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The Social Pipeline: How Friend Influence and Peer Exposure Widen the STEM Gender Gap

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Abstract

Individuals' favorite subjects in school can predetermine their educational and occupational careers. If girls develop weaker preferences for science, technology, engineering, and math (STEM), it can contribute to macrolevel gender inequalities in income and status. Relying on large-scale panel data on adolescents from Sweden (218 classrooms, 4,998 students), we observe a widening gender gap in preferring STEM subjects within a year (girls, 19 to 15 percent; boys, 21 to 20 percent). By applying newly developed random-coefficient multilevel stochastic actor-oriented models on social network data (27,428 friendships), we investigate how social context contributes to those changes. We find strong evidence that students adjust their preferences to those of their friends (friend influence). Moreover, girls tend to retain their STEM preferences when other girls in their classroom also like STEM (peer exposure). We conclude that these mechanisms amplify preexisting preferences and thereby contribute to the observed dramatic widening of the STEM gender gap.

Keywords

peer effects, STEM, gender, social networks, adolescence

Research on horizontal sex segregation in the labor market, that is, the tendency for men and women to work in different fields of occupation, documents a process of girls and women dropping out of a science, technology, engineering, and math (STEM) career path at a higher rate than boys and men throughout the life course (Alper 1993; Ellis, Fosdick, and Rasmussen 2016; Legewie and DiPrete 2014b). That girls tend to increasingly prefer subjects other than STEM over their school career is one example of this phenomenon, which past research has investigated through various factors, including socialization (e.g., Cheryan et al. 2011; Reilly, Neumann, and Andrews 2017). Early-life socialization happens mostly within the family, but the role of peers becomes more important as children grow older. During adolescence, interaction and exchange with friends, especially in school, is a crucial setting for socialization (Osterman 2000; Prinstein, Boergers, and Spirito 2001). Adolescence is an important period of life, not only because of peer socialization, which has implications for long-lasting attitudes, norms, and values (Jacobs et al. 2002), but also because it is the time when people make life choices regarding their careers. Those decisions can have long-lasting effects on life outcomes, such as income and social status (Breen

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and Jonsson 2005). Therefore, many studies have attempted to investigate peer effects and social influence among adolescents in the school context (e.g., DeLay et al. 2016; Legewie and DiPrete 2012; Raabe forthcoming).

In this article, we consider two main ways peers matter for subject preferences in high school: friend influence and peer exposure. *Friend influence* refers to individuals' tendency to develop preferences for subjects their friends like. This type of peer effect focuses on direct influence from friends, that is, friends in the classroom community who are closest to the individual. A past study shows these friends will have a higher impact relative to others (Lomi et al. 2011), and this is in line with previous research on friend selection and influence on multiple behavioral outcomes (for a review, see Veenstra et al. 2013). At the same time, *peer exposure* means that in classrooms in which girls generally like STEM subjects, more female students will develop similar preferences. This type of peer effect captures the classroom context regarding the preferences of other girls; we build on previous research on classroom context that used classroom-level aggregates and their association with individual outcomes (e.g., Rjosk et al. 2014; van Ewijk and Sleegers 2010). Because differential STEM preferences are assumed to be at least partly affected by the extent to which individuals adhere to gender roles in the group context, we propose that the extent to which girls prefer STEM subjects in a class will likely affect those preferences, as well.

We contribute to existing research in several substantial ways. By using multilevel social network models, we are able to distinguish between influence and selection effects (e.g., whether friends influence a person's subject preferences or people choose friends with similar preferences). Thus, we can explicitly account for dynamics in individuals' immediate social surroundings rather than solely consider an aggregate measure on the classroom or school level. At the same time, we are also able to include the peer context within classrooms in our analysis.

OCCUPATIONAL SEX SEGREGATION AND THE LEAKY PIPELINE

More boys than girls and more men than women are interested in STEM; gender differences continuously grow during adolescence and early adulthood (Ellis et al. 2016; Xie, Fang, and Shauman 2015; for a review, see Blickenstaff 2006). Differences in the extent to which students prefer STEM subjects in high school can develop into occupational sex segregation in adult life, that is, the fact that men and women are often not distributed evenly across occupational hierarchies and sectors (Browne 2006; Charles and Grusky 2004; Inglehart and Norris 2003).

