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The gendered maths confidence gap, social influence and social integration

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ABSTRACT
While there is little discernible difference between girls and boys in maths competence during secondary education, on average, girls have lower confidence in their maths skills. Over time, this difference leads to gendered choices of education and occupation. Research explaining the maths confidence gap focusses on psychological factors and socialisation into stereotypical gender roles. However, how the peer context shapes the self-perception of competence and how this self-image affects social integration and popularity of girls and boys is barely understood. We analyse friendship networks and perceptions of maths confidence in Sweden and Germany to answer these questions using the CILS4EU dataset (N = 7,472) and multi-level, longitudinal network models. We find that maths confidence of girls accurately follows their maths grades and social relations have little impact on girls' self-evaluation. Boys tend to overestimate their ability and are more susceptible to peer processes; social comparison processes inform boys' maths confidence. This suggests that math ability is important for boys but socially irrelevant for girls. Concerning friendship choices, we find that boys and girls with higher maths confidence are often more integrated. Thus, we do not find social pressure on girls to adhere to gendered math-stereotypes – the opposite is the case.

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Introduction

Across Western societies, the average secondary school girl has lower confidence in her mathematical ability than the average boy of the

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same age, as shown by several studies and meta-analyses (Correll 2004; Else-Quest *et al.* 2010). Furthermore, the gendered maths confidence gap among adolescents has no objective justification related to pupils' performance: Ample research from the past decades has shown no large differences in girls' and boys' maths performance (Hyde *et al.* 1990, 2008; Lindberg *et al.* 2010); the differences are particularly small in comparison to the size of the gender gap in maths confidence. This well-known and well-documented phenomenon is often framed as girls being not confident enough in their ability; there are, however, also studies that suggest that boys might in fact be overconfident (Cho 2017; Niederle and Vesterlund 2010; Nollenberger *et al.* 2016).

This maths confidence gap has far-reaching consequences; self-perceived competence informs educational and occupational choices and young people choose university subjects and careers in which they think they are talented (Ellis *et al.* 2016; Moakler and Kim 2014). Accordingly, women are underrepresented in STEM (science, technology, engineering, maths) subjects at university, as well as in highly paid STEM occupations that usually require mathematical skills (Barone 2011; Gerber and Cheung 2008).

Previous studies on the maths confidence gap mainly focus on socialisation through parents (Dryler 1998; Jonsson *et al.* 2009; Werfhorst and Luijkx 2010) and teachers (Keller 2001; Li 1999). These studies highlight how socially learned gender role perceptions can lead to a differential evaluation of maths ability (Alon and DiPrete 2015; Correll 2004). In this study, we shift the focus to a mostly neglected, but very informative aspect of the maths confidence gap: The interplay of peer relations and maths confidence. Especially in adolescence, peers are the primary social reference for individual development, and peer processes that operate through friendship networks determine a wide variety of individual outcomes, including physical and mental health, political opinions, substance use, pro- and antisocial behaviour, academic performance and cultural consumption (Veenstra *et al.* 2013). However, currently, only research that discusses the relation between individual and group-average performance considers peer processes, using so-called big fish little pond (BFLP) approaches (Marsh *et al.* 2008).

Analysing subjectively meaningful friendship networks can provide more nuanced insights into the formation of maths confidence in adolescence and allows to scrutinise established theories of socialisation processes. As peer processes cannot be viewed in isolation, we are taking a comprehensive approach to understand the extent to which theoretical peer processes have an effect on individual maths confidence, and to what extent they apply differently to boys and girls. We are then jointly interpreting our results to understand gender differences in the social determinants and consequences of maths confidence in adolescence and discuss the extent to which this can help us understand the gender gap in maths confidence. As there is no research to date that considers these mechanisms, the following five open questions drive our analysis; the first four are concerned with peer processes affecting maths confidence, while the fifth one considers how social integration depends on maths confidence.

First, are there convergent social influence processes, i.e. do individuals adjust their self-image to be more similar to their peers? As friendships among adolescents predominantly exist within genders, social influence could lead to an increase or cementation in pre-existing gender differences on the group level. Second, another plausible expectation is divergent social influence, which implies becoming more dissimilar to one's friends, in line with social comparison processes. Third, do friends with traditional gender views stymie girls' maths confidence and boost that of boys? Fourth, cross-sex friendships confront potentially held stereotypes about ability differences by gender with reality. Does the extent to which girls and boys have cross-sex friendships adjust the evaluation of own ability?

Fifth, taking a network perspective furthermore allows us to study a phenomenon that has received much theoretical attention, but which is hard to study empirically: Peer norms that could lead to girls lowering their maths confidence. By analysing patterns of friendship integration dependent on maths confidence, we can detect the existence of peer norms that are detrimental to girls' maths confidence: Do we see that, for instance, girls who are confident about their maths skills are integrated to a lesser extent in the friendship network in their school class? A pattern like this could be the result of a peer norm that girls should not be good at maths, leading to girls reporting lower confidence.

To answer our questions, we make use of recent advances in the statistical analysis of social networks and a large-scale European data collection project. We study classroom-based network data from the Swedish and German subsamples of the *CILS4EU* dataset (8,812 individuals nested in 358 classrooms). This multi-level data is analysed using multi-level stochastic actor-oriented models (SAOMs). The SAOM allows for the interdependent analysis of social relations and individual behaviour in a generalised linear modelling framework and our approach takes the potential variation by country and school track into account.

Our results are illuminating. As expected, the main predictor of maths confidence is individual maths grades, and girls have lower average maths confidence. However, the relation between grades and confidence is stronger for girls than for boys. Taken together, our first finding is that the maths confidence gap is driven to a large extent by boys that have grades below average but, nevertheless, believe they are doing well in math. This is in line with previous findings (Cho 2017; Niederle and Vesterlund 2010; Nollenberger *et al.* 2016), however, we provide more nuance to this insight: Additionally, boys generally seem to be sensitive to social processes in their self-assessment. We find strong evidence for divergent social influence, which could indicate social comparison processes, among boys and that cross-sex friendships additionally mitigate their confidence. These social predictors are somewhat less relevant for girls, whose subjective evaluation in our data seems to be more driven by objective performance. Gender role attitudes of self and of peers are not relevant for either gender in any of the contexts. Turning to social integration we find that being confident is, with variation in context, and by the gender of the individuals sending and receiving ties, often related to being more socially active and attractive, and in some cases not relevant for friendship formation. Thus, we do not find evidence for the existence of detrimental peer norms.

When abstracting from our results to a broader picture, we are led to conclude that boys more readily assume that they are good at maths and compare themselves to others to validate whether this is the case, even if they are not. Girls pay less attention to maths confidence of others and transform their grades, more or less directly, into self-assessment. Importantly, our findings include that contradicting stereotypes do not seem to have negative social consequences for girls. In one sentence, as boys and girls use different strategies and resources to build their maths confidence, our findings show the social mechanisms that in sum contribute to the emergence and persistence of the maths confidence gap.

Background and theory: relational peer mechanisms

A particular source of socialisation for adolescents is their peers at school. In comparison to socialisation mechanisms from parents or teachers, adolescents are not only the passive recipient of external influences but, additionally, the source of influence for others in their classroom. Most relevantly discussed in relation to maths and STEM research in education are compositional effects (Dasgupta *et al.* 2015; Schneeweis and Zweimüller 2012), attitudes and preferences of others in the same class (Raabe *et al.* 2019; Salikutluk and Heyne 2017), and social comparison processes, such as the Big-Fish-Little-Pond effect (Marsh 1987; Marsh *et al.* 2008). These studies consider peers in the classroom by looking at averages.

We follow a rich literature that highlights the importance of social relations beyond group averages and especially friendship networks in researching individual outcomes in adolescence. Research on adolescence shows that friends are the most important frame of reference for adolescents (Brechwald and Prinstein 2011; Youniss and Smollar 1985), and network-based evidence shows that of everyone in the same classroom, those that are friends are most influential (Lomi *et al.* 2011). We propose and test four possible processes of social influence, and one of social integration.

