Gender Segregation in the Borderlands of E-Science

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Abstract

This article draws on an ethnographic study of an e-science platform in Sweden to analyse how horizontal gender segregation across sciences plays out in e-science, a borderland in which sciences converge around state-of-the art computational technologies for scientific research. While the convergence of sciences in e-science has the potential to open a non-traditional trajectory to attract women to ICTs, we find that this potential remains untapped. Instead horizontal gender segregation is perpetuated through a) restricted mobility of women from scientific fields with higher gender parity to IT, b) gender friction negatively affecting women in cross-disciplinary e-science, c) a gendered developer/user divide permeating e-science collaborations under 'the logic of domains,' and d) perceived self-reliance in computational tool development across sciences acting as 'gendered boundary work' to strengthen the gendered hard/soft divide in sciences.

Keywords: Feminist Science and Technology Studies (FTS), Interdisciplinary Collaboration, E-Infrastructure, Interdisciplinarity, Gendered Asymmetries

Introduction

It is well established in feminist technology studies (FTS) that technology and gender are mutually constructed (Berg, 1994; Berg and Lie, 1995; Faulkner, 2001; Oudshoorn et al., 2002; Montgomery, 2012; Wacjman, 2000, 2004, 2007, 2010). FTS emphasise situated analyses of the ways in which new technologies change how gender is done and how prevailing gender dynamics in turn affect the closure and standardization processes of certain technologies and technological artefacts (Wacjman, 2000). What is at stake is the question of how gender and technology are entangled in context-specific ways. Computerization (Hine, 2006) and digitalization have periodically been sites for technology-related hypes (Ensmenger, 2010). The potential of virtual space and online technologies to produce social changes has been heralded (Plant, 1995; Castells, 2012). Yet, with reference to grid technologies that lay the framework for e-science endeavours, Woolgar and Coopmans

(2006: 3) make clear that "the nature and direction of change is unpredictable". They argue that there is a lack of research regarding the social dynamics of e-science (Woolgar and Coopmans, 2006: 4). This is all the more the case when it comes to research on gender in e-science at a time when earlier e-infrastructure investments have started to give way to data-driven science initiatives, such as the recently founded SciLifelab and the Wallenberg National Program for Data-Driven Life Sciences (DDSL) in Sweden.

E-science is a term used to describe science that involves developing or working with computational methods, tools and applications, very large data sets and distributed network or grid systems to deal with these. Following the publication of the *Revolutionizing Science and Engineering through Cyberinfrastructure Report* in 2003 in the USA, studies on e-science in the STS literature have largely focused on the prospect of distributed collaboration and coordination in e-infrastructure. In hindsight, David Ribes (2019: 520) gives an account of how the role of social science in e-science initiatives was envisaged to be "helping with, for instance, working in a geographically distributed manner, bringing together heterogeneous disciplinary scientists, or examining the difficulties of data sharing". Yet, in these endeavours gender remained either largely understudied, or not dealt with at all. New tools and applications of the rising, male-dominated data sciences (Boston Consulting Group Gamma Study, 2019), such as AI and machine learning (ML), have recently been assembled in e-science platforms without due attention to how gender figures within these. STS scholars who study e-science have started to shift their attention to data science (Ribes, 2019; Paine and Lee, 2020; Beaulieu and Leonelli, 2021; Mökander and Schroeder, 2021). With this shift of attention gendered asymmetries which are sunk into the infrastructure might become further invisibilised. Bowker (1994) underlines the need for 'infrastructural inversion'; that is "shifting the emphasis from changes in infrastructural components to changes in infrastructural relations" (Bowker et al., 2010: 99), not least with respect to gender dynamics. This also speaks to the emphasis in the literature on the need to study the 'human infrastructure' of e-science (Lee 2006; Bietz et al., 2010).

This article analyses how existing gender divisions across the sciences, also known as horizontal gender segregation (Corneliussen, 2021), play out in cross-disciplinary e-science with an analysis of the organisational structure of an e-science platform in Sweden (hereafter called the Platform). The under-representation of women in STEM fields which converge in e-science collaborations is well established (Rua-Gomez and Arias-Gaviria, 2020; Zacharia et al., 2020; Santos et al., 2021). Horizontal gender segregation attests to the fact that gender parity also varies across STEM disciplines (Ceci et al., 2014, Begeny et al., 2020; Fisher et al., 2020). The *Gender InSITE Report* records, for instance, higher numbers of women in biological or life sciences (28%) compared to engineering sciences (10%) and mathematical sciences (8%) and a dire under-representation of women in computer sciences (Kelan, 2007; Michell et al., 2017; Zacharia et al., 2020). How do these gendered differences (Ellingsæter, 2014; in Corneliussen, 2021) play out in e-science collaborations where diverse scientific 'disciplines' converge around the use and development of computational tools and methods? In what ways do traditional gendered divisions across math-intensive and non-math intensive sciences (Ceci et al., 2014) play out in cross-disciplinary e-science collaborations? The article responds to these research questions, focusing on the case of a particular e-science platform established in 2010 as a strategic research area by three major universities in Sweden.

Vitores and Gil-Juarez (2016: 670) emphasise the fact that women's engagement in ICTs might at times take certain pathways which are not well-recorded in the literature as they fall outside the scope of a linear computer science career. They invite us to consider other trajectories that emerge or exist at the intersection of computer sciences and other disciplines such as "art and design, cognitive sciences, new media, biology, information science and education or library science, for example" (Vitores and Gil-Juarez, 2016: 673). E-science, being one such area in which diverse sciences converge around ICTs, is a relevant space as a potential pathway to attract women into ICTs.

It is thus useful to analyse existing e-science initiatives to see how horizontal gender segregation plays out in newly emerging research clusters which "conjoin technology, traditionally male dominated, and disciplines that have traditionally been female dominated" (Griffin, 2021: 1).

The article suggests that e-science collaborations act as borderlands where different communities of practice intersect in individuals and groups. These borderlands thus embody the potential to become an area where researchers of more gender equal communities of practice such as biology, medicine and humanities, enter IT-heavy e-science through application-based collaborations. This potential is discussed below in the findings section. In the same section, we also discuss that this potential is not realized in our case study. Instead, existing horizontal gender segregation is perpetuated. We discuss the mechanisms of this below based on data from our analysis of the organisation structure and gender dynamics of the Platform in Sweden. The next section of the article includes our literature review on horizontal gender segregation across the sciences, and a discussion on e-science as borderland. After that we present the case study and the methodology used for the qualitative research. We then present our findings, followed by a discussion and conclusion section.

