.09	.160
Interest	all	122	4.07	4.18	0.65	0.66	−0.21*	−0.38	−0.03	.025
	girls	76	3.99	4.08	0.70	0.70	−0.17	−0.40	0.06	.141
	boys	45	4.18	4.32	0.56	0.56	−0.26[1]	−0.56	0.04	.083
	CA	16	3.60	4.04	0.86	0.69	−0.74*	−1.28	−0.17	.010
	LS	11	3.40	3.75	0.80	0.89	−0.45	−1.06	0.18	.165
	LC	37	3.97	4.10	0.62	0.69	−0.20	−0.52	0.13	.236
	CU	29	3.52	3.83	0.73	0.64	−0.42**	−0.80	−0.04	.032
	NF	11	3.95	4.07	0.43	0.53	−0.33	−0.93	0.28	.295
	LI	36	3.64	3.85	0.71	0.68	−0.30[1]	−0.63	0.04	.082

[1]$p < .1$, *$p < .05$, **$p < .01$, ***$p < .001$.

Specifically, there was a notable increase in positive feelings (d = 0.59, p = .038), future intentions (d = 0.94,p = 0.003), interest (d = .74, p = .010), and self-efficacy (d = 0.74, p = .012) (see Table 5).

Fig. 4 highlights a substantial positive shift in coding acceptance among these students, indicative of an impactful learning experience (see Fig. 4(a)). Additionally, the perceived relevance of CS increased among these students (see Fig. 4(b)), which was further complemented by a shift in their perception of CS as a field with a broad application range (see Fig. 4(c)). These results suggest that interdisciplinary courses can effectively help students recognize the relevance of the subject, consequently leading to a more positive perception of it.

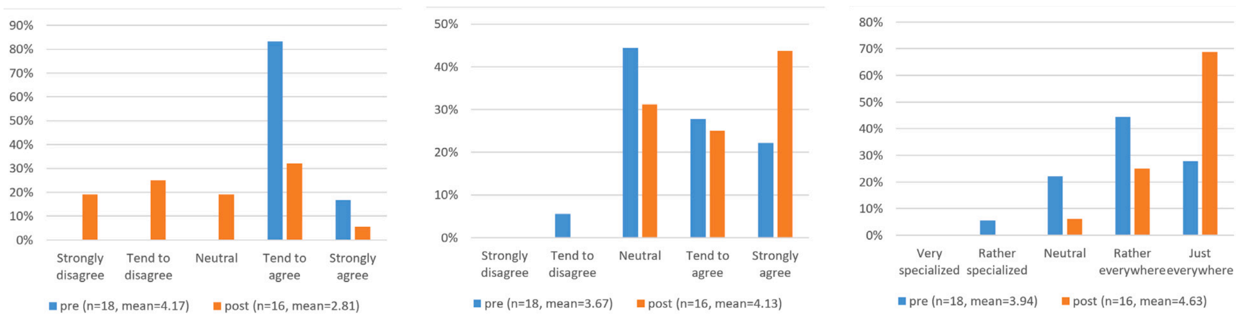
5.2.2. *Exploring the impact on students with low self-efficacy*

Self-efficacy is a crucial factor in empowering underrepresented groups in the field of computer science (Aivaloglou and Hermans, 2019; Beyer, 2014). In this section, we explore the impact of our courses on a group of students (N = 12, f = 9) who initially demonstrated lower self-efficacy, rating two or one on the statement *"I know I can do well in CS"* in the pre-test.

Our evaluation reveals that, while not reaching statistical significance, there was a discernible medium-sized improvement in these students' positive attitudes towards CS, with regard to both their positive feelings (d = 0.44, p = .167) and their interest in the subject (d = 0.45, p = .165). This increased interest is further exemplified by a substantial effect on the statement *"What I learn in CS I know I can put to good use later on"*, t(10) = −3.07, d = −0.93, p = .012 and a medium effect on the statement *"Computing jobs are boring"*, t(11) = 1.82, d = 0.53, p = .096(see Fig. 4(b)).

Table 5 depicts these shifts, indicating that the majority of the students within this low self-efficacy group experienced positive impacts. The most significant shift was observed in self-efficacy (d = −1.05, p = .004), suggesting a robust influence of the course on their confidence in their CS capabilities. It is, however, important to acknowledge that this increase in self-efficacy coincided with a marked rise in the variance of responses (SD_1 = 0.49, SD_2 = 0.94), which may suggest a varying impact of the course across different individuals within the group.