First, we look at convergent social influence. In adolescent friendship research, social influence is generally understood as the tendency of individuals to become more similar to their peers. Much research has documented convergent social influence (for a review see Veenstra *et al.* 2013), and several social mechanisms have been proposed to explain why youths tend to conform to their friend's behaviour. For example, if being good at (or severely disliking) maths is an important aspect for the identity of a group of friends, the individual wish to belong to the group can lead to adolescents adjusting their own appreciation of, and perceived competence in maths. Similar accounts of convergent social influence are discussed in terms of the expected rewards of conformity (Burgess and Akers 1966) or as a response to peer pressure (Brown *et al.* 1986). Such processes can happen consciously or subconsciously through copying what individuals are exposed to, as proposed by Social Learning Theory (Bandura and Walters 1977): If copied behaviour is socially rewarded in a particular context, it is more likely to persist.

Second, we consider divergent social influence, which also relates the maths confidence of a student's friends to her or his own maths confidence, albeit in the opposite direction. Convergent social influence entails that higher maths confidence in one's friends will lead to a *higher* individual self-evaluation – in other words, the better my friends think they are, the better I think I am. Divergent social influence means that higher maths confidence in one's friends will lead to a *lower* individual self-evaluation – in other words, the better my friends think they are, the worse I think I am. This tendency has been received much attention in past research, in the context of social comparison processes and the Big-Fish-Little-Pond (BFLP) effect. BFLP research has robustly shown that social comparison affects individuals' self-evaluation, taking the comparison of the individual to a group average as an empirical basis (Dai and Rinn 2008; Marsh *et al.* 2008; Marsh and Parker 1984). However, using group averages ignores the structure of peer relations. If, first, girls and boys are evaluating their skills in relation to everyone in their class, and, second, girls and boys get equally good grades, then consequently, both, girls and boys should be able to reach quite accurate evaluations of their confidence, and these should not differ systematically by gender. However, if these comparison processes work mainly among friends, who might have a more accurate perception of each other's abilities than the classroom at large, we might get a better understanding of why the observed gender gap in maths confidence emerges (Jansen *et al.* 2022).

Third, we consider the gender-role attitudes of friends. In doing so, we can extend the discussion on gender-normativity of environments, such as countries or schools, on individual outcomes. There is little research on this, for example, it has been found that the extent to which friends hold stereotypical gender role affects educational STEM choices, while individual attitudes did not matter (Vleuten *et al.* 2018). Notably, of the few articles that do exist, none employs network models, so there is a need to follow up on them.

Fourth, the consequences of having cross-sex friends – still rare in adolescents – could either highlight differences or similarities between genders. Empirical evidence points in both directions: On one hand, boys and girls exhibit more gender-typed norms in same-gender groups than in mixed-gender groups (Drury *et al.* 2013; Leaper and Smith 2004; Maccoby 1998). This suggests that girls with male friends are more comfortable in pursuing interests stereotypically associated with the male gender (such as maths). On the other hand, it has also been argued in research on single-sex schooling on educational choices, that girls might have the freedom to explore gender-atypical interests in all-female environments (Deaux and Major 1987). To complicate things further, social comparison processes can be affected by the gender composition of friends: Are girls who are friends with boys more confident, as they realise there is no actual performance difference between genders? Do boys lose faith in their ability when they, potentially, realise that their stereotypical held beliefs about their skills relative to girls are false? Ultimately, only empirical analyses can differentiate between these competing accounts of the effect of cross-sex friendships.

While so far, we treated the social causes of individuals' maths confidence, we now turn the social consequences of different levels of maths confidence among girls and boys. In particular, we focus on social integration; which in this context means the extent that pupil send and receive friendship ties to their classmates. Adolescent friendships are not a source of exogenously given variation, but are a product of preference and opportunity. How this relates to maths confidence has hardly received empirical attention in the literature, even though, we argue, it can allow us to gain valuable insights into peer sanctioning or popularity effects that are caused by maths confidence.

Discussions around math and gender in adolescence suggest a norm exist that says boys should excel at, and like math, while the opposite should be true for girls. Not conforming to a peer norm is sanctioned with social exclusion, which has been shown also particularly for non-conforming to gendered behaviour (Blakemore 2003; Fagot 1977; Kågesten *et al.* 2016). If there were a norm against girls excelling at math, a high confidence should be perceived as norm breaking; in consequence, confident girls should be socially isolated, and less confident girls should be well-integrated in the network.

Past research has been concerned with the fact that girls on average report lower maths confidence than boys do on average, but to our knowledge, research has to date mostly ignored the distribution within genders: There are girls who are reporting very high levels of maths confidence, and also boys who report very low levels of maths confidence. How does this stereotype-violating self-assessment relate to the embeddedness in the social structure in their classrooms? Are they rewarded or punished if they are a lot above or below the average, and by whom? Popular culture suggests that girls that excel at maths and are very confident should be less popular. If this is the case, another question is whether they are only less popular among boys. Similarly, boys that fail expectations might be less popular. However, it is also possible that groups form around maths confidence: boys might choose to spend time with other boys that have a similar attitude towards math.

In summary, our study analyses the multiple facets concerning social determinants and social consequences of maths confidence. We further aim to integrate the different aspects into a coherent picture how girls and boys build and react to math confidence. To achieve this goal, we empirically model five related questions. With regards to the causes, we ask how (1) convergent social influence, (2) divergent social influence, (3) gender role attitudes of friends and (4) opposite-sex friends matter for individual maths confidence, separately for boys and girls. For the consequences, we study (5) how the individual level of maths confidence influences the social integration of girls and boys. In particular, we model whether higher (or lower) maths confidence is related to initiating more social relations, to being more popular, and whether adolescents preferably relate to others with similar levels of maths confidence. Each tendency is modelled separately for girls and boys, and for within and between-sex friendships.

Our study is the first one that uses sophisticated tools of social network analysis to shed light on the gender gap in maths confidence. While the ideas we are testing in our study are grounded in theory and past research, a lack of possibility to empirically test micro-level social mechanisms has likely led to the theory being imprecise when it comes to concrete mechanisms. Our study overcomes this by utilising recently developed multi-level dynamic network models on large-scale complete network data. By taking this approach, we are able to offer a detailed, mechanistical lens to the debate. Our comprehensive approach additionally accounts for many of the already known dynamics around maths confidence, thereby taking the current research on gender and maths confidence a decisive step further.

Data & methods

We analyse the social dynamics of maths confidence in adolescent school classes, entailing both, how social relations shape maths confidence, and how maths confidence shapes social integration. The relationship between maths confidence and social relations is inherently bi-directional, which cannot be captured by standard cause-and-effect regression frameworks. Furthermore, the friendship network itself is endogenously evolving, as friendship ties depend on each other through phenomena such as reciprocity – the tendency of friendship perceptions to be mutual – or transitivity – the tendency to become friends with friends-of-friends.

An analysis on maths confidence and the peer context as represented in a friendship network must consider these factors. Stochastic actor-oriented models (Snijders 2001, 2011; Steglich *et al.* 2010) apply to longitudinal, complete network data to model changes in friendships over time, conditioning on the first observation. SAOMs explicitly model endogenous and exogenous predictors of network evolution, as well as individual-level attributes, such as maths confidence. Changes in the social network and in individual behaviour are modelled simultaneously and interdependently, thus 'controlling for' one another. To account for particularities in the evolution of different networks, while being able to make generalisable claims, we aggregate the results of a large number of network groups in a multilevel framework (Koskinen and Snijders 2023), see below and section A.2 in the Appendix for more information.

Data

We analyse German and Swedish data from the first two waves of the Children of Immigrants Longitudinal Survey in Four European Countries (Kalter *et al.* 2014, 2015). The data is nationally representative, surveys students, teachers and parents, and includes complete data on various social networks in the classrooms. The students are aged 14/15 in wave 1 and 15/16 in wave 2. School systems in Germany and Sweden differ from each other mainly in the fact that Germany has tracked secondary schooling: after primary school at age 10, students change to secondary schools that differ in their academic orientation, whereas in Sweden there is a comprehensive system, i.e. students are not tracked to different school according to their ability until they are older than the respondents in our sample.

Due to technical reasons related to the suitability of the collected network data for the use in longitudinal social network analysis, only data from Sweden and from three of the four school types in the German part of the data are used in this study. Inconsistencies in nomination rules in England, and a restructuring of classrooms in the Netherlands both lead to a lack of continuity in the classroom friendship networks so we had to exclude these countries (Kruse and Jacob 2014).