Horizontal gender segregation across the sciences

When analysing the existing gender dynamics in sciences converging in e-science platforms, an acute and persistent under-representation of women in STEM fields has been diagnosed (Dasgupta and Stout, 2014; Su and Rounds, 2015; Alegria et al., 2016; Sax et al., 2017; Wang and Degol, 2017; Moss-Racusin et al., 2018; Van Veelen et al., 2019; Rua-Gomez and Arias-Gaviria, 2020; Zacharia et al., 2020; Santos et al., 2021). Figures on gender parity in STEM fields attest to this, with different dynamics in math-intensive and non-math intensive fields (Ceci et al., 2014). The International Science Council's *Gender InSITE Report* (2021: 10) analyses gender parity in 85 individual STEM academies from across the world[1] and records the average percentage of women's representation in STEM to be 17% in 2020. This average disguises the fact that gender parity in STEM also varies considerably according to discipline (Barone, 2011; Ceci et al., 2014; Su and Rounds, 2015; Cheryan et al., 2017; Sax et al., 2017; Begeny et al., 2020; Fisher et al., 2020). The *GenderInSITE Report* (2021: xi) states that gender equality varies across disciplines, and it requires a discipline-based action plan. In their comprehensive study on women in academic science in the USA, Ceci et al. (2014) found different patterns within STEM fields both in female representation and in later career attrition rates. Accordingly, they distinguish math-intensive disciplines including geoscience, engineering, economics, mathematics/computer science and the physical sciences - chemistry and physics - (GEEMP) from non-math-intensive disciplines. The latter include life sciences, psychology and social sciences (LPS) (Ceci et al., 2014: 76). Women are clearly under-represented in GEEMP fields. The LPS fields record no gender gap or even over-representation of women at the undergraduate level, while suffering from higher attrition rates at postgraduate level and in moving to associate professorships. In contrast, women who enter GEEMP fields suffer less attrition rates at postgraduate level and in moving to associate professorships when compared to women in LPS (Wang and Degol, 2017: 80).

Gendered computer sciences

The persistent under-representation of women in computer sciences (Lagesen, 2007; Gillard et al., 2007, 2010; Ceci et al., 2014; Vitores and Gil-Juarez, 2016; Cheryan et al., 2017; Sax et al., 2017; Michell et al., 2017, Zacharia et al., 2020) poses a challenge for gender mainstreaming in e-science platforms, given the significant role that computing, computationalisation and ICTs play in these platforms. The *European Parliament Report on Education and Employment of Women in Science, Technology and the Digital Economy* (Zacharia et al., 2020) highlights the under-representation of women in computer sciences in the EU, particularly in artificial intelligence and cybersecurity. The report argues that "even undergraduate female students in computer sciences believe that computer science is a male domain" (Zacharia et al., 2020: 25). It also states that "The percentage of women in

ICT careers still remains relatively low, and it is currently below 2% of women's total share in the European labour market" (Zacharia et al., 2020: 14) and that "the gender gap concerning AI and cybersecurity is the largest among all digital technology domains. The average percentages of females in AI and cybersecurity worldwide are 12% and 20% respectively" (Zacharia et al., 2020: 9). Although the under-representation of women in computer science is not universal and some countries such as Malaysia and India are at odds with this male-dominated picture of the field (Lagesen, 2008; Mellström, 2009; Vitores and Gil-Juarez, 2016: 672), the problem is dire in the more affluent Western world, especially in the Scandinavian countries which also boast higher levels of gender equality. The *Telenor Report on the Gender Gap in Technology in Scandinavia* (2019) states that according to the 2018 OECD Gender Data Portal "only 1 in 5 computer science graduates are women" across 35 European countries. "[T]he gender gap in Norway, Sweden and Denmark is particularly wide" (Telenor, 2019: 9), it adds. Scholars refer to this as the gender equality paradox (Stoet and Greary, 2018; Corneliussen, 2021), or living the contradiction (Griffin, 2022).

One frequent interpretation of the under-representation of women in the field conceives it as a "supply problem" (Vitores and Gil-Juarez, 2016: 670-671) or 'untapped human capital' (Dasgupta and Stout, 2014), generally focusing on wasted human resources. Against this assumption that conceives under-representation of women as a supply problem in the market, we suggest that the problem is rather related to how society is shaped around gendered technological fields of expertise and gendered technologies, feeding into and perpetuating this under-representation (Vitores and Gil-Juarez, 2016). One way in which the problematic of women's under-representation in the sciences might be mitigated is through collaboration across differently gendered sciences, i.e., through collaboration between female-dominated and male-dominated sciences. Such collaboration can potentially occur within e-science platforms that, as explained below, constitute a kind of borderland between diverse sciences.

e-Science as borderland

Following Gloria Anzaldua, Susan Leigh Star (2015: 157) conceptualises the notion of the borderland as the space opened up "when two communities of practice coexist in one person". The concept of borderland enables us to conceive of moving between not only disciplinary boundaries but also gender boundaries across different disciplines. Gendered subjectification acts as an inclusion/exclusion mechanism when it comes to entering certain practices, and climbing the career ladder; it thus contributes to the gendering of sciences as communities of practice. A recent study indicates that "increasing the perceived presence of women in a STEM discipline increases the likelihood that participants would label it a soft science", and "labelling disciplines as soft sciences leads to the fields being devalued, deemed less rigorous, and less worthy of federal funding" (Light et al., 2022: 1). Male-dominated math-intensive disciplines are labelled as hard. One result of this gendered conception of sciences is the so-called math self-efficacy gap, the fact that women exhibit a lower perception of their math competence compared to men. This also plays a role in the under-representation of women in computer science (Cheryan et al., 2017, Fisher et al. 2020; Stearns et al., 2020).[2] Although some argue that there are no longer any math performance gaps between girls and boys (Stearns et al., 2020), math self-efficacy is still low in women. The gendered hard/soft divide across math-intensive and non-math-intensive fields (Ceci et al., 2014) and math self-efficacy feed into each other. Gender stereotypes depicting computer scientists as male geeks or hacker figures serve as another example of how this scientific field is gendered, and how that gendering estranges women from the field (Lagesen, 2007; Reuben et al., 2014; Michell et al., 2017; Sax et al., 2017).

Science and technology studies have contributed a lot to the study of disparities across the sciences, under the rubric of the 'disunity of science' (Galison and Stump, 1996), disciplinary culture (Traweek, 1988), and 'epistemic cultures' (Knorr-Cetina, 1999). But we have yet to understand how the material-semiotic enactments that make up the sciences are laden with distinct gendering mechanisms. This calls for an analysis of horizontal gender segregation across the sciences in terms of epistemic cultures. This article hence integrates (feminist) science and technology studies and studies on women in science, which have largely remained separate (Bauschspies and Puig de la Bellacasa, 2009).

Case study and methodology

The e-science platform discussed here was established by three major Swedish universities in 2010 as a response to the Swedish Government Bill on Research Policy promoting e-science as a strategic research area (SRA). E-science is defined on the official website of the platform as including both the use and development of new computational methods and tools. The potential to collaborate across disciplines in academia and with industry regardless of geographical distance is also emphasised on the website.