The responses of this subgroup to the interdisciplinary approach of the courses offer valuable insights into the enhancement of self-efficacy among students who are less represented in computer science fields, emphasizing the role of tailored educational experiences in fostering self-confidence and interest in the subject.

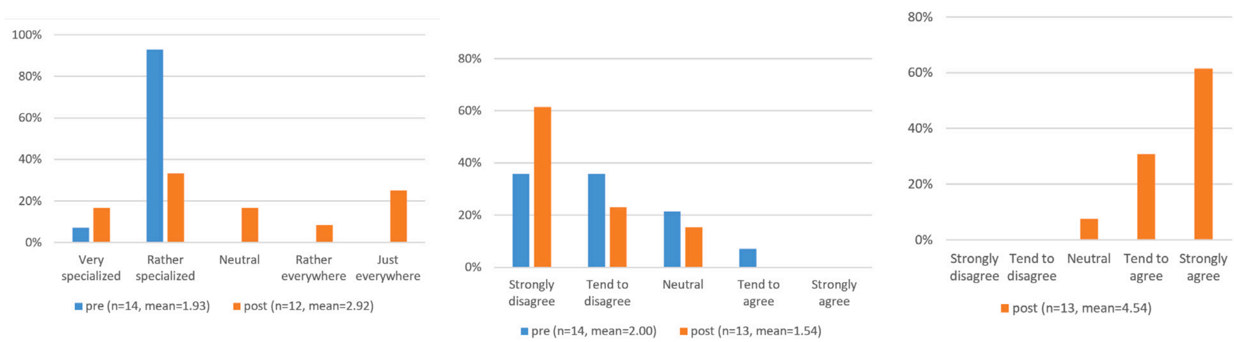


(a) Item: *I do not want to deal with coding in my life*, t(15)=4.04, d=1.01, p=.001

(b) Item: *What I learn in computer science I know I can put to good use later on*, t(15)=-2.45, d=-0.61, p=.027

(c) Item: *Computer science is... rather a very specialized field or just everywhere?*, t(15)=-3.58, d=-0.89, p=.003

Fig. 4. Responses from students of group *Coding Aversion*.



(a) Item: *Computer science is... rather a very specialized field or just everywhere?*

(b) Item: *Computing jobs are boring*

(c) Item: *It was fun to engage with the topics covered in the course*

Fig. 5. Responses from students of group *CS Narrow Field*.

5.2.3. Exploring the impact on students with low computer affinity

This group comprises all students who reported spending, on average, less than one hour per day on a computer, excluding time spent on mobile devices (N = 40, f = 26). The results suggest that participation in the study did not yield statistically significant effects on the future intentions or interest in computer science among this group. However, it is worth noting that there was a small to medium statistically significant effect on their positive feelings (d = −0.38, p = .032). This effect becomes particularly evident in the results of the statement *""Coding is fun for me""* (t(36) = −2.75, d = −0.45, p = .009)(see Fig. 4(c)).

While the overall impact on future intentions and interest may not be significant, the noticeable increase in positive feelings, especially the perception that coding is enjoyable, is an important finding. It highlights the potential for a more engaging approach to computer science, even among students who initially reported lower computer affinity.

5.2.4. Exploring the impact on students considering CS career unlikely

This group comprises students (N = 31, f = 22) who expressed less interest in pursuing a computer science career after school, as indicated by their response of "Strongly disagree" or "Tend to disagree" to the questionnaire item *"I can see myself doing something in the field of computer science later on after school"*. The impact of the interdisciplinary courses on various dimensions of interest within this group is presented in Table 5.

Notably, all dimensions of interest were positively influenced by the interdisciplinary courses. This impact was particularly evident in the responses to the statement *"Coding is fun for me"*, which increased from a mean of 3.28 to 3.90 (t(28) = −2.70, d = −0.50, p = .012). The statement *"I can see myself doing something in the field of computer science later on after school"* also saw a significant change, with the mean increasing from 1.79 to 2.38 (t(28) = −3.34, d = −0.62, p = .002). This suggests that interdisciplinary approaches have the potential to enhance the enjoyment of coding, consequently increasing students' willingness to engage with computer science in the future.

The outcomes observed within this group shed light on the effectiveness of interdisciplinary courses in shifting students' perceptions and fostering a more positive outlook on a career in computer science.