We furthermore excluded classrooms with fewer than 10 people, more than 70% missing observations on maths confidence in either wave 1 or 2, those that have too much change in the friendship network.[1] This meant we had to exclude the data from lower-track schools in Germany, since too many classrooms of this subsample fell under the exclusion criteria,

[1]SAOMs in their basic form also do not work for networks with too little change, however, the multilevel specification and Bayesian estimation can handle such networks, so we did not have to exclude any groups based on this criterion.

and convergence of the multilevel models could not be achieved for the few remaining classes. Eight additional groups returned an error in the estimation, four German and four Swedish classes. We are left with 7472 pupils in 358 classrooms. Full details on how exclusion criteria changed the sample size in each sub-sample (Sweden and the three German tracks) can be found in Table A.1 in the Appendix.

Measurements

Individual-level characteristics

Our discussion of relevant factors on maths confidence has focused on the social sphere, however, individual factors are important predictors of maths confidence. We include the most important ones in our analysis, to control for them: Maths grades, grades in English (a foreign language in both countries), and gender role attitudes.

First, maths grades are an important determinant of individual maths confidence for both, girls and boys – the better the maths grades, the higher the confidence. While grades are not necessarily an objective measure of skills, they are the closest universally available measure for most students.

Second, an important source of differential translation of maths grades to confidence by gender is the comparison to performance in other subjects. Taking an individual perspective, the same maths grade can lead to different self-assessment, dependent on whether maths is among the individual's best subjects or not. As girls tend to have higher grades in languages than in maths (Ceci and Williams 2010; Hyde *et al.* 2008), this can also contribute to explaining the maths confidence gap (Jonsson 1999).

Third, individual gender role attitudes have been suggested to matter for how boys and girls build their maths confidence. Traditional gender roles suggest that boys are better at maths and analytical tasks, while girls are better at languages and are more communicative and nurturing (Jacobs *et al.* 2002; Levanon and Grusky 2016). Men and women have been found to internalise these stereotypes in their identity (Akerlof and Kranton 2000; Sinclair and Carlsson 2013) which affects the way they appreciate their abilities, including their maths skills (Vleuten *et al.* 2016). Stereotyping and gender role attitudes can also affect the way girls and boys interpret their maths grades. Past research has shown that girls are more sensitive to grades than boys (Correll 2001). This has been interpreted as boys receiving a confidence boost from cultural expectation, which makes them less responsive to negative feedback on their actual performance.

Descriptive statistics on individual attributes in the analytical sample can be found in Table 1, Table A.2 in the Appendix shows the same for each German track separately. Table A.3 in the Appendix presents these statistics again for the full sample (the sample before the application of exclusion criteria, see above). There are no substantive differences between the distributions of the variables between the two samples.

The outcome of interest in this study is maths confidence. This measure is based on the survey item ‘How well do you think you are doing in maths?’, which was asked in both waves and is a central item to elicit math confidence. The five answers categories were: ‘not well at all’, ‘not that well’, ‘okay’, ‘quite well’ and ‘very well’.

Gender role attitudes are based on four survey items that measure students’ agreement on the gendered division of labour, in particular, who in a family should take care of the children, cook, clean the house and earn money. Following previous publications using this item (Salikutluk and Heyne 2017), we constructed an additive scale, with respondents scoring higher when they indicated traditional, unequal gender roles (variable ranging from 0 to 1, in increments of 0.25).

The analysis, furthermore, includes self-reported gender, and controls for the grades in maths and English. In Sweden, grades are based on

Table 1. Descriptives of variables used in the analysis, *CILS4EU* data, Swedish and German part. N = 7,472.

	Sweden					Germany				
	n = 4780					*n* = 2692				
	Mean	SD	Min	Max	*n*	Mean	SD	Min	Max	*n*
Female	0.50	0.50	0	1	4808	0.51	0.50	0	1	2692
Maths confidence (wave 1, low to high)	3.74	0.97	1	5	4779	3.3	1.02	1	5	2689
Maths confidence (wave 2, low to high)	3.67	1.04	1	5	3963	3.37	1.03	1	5	2413
Grades in maths (wave 1, low to high)						2.91	1.02	1	5	2638
Grades in maths (wave 2, low to high)	2.98	1.08	1	4	3941	3.07	1.02	1	5	2431
Grades in English (wave 1, low to high)						2.97	0.96	1	5	2630
Grades in English (wave 2, low to high)	3.2	1.08	1	4	3936	3.11	0.95	1	5	2426
Unequal gender role attitudes (wave 1, low to high)	0.22	0.32	0	1	4564	0.4	0.35	0	1	2667
Average maths confidence of friends (wave 1, low to high)	3.76	0.61	1	5	4308	3.3	0.61	1	5	2625
Average maths confidence of friends (wave 2, low to high)	3.69	0.71	1	5	3458	3.37	0.66	1	5	2132
Proportion opposite-sex friends (wave 1)	0.09	0.2	0	1	4309	0.12	0.21	0	1	2625
Average gender role attitudes of friends (wave 1, low to high)	0.21	0.2	0	1	4519	0.36	0.2	0	1	2669

register-data, and in Germany on self-reports. Since in Sweden grades are only available at wave 2, German grades are also taken from wave 2 to ensure consistency. In Sweden, grades are given in four categories: 'pass with high distinction' (MVG), 'pass with distinction' (VG), 'pass' (G) and 'fail' (U): They were recoded into numeric values from 1 to 4, with 4 being the best grade. In Germany, grades are expressed numerically from 1-6, where 5 and 6 were recoded into one joint 'fail' category for the purpose of the analysis. For consistency, we reverse recoded grades so that higher values indicate better performance, so grades range from 1 to 5 in Germany with 5 being the best grade.

There are additional aspects that could be added to the model, however, given the complexity of the system, it is necessary to omit some aspects from consideration to lay out a model that is tractable and thus can be tested.

Friendship networks

Friendship networks are based on the survey item 'Who are your best friends in class?' allowing up to five nominations. Figure A.1 in the Appendix shows nine exemplary friendship network plots from the pool of networks that are analysed in this study. Table 2 presents network descriptives of the 358 networks that are included in the analysis, separately for both countries; network statistics in Germany and in Sweden are largely very similar. For an in-depth discussion of the statistics, see Section A.1 in the Appendix. Table A.4 in the Appendix presents the same statistics by school track in Germany, and Table A.5 in the Appendix for the analytical and the full sample (the sample before the application of exclusion criteria, see above). The excluded groups are smaller on average, since all classrooms with fewer than 10 people

Table 2. Descriptives of friendship networks ('Who are your best friends in class?'), *CILS4EU* data, German and Swedish part. N = 358.

	Sweden				Germany			
	n = 234				*n* = 124			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Size	10.00	32.00	20.55	4.05	10.00	31.00	21.71	4.54
Density	0.01	0.32	0.14	0.05	0.02	0.36	0.17	0.05
Degrees	0.00	5.00	2.75	1.78	0.00	5.00	3.33	1.66
Avg. degree	0.08	4.70	2.70	0.84	0.50	4.68	3.29	0.78
Clustering	0.00	1.00	0.57	0.13	0.23	0.82	0.51	0.09
Jaccard index	0.03	0.68	0.36	0.12	0.10	0.75	0.38	0.10
Same gender ties (t1)	0.54	1.00	0.90	0.08	0.60	1.00	0.87	0.08
Same gender ties (t2)	0.48	1.00	0.88	0.10	0.50	1.00	0.85	0.09

are excluded. The remainder of the network descriptives shows no substantive differences between the included and excluded classes.

Method

The described data is analysed using Stochastic Actor-Oriented Models (SAOMs), also known as Siena-models.[2] These models estimate the relative contribution of different network-related processes that drive tie changes in the networks over time. SAOMs can be specified in a way that they do not only model how the network changes, but simultaneously the change of actors' individual attributes. In this way, friendship selection and social influence processes can be separately accounted for. This analysis takes on this strategy and models the co-evolution of friendship networks and the maths confidence.