Two features, namely distributed collaboration on a shared virtual network and cross-disciplinarity, are presented as the main features of e-science in the literature. STS literature on e-science mostly defines e-science as making use of new information and communication technologies to promote distributed, collaborative, multidisciplinary research (Hine, 2006: vi). It is also defined as "using and processing information in different digital formats to gain new achievements and new scientific insights" (Shokrkhah, 2018: 231), with a special emphasis on collaboration-at-a-distance. E-science is reported to encompass "the use of advanced high-performance computing tools across the sciences" (Schroeder and Fry, 2007: 563), creating new objects, sites and contexts of knowledge (Hine, 2006) in a virtual, hence distributed and connected setting of knowledge production called e-infrastructure. It therefore refers to "the rise of new forms of large-scale distributed scientific enterprises supported primarily through advanced information infrastructures" (Lee et al., 2008: 1). The terms e-science, cyberinfrastructure, e-infrastructure (Ribes and Lee, 2010: 231), as well as grid computing, collaboratories (Lee et al., 2008: 1; Jankowski, 2007: 549), and cyberscience (Nentwich, 2003) are at times used interchangeably to refer to the technological mediation of scientific research within larger collaborative, distributed and multidisciplinary networks supported by ICTs. The revolutionary role of e-science is frequently celebrated and sometimes called the 'the fourth paradigm' (Hey et al., 2009) in which "data-driven, interdisciplinary research is augmenting the existing paradigms of experimental, theoretical and computational science" (Edwards et al., 2011: 67). The *E-infrastructure Report of the Swedish Research Council* defines e-science as "computationally and/or data-intensive science conducted on networked facilities enabling widespread collaboration" (Grönbeck et al., 2014: 19) and a "techno-human ecosystem" (Grönbeck et al., 2014: 22). This report emphasises the human component, the sociality embedded in cyber-structures. It thus gives more space to the 'human infrastructure' (Lee, 2006; Bietz et al., 2010) embedded in the relational ecosystem of the infrastructure (Star and Ruhleder, 1996; Star, 1999).

The immediate effect of the changes introduced with the advent of these techno-human e-science collaborations is stated to be "the redefinition of traditional disciplinary boundaries into vast domains of investigation," also referred to as "the big new sciences" (Ribes and Lee, 2010: 232). Yet it is not clear whether, in practice, disciplinary boundaries are actually blurred or redefined. Van Zundert's (2018: 2) work on Mirador, for instance, focuses on one "open-sourced, web-based, general-purpose image viewer written in JavaScript". It discusses the preservation of data silos partially due to "the institutional makeup of academia and its (grant) funding schemes favour local institution-level digitization and development [...] Collaborative development between institutions is often frustrated by funding limitations, and moreover requires significantly more coordination effort than local development" (Van Zundert, 2018: 10). Our research is a contribution to this discussion on 'the institutional makeup of academia' and our results point towards the preservation, rather than reconfiguration of disciplinary silos, which in turn, contributes to the preservation of data silos. Our study, and the particular focus on the organizational logic, focuses on the interdisciplinary collaborations in which many different technologies are produced for scientific research purposes.

Research within the e-science platform we investigate here is classified on its webpage under the larger trans-disciplinary clusters of material science, life sciences, citizen earth and cornerstone technologies, the first three acting as domains to which cornerstone technologies are applied (see Fig. 1). Note that we write Platform with a capital P when we refer to the specific platform investigated, and use a small p when we refer to e-science platforms in generic terms.

While new computational methods, tools and applications are produced under the research cluster of 'cornerstone technologies', the three other research clusters constitute the so-called 'application areas' of these cornerstone technologies. In the Platform the cornerstone technologies are developed by researchers in the respective scientific computing, mathematics and computing science divisions and departments of the three universities involved. Other research clusters include scholars mainly from life sciences, material sciences, and environmental sciences in application-based projects. Application areas rather than disciplinary boundaries alongside computational technologies are thus emphasised in the public presentation of the Platform. Yet, as we shall see later, disciplinarity remains an important boundary that is preserved rather than blurred or reconfigured in the practical enactment of e-science on the Platform.

Methodology

The data discussed in this article come from participant observation of platform activities during the period September 2021-August 2022 and 45 semi-structured in-depth interviews conducted in March 2022-May 2022 with 18 women and 27 men researchers affiliated to the Platform. They ranged from PhD candidates to junior and senior faculty. All the participants were purposively selected according to the criterion that they had to be members of the Platform. They were thus not self-selecting. The first author initially approached the female researchers affiliated with the Platform in University B, the scientific computing program of the IT department of University A, and the female researchers included in the annual report of University C submitted to the Platform in 2021. She then approached all the researchers included in all three lists, and the PIs working for the Platform in disciplines other than scientific computing, computing science and mathematics in University A. The final list of 45 researchers included everybody who responded positively to the request for interview. She also participated in project presentations and seminars of the Platform. The research was conducted based on the premise that e-science is enactment, "pointing

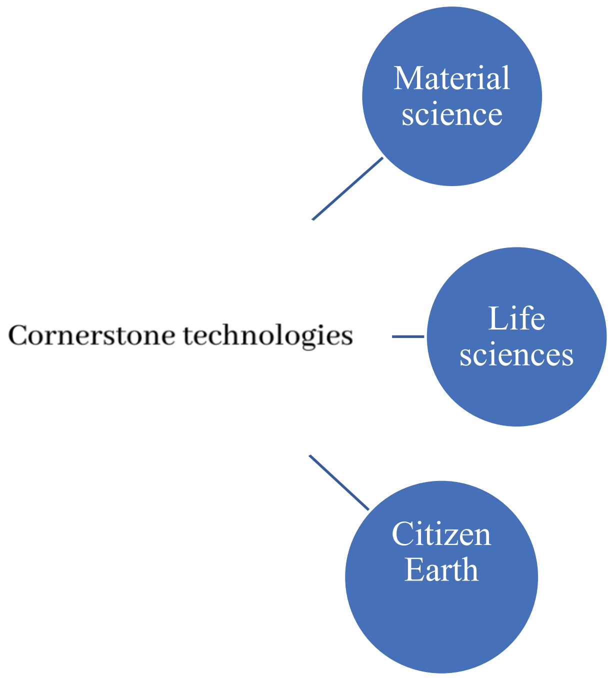

Figure 1. Research clusters of the Platform

to the importance of how socio-material sets of practices achieve and accomplish" e-science "as a meaningful phenomenon" (Bartlett et al., 2018: 2-3). The interviews were conducted either online or in one of the affiliated universities. The research was approved by Swedish Ethical Review Authority (Etikprövningsmyndigheten, No. 2022-00276-01). The interviewed researchers were provided with information sheets about the project and gave written consent for the use of their pseudonymised data in publications. The average length of the interviews was 60 minutes. The interviews covered questions on the interviewees' educational background and how they had entered e-science and the Platform, their interdisciplinary collaborations and associated challenges, the representation of women in their respective disciplines, and in their e-science collaborations, the reasons for the under-representation of women in certain STEM fields, obstacles to women's attraction to and retention in their respective disciplines and in e-science, suggestions to promote gender equality in their respective fields, in e-science, and in the Platform.