5.2.5. Exploring the impact on students considering CS as a narrow field

This group consists of students (N = 15, f = 6) who initially viewed computer science as a specialized field rather than something with broad applicability. Participation in the interdisciplinary courses led to significant changes in their perceptions of computer science, particularly in response to the grouping variable *"Computer science is... rather a very specialized field or just everywhere?"*. The mean score for this variable increased from 1.92 to 2.92 (t(11) = −2.45, d = −0.71, p = .032, see Fig. 5(a)). However, it is important to note that the standard deviation also increased substantially, from 0.29 to 1.5 in the post-test. This suggests that, on average, students still tend to consider computer science as a specialized field. However, the higher standard deviation indicates a broader range of responses, implying that some students may have shifted significantly towards viewing CS as a more diverse and widely applicable field, while others may have maintained their original perception.

A notable observation is the significant change in response to the statement *"Computing jobs are boring"*. The mean score decreased from

Table 6
Independent t-tests for mixed-gender workshops (m) to all-girls workshops (f) results.

		N_m	N_f	M_m	M_f	SD_m	SD_f	Cohen's d	95% CI Lower	95% CI Upper	p
Self-efficacy (Q6)	Pre	33	44	3.48	3.50	0.97	0.93	−0.02	−0.46	0.43	.945
	Post	33	44	3.67	3.64	0.89	0.89	0.03	−0.42	0.48	.890
Stereotype (Q15)	Pre	33	46	4.61	4.78	0.83	0.47	−0.28	−0.72	0.18	.274
	Post	33	43	4.76	4.81	0.50	0.45	−0.12	−0.57	0.34	.614
Future intents	Pre	33	46	3.46	3.70	0.85	0.86	−0.28	−0.73	0.17	.227
	Post	32	43	3.36	3.95	0.67	0.86	−0.75**	−1.22	−0.27	.001
	Course	33	44	3.95	4.08	0.82	0.90	−0.15	−0.60	0.31	.528
Positive feelings	Pre	33	44	3.87	4.26	0.83	0.69	−0.52*	−0.97	−0.06	.028
	Post	32	43	4.05	4.26	0.57	0.86	−0.27	−0.73	0.19	.222
	Course	33	44	4.24	4.31	0.66	0.75	−0.11	−0.56	0.35	.645
Interest	Pre	33	46	3.72	4.16	0.74	0.60	−0.66**	−1.12	−0.20	.005
	Post	33	43	3.84	4.27	0.63	0.70	−0.64**	−1.10	−0.17	.007
	C ourse	33	43	4.36	4.35	0.72	0.93	0.02	−0.44	0.47	.940

[1]p < .1, *p < .05, **p < .01, ***p < .001.

2.09 to 1.54 (t(12) = 2.50, d = 0.69, p = .028, see Fig. 5(b)), indicating that as the perception of the broader application range of computer science increased, computer science jobs became more interesting to the students. In Fig. 5, the analysis of the results highlights the effectiveness of the program in overall positive perception of covered interdisciplinary topics.

These findings shed light on the potential of interdisciplinary courses to transform students' perceptions of CS from a narrow and specialized field to a more dynamic and appealing discipline.

5.2.6. Exploring the impact on students with low interdisciplinary preferences

As a control group in comparison to the previously discussed groups, we sought to investigate whether our courses had a negative impact on students who did not exhibit a preference for interdisciplinary learning (N = 39, f = 27). This group encompasses all students who, in the pre-test, rated the statement *"I like to combine knowledge from different domains to solve problems"* with a score of three or lower.

The results reveal that the courses had no significant effect on this group's positive feelings, future intentions, or interests regarding computer science. However, a positive impact was observed in their interdisciplinary learning preferences. These preferences increased from the pre-test (M_1 = 2.85, SD_1 = 0.37) to the post-test (M_2 = 3.36, SD_2 = 0.81) with a highly significant medium to large effect (t(38) = −4.23, d = −0.68, p < .001).

This significant improvement in interdisciplinary learning preferences indicates that, although the courses did not influence their positive feelings, future intentions, or general interest in computer science, they did have a transformative impact on how these students approach interdisciplinary learning. This observation underscores the potential for our courses to enhance students' readiness to engage with diverse knowledge domains to solve complex problems, even if their interest in computer science remains unaffected.