While the method has been introduced relatively recently, it has been used in analyses in all major Sociological journals by now (Lewis and Kaufman 2018; Schaefer *et al.* 2011; Stark and Flache 2012). Excellent introductions to the method can be found in Snijders (2001), Snijders *et al.* (2010) and Steglich *et al.* (2010). For a more in-depth description of the method as pertaining to our study, see section A.2 in the Appendix.

Since we are interested in average tendencies across a large number of different classrooms to obtain generalisable results, we use a multi-level framework implemented for SAOMs with Bayesian estimation. The random-coefficient multilevel framework for SAOMs (Koskinen and Snijders 2022; Ripley *et al.* 2022) accounts for the multilevel structure of classroom-based educational data. Analogous to the general hierarchical linear model for multilevel analysis, this framework allows the simultaneous estimation of the network and behaviour dynamics for each network group, i.e. school class. This means, first, that all social and peer effects are estimated within-class. For example, the model estimates whether students become more similar in their math confidence to friends *in the same class* compared to non-friends *in the same class* (as opposed to any student in the data). This means that teacher effects or selection bias, for example that schools differ in the average ability of students, are not a concern, since only within-school differences are the basis for the estimated parameters.[3] Aggregation of results of different classes allows to obtain generalisable results across all included (see also Boda

[2]Siena-models refers to the name of the software implementation of SAOMs.

[3]Differences in average ability or average math confidence between classes are represented in the random variation of the linear and quadratic terms in the behaviour part of the model.

2018; Raabe *et al.* 2019). An additional benefit of using multilevel SAOMs is that the joint analysis gives us enough power to estimate effects that are comparably rare, e.g. cross-sex friendships.

Four sets of analyses are undertaken, one for Sweden and one for each of the three German educational tracks. For complete information on the model specifications, see Table A.6 in the Appendix. All analyses have been carried out in *R,* version 3.2.2, using the package *RSienaTest,* version 1.2–17 on a large-scale computer cluster.

To assess convergence, we closely follow the recommendations in the RSiena Manual (Ripley *et al.* 2022). First, the visual inspection of the estimation trace plots indicates good convergence of all models. Second, the formal convergence tests (Gelman *et al.* 2013; Koskinen and Snijders 2022) confirmed this evaluation for all parameters and subsamples (in our case, $\hat{R}$ was smaller than 1.06 for all parameters related to research questions). Convergence statistics for all parameters and all subsamples can be found in Tables A.7 to A.10 in the Appendix.

Since the approach of this study is a statistical analysis of observational data, usual caveats of interpreting observational data apply. We uncover longitudinal, conditional relations between variables and development of endogenous structures, not causal peer effects (Manski 1993; Shalizi and Thomas 2011).

While we are not specifically interested in explaining country-differences, the analysis is carried out for Sweden and each German school track separately. The reason for this is both theoretical and empirical. First, it is likely that the two countries differ in the way that maths confidence is built and upheld in adolescence, given that policies and attitudes in Sweden are more gender egalitarian than in Germany. Second, within Germany, it is also theoretically likely that social dynamics around maths confidence differ between the different school tracks, as pupils in the lower tracks might already think about their skills differently in comparison to those in the upper track. Indeed, empirically, it was not possible to achieve convergence for a model that pooled all German data, which suggests that the modelled tendencies are too different from each other to test in a single model.

Results

Descriptive results

Figure 1 shows the relation between maths confidence and maths grades in our data for girls and boys. If maths grades and confidence were

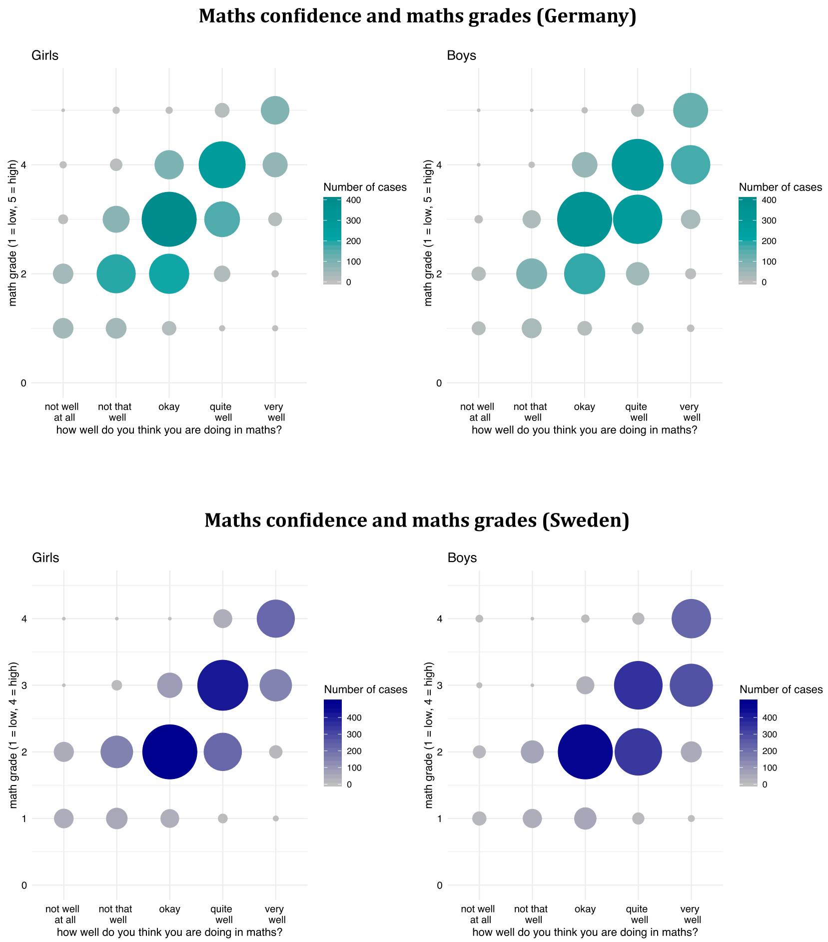

Figure 1. Heatmaps of cross-tabulation maths confidence and maths grades, by country (CILS4EU data).

perfectly correlated, the diagonal of the dot-plots would contain all observations. Indeed, most observations are on or close to the diagonal, indicating a high relevance of maths grades for maths confidence. However, boys in Germany and Sweden tend to place themselves more towards the right side of the diagonal, i.e. there is a tendency for boys to have a higher confidence than their grades would suggest. Conversely, more girls than boys consider themselves to be doing worse in maths than their grades would suggest, in both Sweden and Germany. Overall, girls tend to translate the same maths grade into lower, but more accurate self-perceptions of maths confidence than boys, which indicates that we rather see overconfident boys than underconfident girls. This applies only to maths and gender, not to other subjects. Thus, our data is in line with the literature discussed in the introduction.

Figure 2 presents the cross-sectional association of maths confidence and the variables included in our analysis; this is done separately by country and gender. In all cases, maths grades are most closely correlated with maths confidence. It is furthermore indicative for English grades to be positively associated with maths confidence: those who think of themselves to be good in maths, also receive higher English grades, in line with the experience that student grades in different subjects tend to be correlated. However, we note that those with low levels of maths confidence tend to have higher grades in English than in Maths. Next, maths