One thing that emerged immediately was that the group membership in the Platform was highly ambiguous. The first author observed three ways in which researchers were members of the Platform (see Fig. 2). The first was through working in the research group of a PI who received funding from the Platform, regardless of whether the researchers themselves were funded by the Platform or not. The second was working in the scientific computing division of one of the universities involved (University A), or in the Computing Science Department of another of these universities (University C). Thirdly, they could also be considered a member due to their involvement in a project that was partially or fully funded by the Platform. A considerable number of researchers were themselves unaware of the fact that they were deemed members of the Platform via one of the above affiliations. Due to this, and to the fact that there were no overarching comprehensive statistics on the Platform regarding its personnel, the following data only provide an approximative idea about the number of women involved in Platform activities in the three universities. In 2022 the scientific computing division at the IT Department of University A had 65 researchers in total (13 professors - five women and eight men; 24 teachers and researchers - four women and 20 men; 28 PhD students - nine women and 19 men). In the same year there were 157 researchers (37 women and 129 men) affiliated to the Platform in University B according to the official website of the university. University C had 59 researchers (eight women and 51 men) affiliated to the Platform in 2020 according to the annual report it submitted to the Platform[4]. These figures all indicate a significant under-representation of women on the Platform.

The interviews were audio-recorded and transcribed verbatim by the first author. At this stage the interviewees were pseudonymized by identifying them only by numerals, as we do in this article. The interview transcripts were analysed according to abductive data analysis (Timmermans and Tavory, 2012; Tavory and Timmermans, 2014). Taking a critical distance from grounded theory based on the assertion that "induction doesn't generate theory," (Timmermans and Tavory, 2012: 170); Timmermans and Tavory rather call for abduction. Going beyond the abductive/

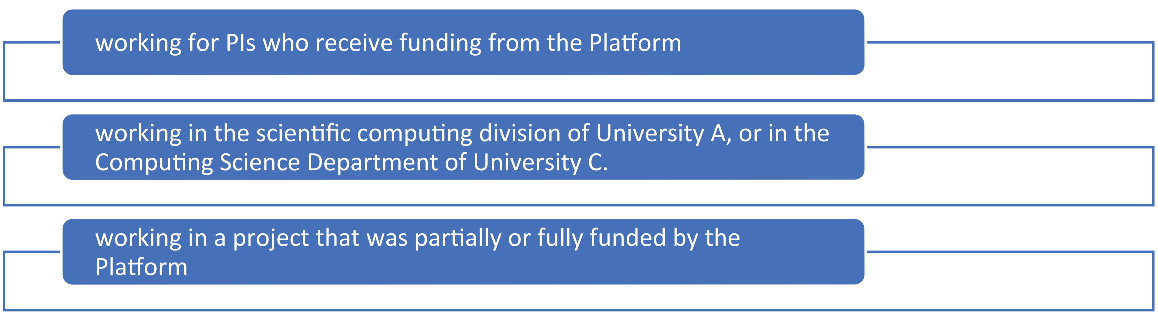

Figure 2. The membership structure of the Platform

deductive dichotomy, abductive analysis resorts to an iterative move between hypotheses on theoretically interesting cases and empirical data at successive stages of the analysis (Vila-Henninger, 2022).

> Once a hypothesis has been formed, deduction helps work out the hypothesis by providing a plausible generalization or causal chain. Induction constitutes the evaluation of the hypothesis because it provides the data that should conform to the deductively delineated premises (Timmermans and Tavory, 2012: 171).

Given this approach, the research started with the hypothesis that e-science collaborations could have the potential to attract female researchers from disciplines where they are better represented to ICTs. The data from the interviews were initially coded under the themes "academic background of researchers," "conceptualization of e-science", "challenges in e-science collaborations," "changes in knowledge production," "level of engagement and sense of belonging in the Platform," "strengths and weaknesses of the Platform," "representation of women in the Platform," "the level of involvement in interdisciplinary collaborations," "collaboration dynamics," "challenges in interdisciplinary collaborations," "gender mainstreaming opportunities in e-science collaborations," "horizontal gender segregation", "vertical gender segregation", "suggestions to promote gender equality in the Platform." These were then extended with codes emerging from the data under the themes of "boundary crossing practices," "the conception of interdisciplinarity", "hard/soft divide across the sciences", "gendered user/developer divide", "prevalence of a technical/engineering conception of collaboration," "limited mobility across sciences", and "the preservation of disciplinary silos". These inductively appearing new codes were then situated within the theoretical explanation in the literatures on women in science and STS, to be checked against the data.

In order to further check the emergent theme of "the preservation of disciplinary silos", co-authorship patterns of researchers at University B were also analysed based on the information provided on the university website. University B was chosen because their e-science collaborations exhibited the greatest disciplinary diversity. Affiliated researchers at University C mostly worked in technology development, with only few projects in other sciences. University A was involved both in technology development with researchers in the scientific computing division at the IT department and in research groups around PIs situated in theoretical chemistry, physics and biology departments. With the departure of the original PIs, University B eventually introduced open calls around projects exhibiting relatively more disciplinary diversity. Based on publications data on the webpage of University B, the disciplines of 113 researchers were compared with the disciplines of the top three researchers they frequently collaborated with. This sampling excluded PhD candidates who do not yet have enough publications for comparison purposes and researchers whose co-authorship data were not provided on the webpage.

FINDINGS

High recognition of horizontal gender segregation

The interviewed researchers articulated a high level of awareness of the horizontal gender segregation across their disciplines, attesting to the higher representation of women in biological sciences and medicine than in engineering, mathematics and IT. They also noted that this gender segregation was reproduced in their e-science collaborations where the so-called application areas of e-science projects involved more women, and the mathematics and IT-heavy work of technology development remained highly male-dominated. As one interviewee, typically, put it: "I've noticed that more men are working with this not application-based things, for some reason, they work on more theoretical stuff, and the applications, for some reason, women seem to think that's more fun" (Interviewee 15, woman, junior researcher).

The majority of the women researchers, as illustrated in the quotes below, thought that the reasons for this division were the gendered perceptions of scientific fields and gendered expectations regarding individual career trajectories:

I mean, I don't believe that women don't like technology. Because I know that many women do. Clearly, but I think that expectations play a larger role than what women actually want to do. I mean, because people don't expect you to want that. So, it's not so easy. I think the resistance from society, from your peers, I think this is a big factor at least. […] And maybe women feel more attracted to environmental sciences also because it's expected that it will be more attractive to women (Interviewee 4, woman, senior researcher).

I think it's the same thing [in computer science], similarly to math where it's seen as a boy's thing, when you are kids in the whole society. […] there is this perception around you all the time that even if people may not notice so much constantly tells you, that's not for you. That's not for you. You shouldn't do that. You're not good at that (Interviewee 39, woman, junior researcher).

E-science, a potential space for gender equality?

The majority of the interviewees thought that e-science, as a new area of research at the intersection of different disciplines and disciplinary cultures entails opportunities to break away from preconceived gendered ideas around math-intensive fields. One interviewee highlighted the potential of this newness to build more gender-equal communities of research:

In some sense, I think that the focus areas have shifted more towards data driven science. And maybe there are more women there because that's new, a newer science. I think that there is a tendency for the old areas to be more male-dominated. […] There are more opportunities [in newer science]. And, the hierarchies haven't formed themselves yet. So that's why I think there could be more [women] (Interviewee 6, woman, senior researcher).

Another interviewee referred to the prevailing notion of 'proper computer science' as a male gendered domain for people involved in computer hardware and software, and stated that application-oriented e-science does not fit this conception and therefore has the potential to attract more women.