5.3. Influence of the environment: Girls in all-girls workshop vs. Girls in mixed-gender workshops

In this section, we explore the potential influence of the learning environment, specifically class heterogeneity, on girls' experiences and feelings towards CS. To investigate this, we compared the responses from girls differentiated by two groups: girls of workshops with female-only participants (all-girls workshops) and regular workshops with mixed-gender participants (mixed-gender workshops). We conducted three all-girls workshops, which involved a total of 46 girls, alongside eleven mixed-gender workshops with a total of 83 students, including 33 female students. On average, the female ratio in these mixed-gender workshops was 36%. Table 6 summarizes the t-test results for the two groups of girls.

5.3.1. How did the different groups of girls experience the course?

Overall, our analysis did not reveal any significant differences between girls from the all-girls groups and those from the mixed-gender groups in terms of their experience of the course, including their future intentions regarding course activities (t(75) = −0.63, d = −0.15, p = .528), positive feelings related to course activities (t(75) = −0.46, d = −0.11, p = .645), and their interest in course topics (t(74) = 0.08, d = 0.02, p = .470). There were low to medium effects of group composition on the items *"It was fun to engage with the topics covered in the course"* (t(75) = −0.89, d = −.20, p = .378) and *"During the course time flew by"* (t(75) = −1.03, d = −0.24, p = .308). But these differences were also not significant. Overall, the workshop type (all-girls group vs. mixed groups) seems not to influence the course experience of girls.

5.3.2. How do future intents, positive feelings, and interest towards CS in general differ between the two groups of girls?

While we did not observe differences in course experiences among students in different workshop types, our analysis revealed significant differences between the groups in terms of their interest in computer science in general.

For future intentions in CS, there was no significant difference before the course in the pre-test (t(77) = −1.22, d = −0.28, p = .227). However, after completing the course, girls from all-girls workshops (mean = 3.95) indicated significantly higher future intentions in CS compared to their peers from mixed-gender workshops (mean = 3.36, t(72.85) = −3.33, d = −0.74, p = .001). This difference is particularly highlighted by their post-test responses to the questionnaire items *"I do not want to deal with coding in my life"* (t(75) = 3.23, d = 0.77, p < .001) and *"I would be interested in learning more about computer science than I need for school"* (t(75) = −2.43, d = −0.56, p = .018).

In contrast, for positive feelings towards CS, we observed the opposite effect. There was a significant medium effect of the workshop type before the course in the pre-test (t(75) = −2.25, d = −0.52,p = 0.014). However, after participating in the course, positive feelings of girls from mixed-gender workshops increased, resulting in the disappearance of the significant effect in the post-test (t(72.32) = −1.23, d = −0.27, p = .222). This shift is especially evident in their responses to the statement *"Coding is fun for me"* (see Fig. 6).

In terms of interest in CS in general, there was a significant medium effect of the workshop type in both the pre-test (t(77) = −2.91, d = −0.66, p = .002) and the post-test (t(74) = −2.75, d = −0.64, p = .004). This effect is particularly reflected in responses to the statement *"Computer scientists deal with interesting topics"* (see Fig. 7).

These findings provide valuable insights into how the workshop environment and gender composition impact students' general interest and intentions towards computer science.

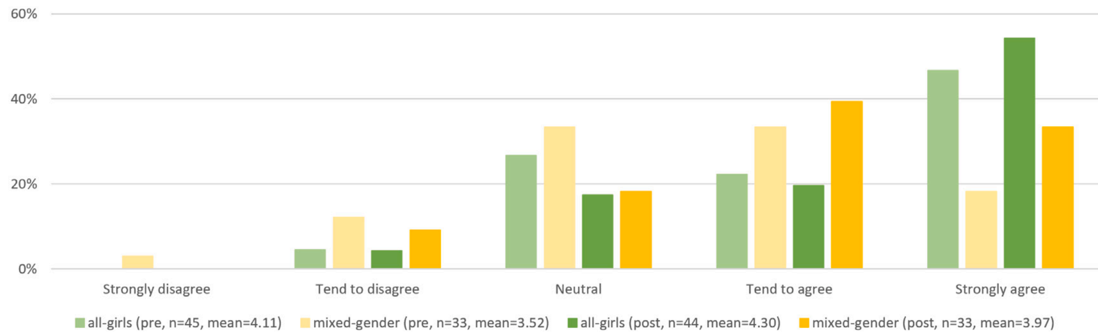


Fig. 6. Responses to the item *"Coding is fun for me"* from girls in all-girls workshops (green) and girls in mixed-gender workshops (yellow) in the pre-test (light) and post-test (dark). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