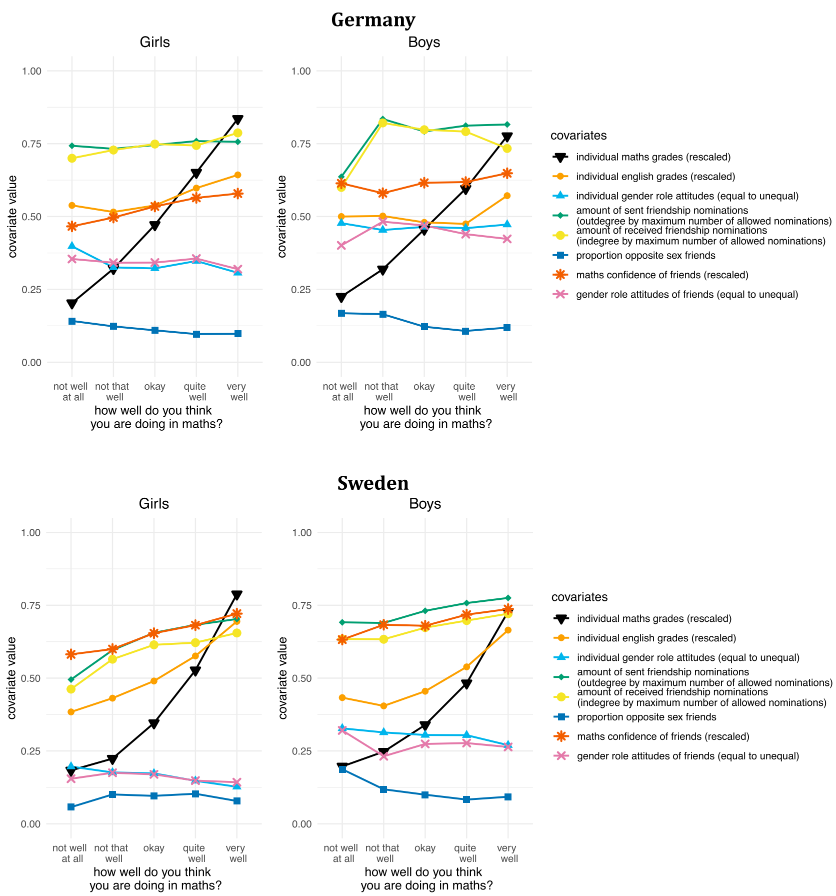

Figure 2. Bivariate associations of maths confidence and individual-level characteristics (CILS4EU data, wave 1).

confidence of friends correlates with individual maths confidence, indicating that individuals tend to be similar to their friends. Further, the number of friends is positively related to maths confidence; however, this tendency is more pronounced in Sweden and hardly visible for German girls. There appears to be a slight tendency for girls and boys in Germany and boys in Sweden to have lower maths confidence the more opposite sex friends they have. Finally, individual and friends' gender-equal gender role attitudes seem to have little relation to levels of maths confidence, neither for boys nor for girls.

While these descriptive statistics show some interesting relations between maths confidence and different predictors that are largely in line with the wider literature, these are bivariate, cross-section correlations and are not able to depict dynamics. Consequently, we now turn to the results of the statistical models.

Results from multilevel network models

Development of maths confidence

We studied four social dynamics that explain the development of maths confidence, and how they differ by gender: (1) convergent social influence, (2) divergent social influence, (3) peer pressure related to gender role attitudes and (4) the extent to which individuals have cross-sex friendships. The results are displayed in Figure 3. The corresponding table can be found in Table A.11 in the Appendix; for full results for the different cases, see Table A.12 to A.15 in the Appendix.

Before discussing the interpretation of the relational effects that motivate this study, the model estimates show that maths grades are a very powerful predictor of maths confidence. Furthermore, the parameter for maths grades for girls is significantly larger in 3 out of the four analysed cases compared to the influence on boys (see Tables A.12 to A.15 in the Appendix). The finding that girls are more sensitive to objective signals in building their maths confidence is in line with the wider literature. Before moving to the three focal parameters of the study, note that the interpretation of parameters described below pertaining to social and peer factors is 'net off' the maths grades adolescents obtain, thus, the model concerns tendencies beyond maths grades that determine maths confidence. Furthermore, the main results table presents the linear combination of main and interaction effects for girls; information on whether this effect is statistically larger or smaller than 0 is provided by an internal

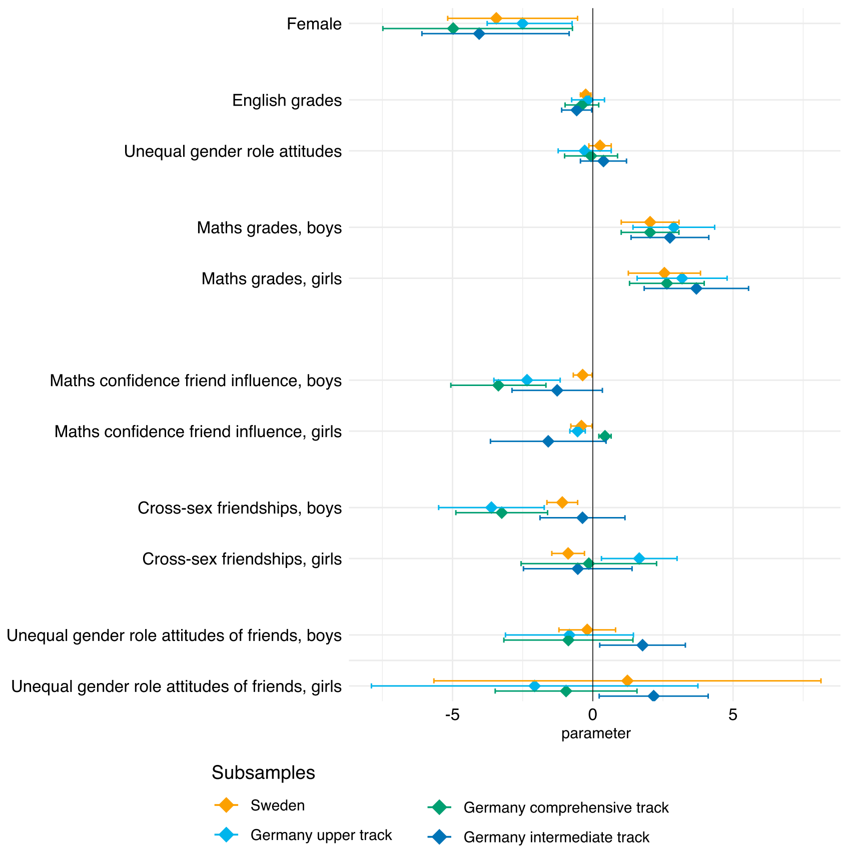

Figure 3. Coefficient plot of main results, multilevel stochastic actor-oriented models (SAOMs), maths confidence part of the model. The plot shows the posterior mean and the credibility interval. Separate effects for gender are based on the sum of the respective main and interaction effect (for girls), and the main effect (for boys). For full results, please see Table A.11, as well as Tables A.12 to A.15.

test of RSiena (‘*multipleBayesTest*’).[4] Whenever we discuss gender differences, we are referring to the interaction term, which is not reported in the main results table here, but in the full results tables in the Appendix (see Tables A.12 to A.15).

First, we are interested in how an adolescent’s maths confidence is influenced by the maths confidence of his/her friend. On the one hand, convergent social influence on maths confidence would mean that individuals change and maintain their maths confidence to be more similar to

[4]The internal RSiena test multipleBayesTest calculates ‘Mahalanobis distances of the elements of the posterior sample from the posterior mean; the *p*-value is the relative frequency that these are greater than the distance between the tested value and the posterior mean’ (RSiena help file).

their friends. On the other hand, divergent social influence indicates social comparison processes regarding maths confidence, i.e. the tendency for individuals to change their maths confidence in the opposite direction than their friends. In the first case, having very confident friends would increase my confidence, in the second case, it would decrease my confidence (all else equal).

To that end, we consider the parameters for *Friend influence on boys* and *on girls*, respectively, where the latter variable is, technically, the interaction between the *Friend influence* main effect and being *female*. We find evidence for boys and girls to engage in social comparison processes to differing extent. In three of the four subsamples we find a clear tendency for divergent social influence in boys; and in the fourth subsample the parameter is just inside the 95% credibility interval. For girls, the parameter related to divergent social influence is significant in only two of the four cases. Furthermore, in two of the four cases, the parameter for girls is significantly more positive (i.e. closer to zero) for girls than for boys. We interpret this as evidence for divergent social influence playing a role among boys, and tentative evidence that these processes are less important for girls, albeit present in some cases.

Second, we consider how peer pressure related to gender role attitudes is associated with individual maths confidence, which is modelled with the effects *gender role attitudes of friends on boys* and *on girls*, respectively. Technically, the latter variable consists of the linear combination of the main effect *gender role attitudes of friends* and its interaction effect with the gender variable *female*. The extent to which one's friends hold equal or unequal gender role attitudes is not associated with one's maths confidence in most of the subsamples for girls and boys. Only in intermediate schools in Germany we do see a significant relationship: Boys and girls whose friends hold more unequal gender role attitudes are more likely to increase or maintain higher level of maths confidence.