I would say there would be more of an equal gender balance in the e-science than there would be in some of the, quote, more core kind of nerdy computer science, if you want to call it that. […] Because there'd be a little bit more breadth of sort of people involved and so on (Interviewee 31, man, senior researcher).

Applications with societal value such as environmental sustainability or cancer research were also thought to be of importance when it comes to attracting more women to e-science. An interviewee told the first author how physics' claims in the past, as a discipline, mostly focused on solving 'hard' problems and that might have deterred women, adding:

I think that if we put more emphasis on the value of sustainable technologies, and we need e-science people in material science, I think we will get more and more women to apply to our program (Interviewee 17, man, senior researcher).

E-science collaborations funded by the Platform indeed bring together researchers coming from and/or intersecting different communities of practice around similar problems. Hence, they have the potential to be spaces where more than one community of practice, both in terms of gender and disciplinary belonging, co-exist in their participants in a way that might alter the gendered perceptions and expectations around disciplines. Some of the interviewed researchers were involved in boundary-crossing practices through interdisciplinary collaborations, being specialized in computational sub-divisions of their disciplines, and/or changing disciplines. Most of the interviewees dated their entrance into e-science, either as users or developers of computational methods, back to their postgraduate studies. As exemplified below, they typically thought that e-science collaborations have the potential to attract more women scientists to computationally heavy areas of research, especially from disciplines with higher representations of women such as biological sciences and medicine:

One thing that in particular comes to mind is exactly life sciences. So, what happens now is that medicine uses increasingly computational

> techniques. And in medicine, […] I believe it's slightly more women than men who study medicine. But I mean, medicine definitely doesn't have a gender problem with regards to women. And so there and as well in biology. So traditionally, fields that would use computational science were engineering, physics, these types of things, then increasingly chemistry, and only let's say, in the last 20 years has it seriously started in biology and medicine. And so therefore, there is, I would say, at least in e-science in Sweden there I see an increase of women because of that (Interviewee 20, man, senior researcher).

Perpetuation of horizontal gender segregation

Yet, the potential hinted at above remained untapped in the Platform, and the existing horizontal gender segregation across the sciences was, as stated above, not bridged, but reproduced. There were four reasons, discussed below, for the perpetuation of horizontal gender segregation in our case study.

Limited mobility across disciplines with higher gender parity to male-dominated computational technology development

Interdisciplinary collaboration[5] was a key concern for the Platform which functioned mainly as a research funding distribution hub. Distribution of funding was mostly centred on a few PIs situated in their disciplines who also manifested strong engagement in Platform activities. They were the principal investigators (PIs) who collaboratively applied for the government's call to establish an e-science SRA (strategic research area). These PIs located in their respective disciplines used Platform funding to hire PhDs and postdoctoral researchers. Only relatively recently with the departure of the original PIs, did University B start to involve new PIs around e-science projects which exhibited a strong focus on application areas in cognitive sciences, life sciences, and environmental sciences.

In this context interdisciplinarity was enacted primarily in two ways. Firstly, funding was granted to PhD candidates and postdocs from new disciplinary constellations and application areas in e-science projects. This resulted in individual boundary-crossing across disciplines. Secondly, technology developers and domain specialists worked in parallel, doing their bits of works in collaborative e-science projects. This being the case, the mobility of the researchers from disciplines with higher gender parity to technology development in the disciplines of scientific computing and mathematics was very limited.

Of the 45 interviewed researchers, only five reported mobility across biological sciences or medicine and male-dominated fields of IT and engineering. Of these five researchers three were men who had entered IT-intensive fields such as bioinformatics and scientific computing from biological sciences and medicine (molecular biology and genetics, physiotherapy and public health, biology). The two women who were in this category, on the other hand, were situated in evolutionary biology with a background in mechanical engineering, and in scientific computing with a background in biology respectively. It is thus clear that women's mobility across biological sciences and medicine to IT-intensive fields remained very limited in the case of the interviewed Platform researchers.

Gender friction in e-science collaborations

The female researchers involved in the Platform experienced not only science friction, interoperability problems that occur when two or more disciplines work together on similar problems (Edwards et al, 2011), but also what we might call gender friction. Here we use the term gender friction to refer to the gendered aspect of interoperability problems in e-science interdisciplinary collaborations which adversely affect women. The literature on women in interdisciplinary STEM collaborations records certain gendered challenges. Zippel (2019), for instance, reports that existing institutional and organizational gender inequalities also permeate interdisciplinary STEM collaborations, and a gendered imaginary prevails in interdisciplinary collaborations, marked through terms such as 'patronizing helper', 'exploiter', 'partner' and 'friend'. This imaginary "reproduce[s] inequalities through symbols and practices" (Zippel, 2019: 1802). Griffiths et al. (2022: 233), on the other hand, state that "a survey of STEM faculty at a large public research university found that faculty from under-represented groups - in terms of gender, race, and sexual orientation - had more negative experiences with department-level research collaborations."

In our case study, the above-discussed nature of interdisciplinarity in the Platform, along with the need for constant self-training in the use of ICTs, posed certain challenges, especially for contingent junior female faculty. These challenges prominently included how much one actually needed to know about other disciplines one engages with in an interdisciplinary context. In an environment where interdisciplinarity was mostly conceived as technology developers' and domain specialists' working in parallel, it was rather ambiguous as to what it meant to be competent in a new discipline. The interviewee below talked of her impression of interdisciplinary work as "intruding on" another area of expertise, which was perceived to be harder for women.

> I think it's common that people in interdisciplinary topics, and maybe especially women, feel a little bit like they are intruding in someone else's field. […] like as an engineer, in a medical application, you feel that you don't know anything about medicine, and then you don't have anything to say about things there (Interviewee 1, woman, senior).

This was observed to go hand in hand with a high sense of self-responsibility especially among contingent female faculty who tended to overperform in e-science projects. "I think there has been a lot of this fear of not doing well enough," said Interviewee 13 about her work in her research group (PhD candidate). Interviewee 12, a PhD candidate with a background in engineering who started working in an evolutionary biology department as part of her e-science project, expressed issues she experienced mostly because the biology department which hired her was not well set up to conduct cross-disciplinary projects. "But me being on the fringe, I know that it's going to cause an issue because at every meeting we have on my progress, there's new information and new directives and new things that are applied," she said, adding "the issue is mine because I need to learn where I am right now." This becomes a challenge when interdisciplinary work mostly relies upon such individual cross-boundary action, and the disciplinary organizational structure of universities is sometimes not yet ready to accommodate such boundary-crossing actors (Griffin, 2022). In our case, especially junior women researchers internalized these issues which were not necessarily about them. They exhibited great degrees of self-responsibility, anxiety and stress.

Limited female mobility from biological sciences and medicine to IT fields, and gender friction restricted e-science borderlands' capacity to meaningfully alter asymmetrical gender divisions across disciplines in e-science projects. Furthermore, as we shall see below, even when there was gender parity in cross-disciplinary e-science collaborations, the gendered developer/user divide permeated research groups. Computational system/tool/method developers mostly were men, and computational self-reliance across disciplines acted as 'gendered boundary work' (Pereira, 2019; Vuolanto and Kolehmainen, 2020) to further strengthen the hard/soft divide across the sciences depending on their perceived proximity to mathematics and IT.