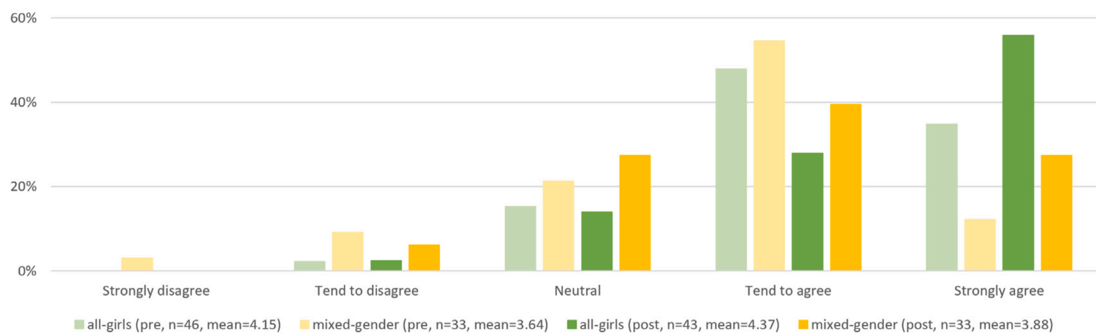


Fig. 7. Responses to the item *"Computer scientists deal with interesting topics"* from girls in all-girls workshops (green) and girls in mixed-gender workshops (yellow) in the pre-test (light) and post-test (dark). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5.3.3. *How do self-efficacy and gender stereotype differ between girls from all-girls vs. Mixed-gender workshops?*

Self-efficacy in computer science was already at a high level at the beginning for girls in both the all-girls and mixed-gender workshops. Interestingly, the interdisciplinary courses had an equally positive impact on the self-efficacy of girls from both groups.

In terms of gender stereotype bias, related to the statement *"Computer science is an appropriate subject for both boys and girls"*, no significant gender bias was observed in either group. However, there were subtle differences between the groups. Girls from mixed-gender workshops seemed to agree less with the statement initially, as indicated by the pre-test results (mean = 4.61), compared to girls from all-girls workshops (mean = 4.78). However, these differences diminished after the workshops. Girls from mixed-gender workshops began to agree more with the statement, and the standard deviation decreased, indicating a convergence towards a more common understanding that computer science is equally suitable for both boys and girls.

While both groups initially demonstrated no serious gender bias in their perceptions, the results indicate that the workshops helped create a more inclusive and balanced perspective regarding the suitability of computer science for both genders.

6. Discussion

Our findings support the claims of previous studies that interdisciplinary education can be an effective approach for increasing interest, and engagement in CS, and addressing diversity in CSEd (e.g. Ng and Fergusson, 2020; Happe et al., 2021; Barr, 2016; Takeuchi et al., 2020; Salloum et al., 2021). Our results also indicate, that the majority of students in the sub-groups identified as having coding aversion and low initial self-efficacy are female, which highlights the importance of promoting a positive image of coding and strengthening self-efficacy to make students feel comfortable and confident in the field of CS (Tellhed et al., 2022; Aivaloglou and Hermans, 2019). This observation is further supported by findings presented in Happe and Buhnova (2022), which indicate that girls' first contact with CS typically happens in the presence of more experienced learners, typically boys who tend to have a one-year head start in computer usage due to their strong focus on one discipline. As a result, girls often struggle and feel uncomfortable, leading to aversion towards typical CS course activities, such as coding, and low self-efficacy.

The results of our study also show that the courses had a striking effect in increasing girls' interdisciplinary learning preferences. This could suggest that some students may not have had a clear understanding of what interdisciplinary learning means, and may have initially viewed it as rather negative, because combining knowledge may be considered something more difficult in general. Nevertheless, participation in interdisciplinary courses increased their preference for this type of learning. This aligns with previous studies that have shown the benefits of learning environments that embed topics into a broader context and involve creative and problem-solving skills, particularly for underrepresented groups in STEM (Tytler et al., 2019; DesJardins and Littman, 2010; Plucker and Zabelina, 2009).

Our work also responds to the challenge identified recently by Tellhed et al. who found an essential interaction between interest in CS and programming self-efficacy: "To attract more women to IT, we thus need to find ways to not only to make girls think 'Sure I can code', but also 'and I want to!' " (Tellhed et al., 2022, p. 9). Our courses increased the willingness to program, particularly among students who were not initially programming enthusiasts. Since programming was not a primary focus of our courses, our approach of communicating programming as a tool to achieve something more remarkable may be an alternative pathway into CS, and the ones taking this way gain self-efficacy and collect success experiences by having a relatable impact in the area of their interest.