Third, we investigate the role of cross-sex friendships in the formation and upkeep of maths confidence, considering the variables *Cross-sex friendships on boys* and *on girls*. Overall, we see that boys who have cross-sex friendships tend to have lower maths confidence over time in Sweden, and in upper and comprehensive schools in Germany. In intermediate schools in Germany, the estimate points to the same conclusion, but is not statistically significant. For girls, the results are mixed: In Sweden, girls tend to decrease their maths confidence when they have cross-sex friendships, in upper schools in Germany they tend to increase, and in the remaining subsamples, there is no statistically significant effect. We interpret this pattern as evidence for a negative effect of cross-sex friendships on boys and no evidence for a consistent influence on girls.

Next to these focal parameters, all of our models exhibit a strong gender effect. Thus, the processes tested here cannot account for the gender gap in maths confidence that we observe, which is present in addition to the discussed factors. We include two other individual-level factors in the model. The extent to which individuals hold equal or unequal gender role attitudes is not related to their maths confidence throughout our data. Grades in English have a negative impact in three of the four cases, supporting arguments made by Jonsson (1999) or Ceci and Williams (2010).

Evolution of friendship networks

We now turn to the question of how social integration depends on the gender and the maths confidence of the sender and receiver of a friendship nomination in the different school contexts. Thus, we are interested in the propensity of, for example, a boy with low maths confidence to befriend a girl with high maths confidence, or of a girl with average maths confidence to befriend another girl with average maths confidence. Each combination of gender and maths confidence regarding the activity, popularity and homophily of either variable is modelled using the interaction terms outlined in the subsection on 'Model specification' to get a complete understanding of the gender dynamics of interest. This part of the analysis tests whether girls with a high math confidence are less integrated, which would point to a norm that girls should not excel at or enjoy math.

Results are depicted in Figure 4 and can be interpreted as follows: Each sender-receiver combination by gender (girl-to-girl, girl-to-boy, boy-to-boy and boy-to-girl) is depicted in one of the four panels. Within each panel, four heatmaps relate to the different contexts that we model (Sweden, Germany upper school track, Germany comprehensive school track, Germany intermediate school track). The heatmaps indicate the linear combination of all relevant parameters to the propensity of forming a tie for this particular combination of gender and maths confidence of sender and receiver. The size of the parameter as indicated by the colour can be interpreted similar to a parameter in a multinomial logit model.[5] To assess statistical significance of the differences in

[5]Technically, it is the contribution to the objective function of the sum of all the different parameters that contribute to the case of interest. For an introduction on the precise interpretation of parameters in the objective function, see Snijders *et al.* (2010).

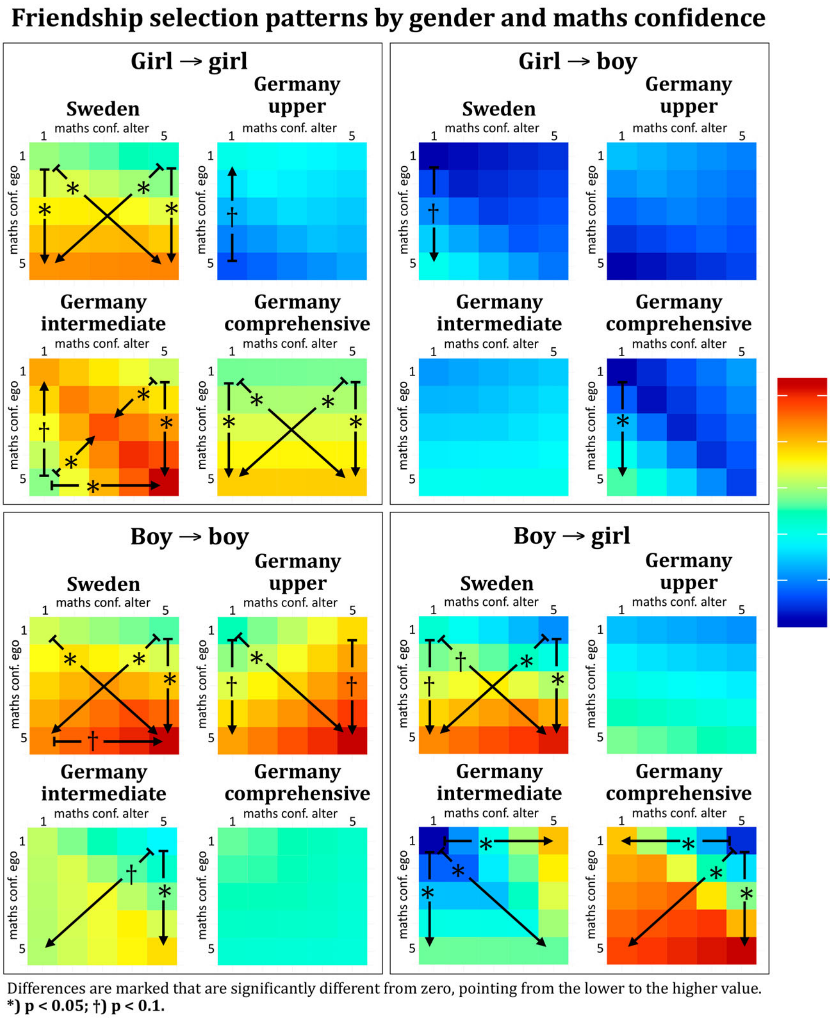

Figure 4. Heatmaps of ego-alter selection table based on maths confidence, by friendship gender selection pattern and sub-sample. Cells are coloured according to the relative gain to ego's objective function when choosing alters with various levels of maths confidence (red = more positive, blue = more negative). Whether differences in the relative gain between the extreme cases are significantly different from zero is shown by arrows, pointing from the lower to the higher value.

parameters within heatmaps, we compare all four corner cases of the heatmaps using the posterior distribution of the combination of parameters. In case the difference in linear combination of parameters between two corners is significant, we depict this by an arrow pointing from the corner with the lower value to the corner with a higher value. Interpretation of the heatmaps will focus on the significant differences.

As an illustration of the interpretation, if we consider the heatmap for Sweden in the girl-to-girl panel, we can compare activity and popularity for this case in a straightforward manner within rows and within columns, respectively. The top row of the heatmap indicates the relative propensity of a girl with the lowest maths confidence (ego's maths confidence = 1) to send a friendship nomination to girls with differing maths confidence. Since the colour moves from yellow to light blue from the left to the right, we can see that girls in Sweden with low maths confidence are more likely to send ties to other girls with low maths confidence. However, the difference is not significant. The left-most column of this heatmap compares the maths confidence of different senders to a receiving girl with the lowest maths confidence (alter's maths confidence = 1). Since the values in the column increase when moving downwards, we see that girls with increasing maths confidence are more active in sending ties (here to girls with low maths confidence). The arrow indicates that the difference is significant.

Concerning the actual interpretation of the graph, we see some variation in the four different same- and cross-friendship scenarios, but one main pattern stands out: Those that have higher maths confidence are more integrated in the friendship networks; in particular, they tend to send more friendship ties. This is shown in the plots by downward-pointing arrows: They indicate that friendships are significantly more likely to be sent by adolescents with more maths confidence. Being more attractive as a friend when having a higher maths confidence is indicated by arrows pointing from left to right. We see some instances of this, but less of an overall pattern. However, it is worth pointing out that sending more friendships also leads to receiving more friendships by itself, via endogenous network tendencies, such as reciprocity and transitivity. Most observed patterns in particular play a role in same-sex friendships, i.e. the upper and lower panel on the left, and in particular in the Swedish sample, but this is likely related to the increased statistical power, since same-sex friendships are the norm in many cases and we have most observations in Sweden.

Moving from general patterns to more specific question of our study, we can determine whether confident girls are avoided as friends – especially by boys – as a normative view of gendered maths confidence would suggest. As shown in the lower right panel, this is not the case – only boys with the lowest confidence in the intermediate school track in Germany seem to prefer girls with low maths confidence over more confident girls. However, it is mostly the confident boys that send friendship nominations to girls. We also find no pattern of girls being avoided by other girls when they have a higher maths confidence, as shown in the upper left panel. Here, again, more confident girls initiate more same-sex friendships. In boy-boy friendships (lower left panel) more confident boys also generally initiate more friendships, while in girl-to-boy friendships (upper right panel), maths confidence seems to play a minor role. Finally, we only find one case in which we see homophily regarding maths confidence, in friendships between girls, in intermediate schools in Germany. Thus, the observed correlation between the math confidence of friends shown in Figure 2 cannot be explained by a tendency to select others with similar math confidence.