Gendered user/developer divide

The logic of domains and the user/developer divide

The above-mentioned conception of interdisciplinary work was operative under a particular organizational logic, namely the logic of domains, described by Ribes et al. (2019: 281) as "a de facto organizing principle for science policy and technology development". According to this logic, application areas in the Platform were classified as specific domains of action in which research was supported through 'cornerstone technologies' (see Fig. 1 above). Ribes et al. (2019) state that this logic envisages a 'domain independent' area of expertise, namely computing, information sciences and more recently data science, presumed to be universal and general. On the Platform website, the research cluster called cornerstone technologies bore this attribute of domain-independence, as the technologies were described as "transcendent" in relation to the domains of material sciences, life sciences and citizen earth.

Tool developers in the Platform also enacted this logic in how they developed generic models from particular datasets and/or vice versa. This was described by one interviewee as "tweaking aspects of the model so that they can latch on to this data" (Interviewee 24, woman, senior researcher). This logic was also apparent in how the interviewees conceptualized the need for the domain-independence of computational tools:

> Well, I mean, e-science is broader than what we're doing in computational sciences, what we're doing in chemistry for instance, because then we are sort of focused on methods that give chemistry results. And then, of course, in mechanics, they focus on things that sort of solve mechanics problems. So, the methods are quite distinct, there are similarities, but they are doing sort of different things. E-science collects all of these, and also puts the focus on the methods rather than the discipline. So that's a new thing about e-science. It sort of creates a network above the disciplines, a full umbrella zone of the disciplines, and connects people (Interviewee 15, woman, junior researcher).

The discourse of supporting sciences through e-science whose computational tools remain generic, domain-independent and beyond scientific disciplines prevailed among the tool developers in scientific computing, mathematics and computing sciences. "We try to support emerging science" said a senior researcher, adding "So, it is part of our mission to make sure that all sciences can access computational resources that are needed" (Interviewee 4, woman, senior researcher).

This organizational logic, along with the particular enactment of interdisciplinarity mostly relying on working in parallel, within one's disciplinary boundaries, around a common problem, perpetuated a developer/user divide within interdisciplinary e-science collaborations. It was common to observe that technology developers referred to scientists in application areas as their 'users':

> It's difficult to characterize what exactly people need, you know, I mean, when your user comes and says, "I need this to work." "Okay, what do you mean, by saying work?" And it's difficult for people who don't know how this works (Interviewee 3, woman, senior researcher).

This showed that computational technology development was conceived as an engineering problem, and e-science as a form of technology

Table 1. The 10 researchers at University B who frequently co-authored with researchers from another discipline.

Researcher	Department	Frequently co-authors with (as per top 3 collaborators)	Discipline
Researcher (male)	Economics and Management	1) Researcher, (male) 3) Researcher, (male) The 2nd collaborator is from the same department.	1. Medicine 3. Clinical Chemistry and Pharmacology
Researcher (male)	Mathematics (Faculty of Science)	1) Researcher, (male), • 2nd and 3rd most frequent collaborators are from the same department	1. Economics
Researcher (male)	Astrophysics	1) Researcher, (male) • 2nd and 3rd most frequent collaborators are from the same department	1. Mathematics
Researcher (male)	Mathematics (Faculty of Science)	All three male researchers	Astrophysics
Researcher (female)	Geology	All three male researchers	Astrophysics
Researcher (male)	Bioinformatician, at the Faculty of Medicine	1) Researcher (male) 2) Researcher (male) 3) Researcher (female)	1. IT 2. Electrical and Information Technology 3. Physics
Researcher (male)	Scientific and technical computing	All three male researchers	Structural mechanics
Researcher (male)	Mathematical statistics	All three male researchers	Physical geography and ecosystem science
Researcher (male)	Data scientist at the Faculty of Medicine	3 male researchers	Biochemistry and structural biology
Researcher (male)	Mathematics (Faculty of Engineering)	Two male, one female researchers	Communications engineering

transfer to support computationalisation trajectories of scientific disciplines rather than a research innovation which reconfigured disciplinary boundaries. The impression was

> that the level of ambition is not about bringing the disciplines into e-science, or [bridging] that gap that we were talking about [between scientific disciplines and e-science], but rather facilitating the use of e-science across disciplines, but still within their disciplinary silos. So, [this platform] isn't really providing a platform for, you know, dissolving the boundaries between those disciplinary silos, but rather, it's about increasing the accessibility of e-science within each discipline (Interviewee 32, man, senior researcher).

The preservation, rather than reconfiguration, of disciplinary silos was also visible in the co-authorship patterns of affiliated researchers. The top three collaborators of the vast majority of 113 researchers at University B (see the section on methodology above for selection criteria), were from their own departments or centres. Only 10 researchers, of whom only three were female, were recorded to frequently co-author with researchers from other disciplines (see Table I). 7 researchers were involved in co-authorship practices with researchers from other disciplines to a lesser extent.

This also led to the preservation of disciplinary cultures as attested by the interviewee cited below.

> So also in [this Platform], in e-science platforms, do you think that scientists inherit the culture of their own disciplines?
>
> I think so. Yes. Or how do they blend? Do they change each other? Do they interact? Perhaps a bit, but I think which department you are in is important. And then of course, it depends if you are dominating the department or the department is dominating you. So, it depends on the size of the groups also. But yes, I think the culture is more tied to domains than to what you actually do (Interviewee 4, woman, senior researcher).

Although e-science brings together scientific disciplines with varying degrees of gender diversity, hence has the potential to act as a borderland in which communities of practice intersect in one person and researchers are exposed to one another's 'disciplinary' (Traweek, 1988) or 'epistemic' (Knorr-Cetina, 1999) culture, this potential was not realized in this Platform. Disciplinary silos were largely preserved and e-science solutions were mostly conceived in terms of engineering problems around technology transfer. One result of this is that a gendered user/developer divide permeated these e-science collaborations, which reflected the traditional gender divisions across the disciplines.

Gendered technology user/developer divide in the platform

The enactment of the logic of domains, the nature of interdisciplinarity in the Platform, and the resulting preservation of disciplinary silos all meant that the already existing horizontal gender segregation across the disciplines was reproduced. A closer look at e-science projects in this Platform not only in terms of the numeric representation of women but also, and especially, the type of work conducted within the interdisciplinary research projects showed that existing gender divisions across the disciplines permeated the e-science projects. The interviewees typically reported that the task of computational technology development which involved the theoretical work of numerical analysis and computational simulation, among others, remained highly male-dominated. Interviewees from quite different fields of research involved in e-science collaborations, such as the examples below, all stated this.