In a previous study (Marquardt et al., 2023), we observed significant differences between all-girls classes and mixed-gender classes with regard to students' levels of interest, future intentions, and positive feelings towards computer science. Furthermore, we identified a noticeable distinction in terms of gender bias, where girls in mixed-gender classes exhibited a lower inclination to view computer science as a subject suitable for girls compared to their peers in all-girls classes. These findings underscore the potential of interdisciplinary workshops to challenge and mitigate such gender-based stereotypes and biases.

Notably, the utilization of homogeneous settings, such as all-girls workshops, may offer additional advantages in promoting inclusivity and fostering a more equitable perception of computer science as an accessible field for all genders (Crombie et al., 2000; Margolis and Fisher, 2003; Moorman and Johnson, 2003; Franklin and Rangel, 2022). However, our current study has demonstrated that for informal, out-of-school activities using interdisciplinary courses, the workshop type (all-girls or mixed-gender) appears to have a negligible effect. Girls in both settings enjoyed the workshops independently of peer composition. This suggests that the interdisciplinary approach could be a promising alternative to increase girls' engagement with computer science, regardless of peer structure and previous experiences.

Recommendation: Incorporate more interdisciplinary contexts in the CS curriculum. This might help underrepresented groups build self-confidence and develop a better relationship with CS.

In order to achieve the benefits of authentic interdisciplinary learning experiences, we recommend that programs targeting similar goals should aim to achieve the following learning outcomes:

- Developing a holistic, interdisciplinary understanding of complex problems and challenges.
- Integrating knowledge and skills from computer science and at least one other discipline to approach problem-solving.
- Providing hands-on, real-world experience in tasks and methods relevant to existing software engineering roles.
- Fostering transferable problem-solving, interpretation, and other skills that can be applied across disciplines.
- Encouraging the development of collaboration and communication skills that can be applied in diverse contexts.

While long-term learning experiences may not always be feasible in an educational setting, shorter-term, immersive workshops or self-study sessions can still provide valuable opportunities for students to explore computer science and gain a deeper understanding of the field. These types of experiences can be incredibly impactful in raising students' awareness of the possibilities and potential impact of computer science, and can also serve as a catalyst for further study and exploration in the field. By providing students with opportunities to immerse themselves in computer science in a shorter-term format, educators can help to foster a deeper understanding of the field, increase students' interest and motivation, and ultimately pave the way for a more diverse and skilled computing workforce.

To summarize an immersive learning experience that provides opportunities for girls to fully engage, enjoy, and identify with computer science should allow students to experience:

1. Relevance and Authenticity: The material should be relevant to the student's lives and interests, making the material more engaging and meaningful. This can be achieved by incorporating real-world problems and applications that are directly connected to the student's passions and interests.
2. Experiential and Hands-on Learning: The learning experience should provide opportunities for students to apply their knowledge and skills in real-world settings. This can be achieved through project-based learning or hands-on activities that allow students to see the relevance and practical application of the material and gain valuable experience and skills. Additionally, experiencing it can help to break down stereotypes about who can succeed in the field of computing.
3. Diverse Representation and Perspectives: The learning experience should be diverse in terms of the representation of different perspectives and experiences. This can be achieved by including a diverse range of voices in the curriculum, readings, and discussions, and by making sure that the curriculum reflects the experiences of different groups of people. Additionally, it is important to provide positive role models and representation of successful female engineers, computer scientists and in the field of technology to show girls that they can succeed in the field and to help them envision themselves in those careers.

By incorporating these elements, an immersive authentic learning experience can provide opportunities for girls to fully engage, enjoy, and identify with computer science. Furthermore, interdisciplinary approaches can further enhance formal education by incorporating other sciences and humanities and promoting versatility for future jobs and real innovation. By breaking down the barriers between disciplines, we can tap into a wider range of skills and perspectives, leading to more effective solutions to real-world problems. Education must respond to this need by introducing computer science in an interdisciplinary context and application, in order to increase diversity and innovation in the field.

7. Limitations and threats to validity

While this study provides valuable insights into the potential of interdisciplinary education to positively impact girls' attitudes and perceptions towards computer science, it is essential to consider several limitations and potential threats to the validity of our results.