Estimates for other exogenous and endogenous parameters of the friendship evolution model (see Appendix Tables A.12 to A.15) that were included to model basic tendencies in friendship networks are in line with the large body on network formation in adolescence.

Robustness analyses

To ensure the robustness of our results, we ran our main model on all four subsamples with an indicator of parental educational background in both the network part (as an ego, alter and homophily effect) and the behaviour part of the model (as the effect of parental education on maths confidence). Detailed results can be found in Tables A.16 to A.19 in the Appendix: We do not see any statistically significant effect of parental education on friendship formation, nor any statistically significant effect of parental education on maths confidence – all else equal – in any of the subsamples. All models show the same substantive conclusions. Furthermore, as the main analysis uses grades at wave 2, we reran our analysis with the information on grades at wave 1, which were only available for the German subsamples – again, our substantive conclusions remain the same with this strategy, too. Detailed results can be found in Tables A.20 to A.22 in the Appendix.

Discussion

How do boys and girls form different levels of maths-confidence gender given their similarity in objective maths performance? Our study focusses on peer-level social processes that have been hypothesised to contribute to the maths gender gap and explores empirical regularities whose presence can be derived from past theoretical work. We simultaneously model individual-level predictors to account for known individual factors in self-perception of maths abilities. Our analyses cannot explain the full documented gender gap in maths confidence, that is, we still see an unexplained difference between girls' and boys' performance in our analyses expressed by the main effect. However, our results reveal several differences in the way boys and girls build and uphold their maths confidence, that illuminates the extent to which they face norms, pressures and expectations.

Based on these empirical results, we can attempt to build a theoretical model concerning the determinants of maths confidence among adolescents in the countries we studied. While not all empirical regularities are perfectly consistent across all contexts, taken together, our results generate a coherent picture. Below we abstract to what we can learn in broad terms from our study before discussing limitations.

First, the story we are revealing is more about over-confidence of boys than under-confidence of girls. The descriptive data shows that girls' maths confidence closely follows their maths grades, while more boys with average (or worse) grades perceive that they are doing 'quite well' or 'very well' in math. This is no new insight; however, we are able to provide more nuance to this finding. Our inferential analysis confirms that girls are more sensitive to their maths grades – they use objective feedback on their maths performance to evaluate how good there are. Boys, however, seem to rely less on this objective feedback, and turn towards other sources of validation. How they generate maths confidence and, more importantly, why they turn to other sources are the core questions we answer in this study.

In a nutshell, boys seem to assign higher importance to being good at maths following social and cultural expectations that boys should excel in mathematical and technical subjects. Maths skills seem to be a sort of social validation of boys' gender identity: Boys have a high baseline self-evaluation in line with these norms that they adjust to information from their social surrounding beyond their maths grades. One of these sources is divergent social influence among friends. A consistent pattern we find is that boys whose friends – mostly other boys – are doing well perceive themselves as less competent and boys with friends that have a low confidence evaluate themselves more favourably. This is seen additionally to the effect from maths grades that should give them a decent guide to how well they are doing.

A second indication for our interpretation comes from the influence of cross-sex friendships, which tend to lower maths confidence of boys. This can be interpreted as boys benefitting less from this 'stereotype boost'

(Correll 2001) when they are friends with girls, as stereotypes of who is better at maths are being deconstructed through cross-sex friendships – by exposing them to reality. In other words, boys become more accurate in judging their own maths skills when they have female friends. Third, we see that boys who have a higher maths confidence also are more integrated in the friendship networks within their classrooms in terms of sending more ties. This is statistically significant for friendships with other boys in three of the four studied contexts. More interesting in our study is, however, that this pattern is also observable in friendship nominations from boys to girls, higher confidence boys have a stronger tendency to befriend girls than boys with lower confidence do. We argue that the courage to engage in rare cross-sex friendships for these boys can be explained by the validation of the masculine gender roles these boys experience from their self-perception of maths ability.

While our interpretation that boys follow gendered expectations is largely in line with the wider literature, we find no evidence for the other side of the story: We have no indication that girls are expected to be bad and not confident in maths. This is where we depart substantially from previous literature (Alon and DiPrete 2015; Hyde *et al.* 2009; Vleuten *et al.* 2018). First, we find that unequal gender role attitudes of girls, or of their (mostly female) friends are not related to maths confidence. Thus, even girls who believe that a woman's responsibility is mainly to do domestic work while men engage in the formal labour market do not perceive their maths competence lower than their grades would suggest. The same holds for girls whose friends hold these beliefs. While this contrasts with earlier findings with the same data (Salikutluk and Heyne 2017) these studies on gendered self-confidence in maths have not been able to test gender role attitudes of relevant peers but instead relied on class-level gender role attitudes. These are comparably crude measures, often employed in a research design unable to account for the joint dynamics of maths confidence and friendship choices. Our study design improves this by using complete friendship networks, accurately detecting those peers who are most likely to have the highest impact on the individual.

Second, and more importantly for our case that there are no expectations that girls should be bad at math, we find there are no negative social consequences for girls who have high maths confidence – Girls do not have to be less confident in their maths skills to be socially integrated. If there were a norm against girls excelling at math, a high confidence should be perceived as norm breaking, which is generally sanctioned by a decrease in social integration or even ostracism in extreme cases. However, we see the opposite: Girls with higher maths confidence are more integrated in the sense that they send more friendship ties to other girls, while in girl-to-boy friendships maths confidence plays no substantial role. As discussed above, a higher propensity to send ties also goes hand in hand with receiving more ties through endogenous network processes such as reciprocity or transitivity. Along these lines, there is also no evidence that having male friends, who might be the ones exerting a potential pressure, is related to lowered maths confidence. Thus, ultimately it is the absence of negative social consequences for having a high maths confidence for girls that convinces us that there is no negative pressure on girls to stay away from maths; a finding which is made possible by using a social network approach. This is contrary to images of unpopular 'nerdy girls' portrayed in, albeit somewhat dated, popular culture, such as US high-school comedies from the 1990s.

Summing up our interpretation of the findings in one sentence, cultural norms suggest that girls can be, but boys should be good at maths.

In some parts our study stands in contrast to previous literature, especially concerning the pressure on girls to have a lower self-perception on maths ability. However, since girls' performance and confidence in maths is a longstanding research issue, empirical studies that we can compare our findings to come from multiple decades. We believe that the world in the early 2010s, when our data was collected, is likely very different with regards to gender expectations than, for example the 1990s that informed previous studies. Thus, the discordance in findings to earlier literature might reflect genuine changes in expectations to girls' gendered behaviour. Table 3 gives some preliminary evidence that this might be the case; it shows the proportion of female students and graduates in a number of STEM subjects in Germany taken from the German Federal Statistical Office (2020). In 2018, when the

Table 3. Proportion of women enrolled in and graduating from selected STEM subjects in 1998 and 2018.

	Students		Graduates	
Subject	% fem. 1998	% fem. 2018	% fem. 1998	% fem. 2018
Biology	57%	64%	56%	66%
Mathematics	41%	48%	43%	48%
Chemistry	32%	41%	27%	40%
Process Engineering	17%	38%	16%	38%
Physics	14%	29%	11%	22%
Automotive Engineering	3%	7%	2%	8%

Source: German Federal Statistical Office (2020).

adolescents studied in this paper were at the age to start their undergraduate degrees, the female share of students and graduates in maths-heavy subjects had risen substantially over the preceding 20 years – even in still strongly unbalanced in the most male-type subjects. Thus, young women in STEM subjects were common for the studied cohort. Unfortunately, we have no comparable network data from an earlier period to repeat our study; thus, we are limited to speculations that the discordance with the literature is driven by a period effect.