> I know plenty of women in astronomy, who get involved with sort of e-science and big data. And they are quite happy with it, and they do fine. But also, I know that, within astronomy, studies that are more focused on stars […] tend to be a much friendlier field [for women], rather than, say, cosmology, or [working on] things that are very distant in the universe, or things like cosmological simulations, which are just theoretical computer simulations of the universe […] that field is a little bit more male-dominated, and I guess a little less friendly than, say, fields using stellar data. […] *Observation of stars, you know, requires a lot of work, but you're also sort of limited to the data that you*

> *get from stars that are available or, you know, the instruments that you use.* And so, I think somehow, it's not as personal. The result doesn't reflect what you think. And so, in that way, *the theoretical fields are the fields where you create these huge simulations*. I think it tends to build an environment that is much more protective of your own data. And, and a little bit more guarded of your own science [Interviewee 9, woman, senior researcher, emphasis added].

Here, the interviewee drew on the distinction between the work of mere observation, the "use" of observed data, as well as instruments, and the theoretically heavy work of designing computational simulations. We see how within the same discipline, the work relying on the 'use' of data and computational tools, and the development/ design of these tools remains gendered.

> Yeah, we have like, groups, I'm in the systems [system development] group. So, we are 8 people and there are two women if I recall well, yeah, and then there is a bioinformatics group, where it's four people and there are no women, and then there are like more lab-oriented groups, which I don't know as much because I don't interact with them as much. But there, I think, there are many more women (Interviewee 35, man, junior researcher).

Here again, we see that in the same life sciences centre - life sciences being a STEM field with relatively higher gender parity - the work of technology development [system development] and bioinformatics remained highly male-dominated.

One interviewee who thought that e-science collaborations have limited capacity to contribute to an increase in the number of women in computational tool development referred to the problem of their inclusion in e-science collaborations as users and not as developers:

> [Women] have to learn something because they're using. But they will never become a developer. They may say to the developer, "Look, here, you have done lousy work, change it, because we don't use this" and things like that. […] Some people from computer science will teach the biologists. Yes, sure. But this will not lead to more people, female people in computer science. Of course, synergies are great, there will be something, there will be some people who learn biology and vice versa. And start programming and so on, sure, but it's not going to solve the major problem (Interviewee 7, woman, senior researcher).

Thus, even when there was gender parity in an interdisciplinary e-science research group, the traditional gender division across the math-intensive and non-math-intensive divide (Ceci et al., 2014) seemed to be reproduced and not mitigated in e-science collaborations.

Gendered boundary work around self-reliance in computational tool development

The term boundary work was originally developed to refer to rhetorical tools used by scientists to distinguish science from non-science in a time when modern sciences aspired to distinguish themselves from religion and technical know-how for claims of authority (Gieryn, 1983). In time, the term came to be used also to define practices and discourses that serve to create distinctions and boundaries across and within sciences. There are also studies which discuss boundary work that occurs as a response to new technologies for scientific research (see Burri, 2008; Reyes-Galindo L., 2016, among others). Recently, the gendered character of boundary work has started to be analysed (Pereira, 2019; Vuolanto and Kolehmainen, 2020). Below, we discuss how distinctions made across sciences with respect to their perceived computational self-reliance acted as gendered boundary work in the Platform which solidified the gendered hard/soft divide.

It was common among male interviewees to classify disciplines along a scale depending on the disciplines' proximity to mathematics and computing. Physics and theoretical chemistry were two disciplines which were perceived to be close to mathematics and computing. The presumed self-reliance regarding computational tools and methods development especially in physics, but also in theoretical chemistry, served as a boundary work for the scientists to draw boundaries around their disciplines to reinforce their authority. For example, the requirement to have discipline-specific knowledge was very much accentuated in the case of physics; it was cited as the reason why it is physicists themselves who need to develop their computational tools.

One interviewee (Interviewee 19, man, senior researcher) told the first author how a computer scientist who was hired by the research group to do programming to address their scientific problems failed to be efficient, as he did not know the problems in the field, and could not write hundreds of lines of codes at once. He then added the story of when CERN opted to buy commercial software instead of asking physicists to do the programming:

> […] This was especially true at CERN, because at CERN, actually it's a bit of a funny story, but it's like 30 years ago almost, right? When they started to plan for this new collider, they said, "We don't want to program things at CERN, we want to buy commercial software." And so, for 10 years, they had a big investment in commercial software, because they said, "We don't want physicists to write the program." But in the end, it turned out that this commercial software didn't really deliver. Because they didn't understand the problem we faced. And so, RUTH, this program that we use today, was really started as kind of like a renegade project, it was not really sanctioned by the management, they really looked down upon it for many years. But the problem was that they knew exactly what we needed, right? So, they made a program that could do all the things we needed, whereas other people made maybe more beautiful programs, but they couldn't do what we needed to do, right? (Interviewee 19, man, senior researcher).

The same requirement for discipline-specific knowledge was not as much highlighted in biological sciences and in medicine. There, just as in the example below, the emphasis was on the researchers' dependence on tool developers outside of their discipline.

> So, that's where I think a platform … could fulfil an important role because we may have quite uneven formal training and uneven knowledge of [computational] methods and, previously your research was normally more focused and now we are forced to do research that is a lot more complex and you need to be quite good at almost everything, but you're not very good at anything, you are kind of more superficial sometimes (Interviewee 5, woman, senior researcher).

In this discourse of varying levels of computational self-reliance and confidence across disciplines, it was observed that the gendered hard/soft divide between the sciences was reinforced. Hence, the presumed computational savviness and self-reliance of a discipline was used as gendered boundary work to underline how hard or soft a discipline was.

Some male interviewees drew the boundary between physics and biology as to how deterministic or stochastic their computational models were. In the quote below, the presumed precision of correspondence between real-life interactions and computational models in physics - i.e., deterministic over stochastic - which enables the "staging" of a physical action (Knorr-Cetina, 1999: 34)- was used as boundary work between physics and biology:

> Computationalisation of scientific disciplines is related to how deterministic or stochastic their models are, how much noise they incorporate. Models are more deterministic in physics and less so in biology, also leading to how suitable their problems are to being computationally simulated (Interviewee 26, man, senior researcher).

Another male interviewee associated the different pace of diverse sciences in adopting mathematical and computational models, or their computationalisation, to how hard/soft they were supposed to be, reformulating the boundary in terms of the hard/soft divide:

> If you put like all kinds of sciences, so to say, like on a scale with the hard sciences at the bottom and the soft, softer sciences at the top, you could see, along this scale, people started to use more and more mathematical models, and that's what I would qualify as e-science, this use of maths to model a problem (Interviewee 35, man, junior researcher).

Researchers were aware that biology was labelled as 'not hard'. A junior woman researcher stated that in high school, biology was considered a "loss for science because it's not a hard science" and the overall feeling she got was that "biology was a bit deprecated as a science, it was not a pure, hard science" (Interviewee 13).

A male interviewee was quick to associate the higher number of women in biology with the discipline being less math-intensive:

> So why do you think we have more women in biology?
>
> I don't know. It's less maths maybe. If I would say that. So, if one would label, say this physics and maths, they are more male-oriented disciplines, then biology would be the opposite of it (Interviewee 30, man, junior researcher).

Overall, as opposed to physics and theoretical chemistry, computational competence in biology was in general perceived to be low:

> [In biology] they are kind of in a less privileged situation. In physics, we could help ourselves [in computational tool development], while in biology, they probably can't, so the more dire need for this kind of organization falls in those departments (Interviewee 3, woman, senior researcher).