Firstly, the data presented in this paper originate from various workshops, potentially introducing validity threats stemming from the diverse settings. To mitigate this, we employed a repeated case study design (Wieringa and Daneva, 2015) to extend the generalizability of our findings beyond a single case. However, if we want to transfer our findings into recommendations for traditional computer science education, a setting variety might be substantial since classroom settings also vary greatly.

Secondly, the responses provided by students in our survey are subjective and may be influenced by their immediate context, leading to a potential discrepancy from reality. Likert scales, in particular, may introduce complexities in assessing perceived differences between ratings, potentially resulting in an underestimation of the effects (Harpe, 2015), especially when the initial level of interest is already high. Additionally, the use of a single item for sub-grouping students may not fully capture the complexity of students' affiliations with identified subgroups. Balancing survey comprehensiveness with response reliability is a challenge. Our study's primary goal was to identify tendencies with selected items assumed to be good indicators.

Thirdly, the sample size in our study is relatively small and geographically focused on southwestern Germany, necessitating further investigations with larger and more diverse samples to validate our findings. Our focus on pre-post matching responses limited the total number of participants to approximately 130 students. Furthermore, the nature of pre-post studies, such as ours, is closely tied to the concept of *situational interest*. This may be influenced by factors beyond the courses themselves, including novelty effects. While situational interest is a crucial component in the development of long-lasting interest (Rotgans and Schmidt, 2017), it remains important to acknowledge this limitation when interpreting our findings.

8. Conclusion

It is crucial for girls to have equal access and opportunities to engage in the field of computer science. The lack of representation of women in the field not only perpetuates stereotypes and biases, but also diminishes the potential for innovation and creativity in the field. In a technology-driven world and rapidly changing economic environment, it is vital to diversify the computing workforce and provide all students equal access to computer science. By providing interdisciplinary, authentic and inclusive learning experiences, we can encourage girls to explore and pursue careers in computer science, and in turn, increase diversity in the field. This will not only help to break down stereotypes and biases, but also tap into a larger pool of talent and ideas, ultimately leading to a more innovative and dynamic computing industry.

This research study delved into the impact of incorporating interdisciplinary computer science education in high school curriculums as a means to enhance accessibility and engagement for students. By reflecting on our experience in creating authentic interdisciplinary programs, we were able to evaluate the benefits of such programs for high school students studying computer science. Furthermore, through the analysis of students' experiences, we were able to understand the extent to which these programs successfully shaped a more inclusive and diverse perception of computer science among female students.

The presented study highlights the potential of interdisciplinary education in raising interest and engagement in CS and addressing diversity in the field. We were able to demonstrate the effectiveness of our interdisciplinary *"Save the Bees"* curriculum by *RockStartIT* in increasing interest and engagement in CS for all students, with particularly positive effects for female students as well as sub-groups of students who initially showed less interest, less self-efficacy, and coding aversion. By breaking down the barriers between disciplines, we can tap into a broader range of skills and perspectives, resulting in a particularly impactful approach to addressing the underrepresentation of certain groups, such as women, in CS. When CS is incorporated into other fields, it becomes clear that there are many different ways to use and understand CS and that anyone can succeed in the field. This can help remove barriers and open the field to a more diverse group of students, including girls. The results of this research can inform educators and policymakers on how to design and deliver CSEd in a way that addresses the diverse needs of students. It is essential to continue exploring and developing interdisciplinary approaches to CSEd to promote greater inclusion and engagement in CS. This can also help to make the field more accessible and inclusive, as it shows that there are many different paths to success in computing, as summarized by a quote from Cheryan et al. (2015, p.6):

> *"By broadening the mental picture of what it means to be a computer scientist or engineer, we may not only attract more women to these fields, but also be more accurate about what computer science and engineering are like and what they have the potential to become".*

In summary, the courses offered are more than just a supplement to traditional school lessons; they serve as a bridge to real-world applications and provide a stimulating environment that fosters curiosity, engagement, and self-paced learning. The feedback from the students vividly captures the positive impact of these courses on their perception and attitudes towards CS.

CRediT authorship contribution statement

Lucia Happe: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Kai Marquardt:** Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Lucia Happe reports financial support was provided by Vector Foundation. Lucia Happe reports a relationship with Karlsruhe Institute of Technology that includes: employment. Kai Marquardt reports a relationship with Karlsruhe Institute of Technology that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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