A related problem is that we are unable to consider within-person long-term temporal dynamics. While we take an over-time approach, the time covered in our data is only about a year, when the subjects of the study are already teenagers. It is likely that the dynamics we are discussing here are taking place over a much longer time frame, from kindergarten to university and beyond, and that we are only able to shed light on a snapshot of a much longer process. The fact that we are still able to see some change over the one year we are able to study is encouraging, however, it is still likely that we are missing out on a substantial part of the explanation. The fact that we see a higher baseline confidence of boys throughout the data provides further evidence that a difference in self-perception between girls and boys was formed at a younger age already.

Moving from time to space, we only analyse two countries and do not know whether the findings generalise to other countries. While systematic research is missing, literature on the evolution of friendship networks in a school context seems to show some differences, for example, between the US and Europe.[6] Thus, gender role expectations and how they pan out might be different in other countries. Nevertheless, we analyse data from Sweden and Germany in this study – two countries that differ in their level of gender equality policies, gender role attitudes and educational and social policies – and from different school tracks within Germany. However, the lowest school track is excluded from the analysis due to data quality concerns. We see the same general tendencies in both countries and the three tracking contexts: It seems that differences in macro-level gender role attitudes and policies between the modelled contexts have little impact on how individuals judge themselves and their talents in our comparison cases. Nevertheless, we do not claim that the results equally apply in a context that was not analysed here.

[6]One apparent difference is in terms of the role of status and hierarchy in friendship formation, which is often discussed in a US context but is mostly irrelevant in European friendships (Vörös *et al*. 2019).

The *CILS4EU* data was collected with the specific aim to study children of immigrants; hence, the sampling strategy was to oversample classrooms with high numbers of children of immigrants. Due to the complicated model necessary to answer our research questions, we were unable to explicitly control for ethnicity, although ethnicity is a strong predictor for friendship (McPherson *et al.* 2001). The diagnostics we used to assess convergence, however, indicate that we are able to model the friendship network structure well, so we are reasonably confident on the robustness of our results. Whether ethnicity affects the effect of e.g. gender role attitudes on maths confidence is beyond the scope of this paper. Exploring the social dynamics around the intersection of gender as well as ethnicity on maths confidence would certainly be an interesting avenue for future research, extending existing research on individual-level gender and ethnicity on STEM-related outcomes (Litzler *et al.* 2014; Riegle-Crumb and King 2010).

Furthermore, our study is subject to biases inherent to survey data, such as the self-reported nature of key items or response biases. The *CILS4EU* data has been analysed in over 200 publications over the last decade (see www.cils4eu.eu) and has been found to yield robust insights into a variety of different research areas. We therefore are confident that our conclusions are sound, while simultaneously acknowledging the need to follow up on our insights with new data and/or other methodological approaches.

The last limitation we discuss is other sources of socialisation on gender roles: Parents, teachers and neighbourhoods. Parents are the main source of socialisation in children's early years. Children imitate their parents, and depending on gender role attitudes parents hold, they are more or less encouraged to copy and exhibit gender-typed behaviour (Bandura and Walters 1977). The vast literature on inheriting occupations from the parents furthermore highlights the importance of parental role models (Jonsson *et al.* 2009). Some studies explore the link between parents' field of occupation and their children's field of study: When mothers work in a non-gender typical job, their daughters are more likely to follow (van de Werfhorst and Luijkx 2010), which can directly be linked to STEM-related occupations. Furthermore, parental networks have been found to influence individual outcomes (Geven and van de Werfhorst 2020; Olivetti *et al.* 2018).[7] The *CILS4EU* data

[7]For the context of this study, this might mean that the estimated divergent social influence results not from comparison with peers but from more complicated processes involving friends' parents. For example, friends' parents might behave in a way that reduces ego's math confidence in case ego is worse in math than the friend. Arguably, this would be more credibly had the study found positive influence. Nevertheless, it is possible that this produces the modelling results, but following Occam's razor, we prefer the simpler explanation.

does include some of these information, however, taking them into account was beyond the scope of this study; as mentioned above, we performed robustness analyses with parental educational background, which did not change our conclusions.

Teachers have been found to affect their pupils' maths confidence, too. They can function as role models (Bussey and Bandura 1984), can endorse gendered stereotypes (Keller 2001), and have been found to judge high-performing pupils in maths differently, depending on their gender: Boys are praised for their abilities, girls for their effort (Li 1999). While our data does in fact include information on one teacher of the pupil, the teacher only in some cases teaches maths. Thus, we could not include this information in our analyses, which might influence some of the estimated parameters. For example, teachers' didactic actions towards different groups of friends within the same class could influence their math confidence differently, which could positively bias social influence parameters, i.e. the 'true' social influence would be more negative than estimated. Other teacher-related scenarios that induce bias are equally possible. Going beyond teachers' behaviour, the estimated parameters could generally be biased by unobserved variables (as is common in studies using observational data). However, the multi-level framework used in the analysis alleviates these concerns somewhat. Teachers and other contextual effects apply homogenously to all students in a class, while the parameters of interest concern differences between students in the same class, reducing the risk of bias considerably.

Lastly, the neighbourhood adolescents live in could affect individual outcomes (Kretschmer and Kruse 2019; Kruse 2017). A higher share of university-education parents in the area, or the geographical proximity to (for example) a large pharmaceutical corporation that many parents work at, could affect individual maths confidences. However, shared neighbourhood characteristics lead to students being more similar and, accordingly, the social influence parameter would be biased positively. Since we mainly find divergent (negative) social influence, this bias means that the 'true' parameter would be even more negative than found, i.e. the estimated parameters are conservative. Empirically, we do not have further information on the geographical location of the schools that are in the sample, and therefore are unable to control for such influences. Notably, as mentioned above, the multilevel analysis considers processes within classes, hence, this is analytically less of a concern.

This research suggests some implications for educational practises. First, the framing of the problem that should be addressed might have to change;

perhaps the question should not only focus on how to boost girls' maths confidence but also on how to make boys' confidence more realistic. We do not think it is a good idea to close the maths confidence gap by convincing girls that they are better than their objective performance suggests in order to become more similar to over-confident boys.

Second, our results reveal a pattern that underlines the importance of cross-sex friendships for a more realistic view on boys' own maths skills. At the same time, fears of peer pressure in gender-integrated settings being detrimental to girls' maths confidence seem unfounded. Hence, this study suggests that mixed educational setting that encourage friendships between girls and boys should be promoted. This can happen by teachers or through the school structure, for example through creating mixed-gender homework or project groups, or through providing options of non-gender segregated extracurricular activities. This is in line with Legewie and DiPrete (2014), who found that the gender gap in intentions to go into a technical occupation is lower in schools where extracurricular activities are more integrated. However, Kessels and Hannover (2008) find that girls' physics confidence is higher in single- vs mixed-gender education settings, suggesting that more research is needed.

The importance of addressing these issues becomes clear when considering the life-long implications of not facing boys' over-confidence. It is also to their advantage if they are discouraged from forming unrealistic self-evaluations of ability in maths, since this entails the danger that they pursue a career that is not suitable for them, and miss out on a career that would be more fulfilling. At the same time, it is not very efficient in an economic sense if, for example, a substantial share of engineering jobs is filled by talentless men just because nobody discouraged them to go into this field. This is tapping into rethinking the main purpose of education systems – schools should help students to find out what they actually are good at, rather than encourage them to pursue what they think they are good at, instilled by their social environment.

Conclusion

In this paper, we brought forward a new conceptual and analytical approach to study the development of maths confidence of girls and boys – through looking at the determinants and consequences of peer relations. We interpret the findings from our longitudinal network analysis that boys are more sensitive to cues from their social surrounding in evaluating their competence, while girls look to a stronger extent to their maths grades. The finding that girls' self-perception in mathematical ability is not stymied by social pressures and expectations stands in contrast to the previous literature. Whether this divergence of our results is due to a different, refined methodological approach, due to the selection of countries under study, or represents genuine social change needs to be resolved in future studies. Nevertheless, our study provides new insights into an issue that lies at the root of important gender differences in occupational life that are widely perceived as unjust and that should not be accepted in modern, liberal democracies.

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Disclosure statement

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Data availability statement

The data that support the findings of this study are available at GESIS: https://search.gesis.org/research_data/ZA5656.

DOIs:
10.4232/cils4eu.5656.1.1.0 (wave 1).
10.4232/cils4eu.5656.2.1.0 (wave 2).

We provide a replication package that contains the R scripts for data preparation and analysis.

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