While chemistry was also deemed less math-intensive and 'softer', there was clear gendered boundary between laboratory work and computational chemistry. "For some reason, theory is not attractive [for women]", said an interviewee, adding that "it could be that what attracts females to chemistry is sort of the chemistry of doing things with your hands in a way, working with sort of practical things" (Interviewee 2, man, senior researcher). He stated that chemistry in that sense was closer to biology and "kind of a softer subject", and added that it could be the reason why they needed to recruit PhD students to work on e-science projects from physics and other departments. This was somehow in conflict with his previous statements on the self-reliance of chemistry when it comes to developing computational tools to solve problems in the field. Yet, it is illustrative of the way in which perceived computational self-reliance is used to draw boundaries both between biology and chemistry, the first otherwise stated to be close to chemistry, and between laboratory work in chemistry and computational chemistry.

In the case of the Platform, the perceived or real computational self-reliance of a discipline was mobilized to draw boundaries both across the sciences and between theoretical/computational and wet-lab work within the same science, all in line with the hard/soft divide. Given the gendered nature of the hard/soft divide across the sciences, which goes hand in hand with the gender division both within and across the sciences, computational self-reliance also acted as gendered boundary work for claims of authority. This gendered boundary work around disciplinary computational self-reliance hence strengthened the gender division across the scientific disciplines.

Discussion and conclusion

In this article, we attend to situated practices and meaning-making around technology development and use in a particular e-science platform in Sweden to account for the extent to which existing horizontal gender division across the sciences is enacted in the borderland opened by e-science collaborations around the use and development of the state-of-the-art computational tools. This can also be reframed in terms of the more general question of "shifts in power relations around knowledge" (Wouters et al., 2013: 3) and the possibility of social transformation within existing inequality regimes (Acker, 2006). These inequality regimes have become persistent and resistant to change, especially in the case of gender imparity in computer sciences and ICTs, and gender divisions across the sciences.

Although there exist discussions and data on the possible "levelling effect" of new e-science technologies (Hine, 2006: xvi) when it comes to enhancing female participation in scientific endeavours and the workforce (Palackal et al., 2006; Oleksy, 2012; Oladejo et al., 2021), and the career advancement of female academics (Ojo et al., 2015), the findings from the Platform offer a grim response to the question of whether the position of women in science is changing with this new technology (Kretschmer and Aguillo, 2005). They attest to the perseverance of the traditional horizontal gender segregation, and gender inequalities across disciplines, including within e-science collaborations.

Although Platform members articulated the notion of a potential for e-science collaborations to attract more women to computationally supported research, one could see that in practice this potential remained largely untapped and the existing horizontal gender segregation was perpetuated through the following mechanisms which we also used to structure this article: a) mobility across disciplines with asymmetrical gender divisions remained limited; b) gender friction, gender-specific problems suffered by women in interdisciplinary collaborations, took its toll on female researchers; c) traditional gendered divisions across scientific disciplines permeated e-science collaborations and perpetuated the gendered technology developer/user divide where developers mostly remain men[6]; and d) different levels of self-reliance in technology development across disciplines and the perception of scientific fields' proximity to IT and maths acted as 'gendered boundary work' (Pereira, 2019; Vuolanto and Kolehmainen, 2020). All this reinforces the gendered hard/soft science divide. Disciplinary silos were preserved rather than blurred or reconfigured. Technology development was deemed an engineering problem, and e-science computational technology transfer, rather than a reconfiguration of disciplinary boundaries. This all mitigated the potential of boundary crossing to alter existing gender asymmetries in the sciences. How can we account for this persistence of gender asymmetries in new technology formations such as e-science?

It is well known in STS that new technologies are "built on an installed base" (Star, 1999: 382), a base that also includes existing asymmetrical social relations across 'the human infrastructure' (Lee, 2006; Bietz et al., 2010). This needs to be kept under consideration, especially in the case of technologies which enable disembodied and distributed communication in the virtual or cyber space. Virtual space is closely tied to existing inequalities in the broader social world and it supplements rather than completely replaces real-life interactions (Woolgar, 2002). That space "reflect[s] and reinforce[s] existing social orders, expressing and materializing hierarchical relations" (Davis et al., 2021: 1). Hence the belief in e-science's potential to mitigate gender asymmetries across sciences has, in the Platform under study, turned out to be the 'cruel optimism' that Lauren Berlant (2011) invokes to characterize the failed promises held out to women of the possibilities of inclusion under changing conditions.

Our case study turns our attention to the fact that new technologies are assembled and become embedded in the existing techno-human infrastructure, and do not create a ground-zero for social emancipation. To be able to tap into the potential of cross-disciplinary e-science collaborations to meaningfully bridge the gender gap across the sciences, we need concerted efforts and collective positive action at organisational level. These efforts will inevitably need to address the gendered technology user/developer divide and the way interdisciplinarity is practically enacted. They will need to analyse the repercussions of the prevalence of the logic of domains as an organisational principle in e-science initiatives, and tackle the ways in which computational self-reliance in the sciences with respect to computational tool development acts as gendered boundary work. This points towards the requirement for future studies on the extent to which disciplinarity remains important in e-science collaborations, on the gendered aspects of epistemic cultures (Knorr-Cetina, 1999), and on how and whether the computationalisation of the sciences alters existing epistemic cultures, or creates new ones, with possibly different gender relations.

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Notes

1 The report uses a complex methodology covering all continents (see Gender InSite, 2021: viii).

2 There may, of course, be other reasons for this under-representation, such as fear of harassment from male colleagues or a sense of lack of social safety. For the purposes of the article, we focused on the ones which have appeared during the data analysis.

3 The project which led to the research whose findings are discussed in this article was conceived by Griffin who also secured the funding for Karakaş's postdoc at Uppsala University. Karakaş designed the research and conducted the ethnographic field study. She analysed the data from the fieldwork, the interviews, and online information on researchers' biographies and co-authorship practices. She drafted the article, and attended to its revision during the peer-review process.

4 As seen above, different sets are used to give an approximative idea about the number of women in the three universities of the Platform. This is related both to the ambiguity around group membership in the Platform and to the lack of availability of a list of affiliated researchers. Only University B had a list of the staff affiliated to the Platform, therefore this list was the most exact document to rely upon. Group membership in University C and A depended on the affiliation to the afore-mentioned departments and research groups of PIs funded by the Platform. University C submitted an annual report to the Platform, while University A did not. Here, we resorted to the list of researchers in the annual report of University C, and the number of researchers affiliated to the scientific computing division in University A. The number of women in the research groups of PIs funded by the platform therefore couldn't be counted in the latter case.

5 Interdisciplinarity as a concept has many meanings. For some it means working together across sub-areas of one academic field. However, the type of interdisciplinary that is of concern for us here involves broader interdisciplinary work across disciplines, e.g. between more gender-equal sciences, such as medicine, biological sciences and environmental sciences *and* the male-dominated engineering and IT.

6 See Suchman (2002) for the demystification of the designer/user opposition in technology production.