Two forms of segregation, horizontal and vertical, have been documented repeatedly in the past decades and are still persistent (Levanon and Grusky 2016). Vertical sex segregation (i.e., men occupying higher-paying jobs) has started to equalize somewhat in the past decades, but horizontal sex segregation (i.e., men and women working in different sectors) has changed little (England et al. 2007; Weeden, Thébaud, and Gelbgiser 2017). Horizontal segregation is especially apparent is the STEM field: a recent report by the European Union states that in almost all European countries, the proportion of female scientists and engineers in the total labor force is lower than the male proportion (European Commission 2016).

Women's relatively higher rate of dropping out from STEM educational tracks and occupations, thus creating and widening the gender gap, is often metaphorically described as a leaky pipeline (Alper 1993). STEM career paths are conceptualized as a pipeline because they require a relatively strict pathway: from subject electives and advanced courses in high school, to an undergraduate degree with a STEM focus, to a postgraduate degree, to a first job. Joining this trajectory at later stages is difficult or even structurally impossible, because prerequisites of previous STEM involvement often have to be fulfilled (Berryman 1983). When it comes to leaving this trajectory, women drop out ("leak out") of the pipeline at a higher rate than men. At every stage of the education system, gender differences in performance in relevant subjects do not explain this difference (Blickenstaff 2006; Hyde 2005), but favorite subjects in school are thought to be a factor (Kudenko and Gras-Velázquez 2016). Students will pick advanced courses based on their favorite classes, which will eventually inform choices in tertiary education and determine labor market trajectories.

The leaky pipeline model provides a life-course perspective on segregation, but it does not offer an explanation. Individual-level (Morgan, Gelbgiser, and Weeden 2013; Riegle Crumb et al. 2012; Xie and Shauman 2003) and contextuallevel (Eccles 2011a, 2011b; Ridgeway 2013; Shepherd 2011) factors have both been proposed as reasons why women drop out of STEM careers. In this article, we examine both and are able to differentiate between them.

Research shows hardly any gender differences when it comes to math and analytic skills in school, but girls are more likely than boys to have high math and high verbal skills (Park, Lubinski, and Benhow 2008; for reviews, see Buchmann, DiPrete, and McDaniel 2008; Hyde 2005). This can be interpreted as girls having more choices when it comes to careers (Ceci and Williams 2010; Wang, Eccles, and Kenny 2013). Following this argument, more women might choose a path related to their non-STEM skills, even if just by chance or potentially due to avoidance of competition. The fact that girls outperform boys in verbal skills, and therefore have comparative advantages in subjects such as languages, means that girls may prefer these subjects even if they do quite well in STEM subjects, because their relative position in STEM is worse (Jonsson 1999).

Another important approach focuses on the extent to which adolescents incorporate gender roles that relate to skills and aptitude into their identity (Akerlof and Kranton 2000; Sinclair and Carlsson 2013), for example, views that women should be caring and nurturing, and men should provide for their family (Kroska 2007). Although this does not include a hierarchical notion per se, it creates a narrative in which women are particularly suited for subject areas that lead to low-paying, low-social-status jobs and men are particularly suited for highly prestigious, highly paid jobs. Cross-national variations in STEM gaps, the fact that we find gender gaps in educational and occupational choices in the most egalitarian countries (McDaniel 2016), and individual-level differences all suggest that these gender norms are not universally determinative but depend on context.

PEER EFFECTS AND GENDER ROLES: THE SOCIAL PIPELINE

The extent to which gender norms are salient in individuals' choices depends on a variety of factors. Presumptions about male and female gender characteristics are disseminated and reinforced through popular culture, the media, and individual experiences and events (Sutton et al. 2002); evidence consistent with preexisting stereotypes tends to be remembered, and counterexamples tend to be ignored or forgotten (Correll 2001).[1]

These dynamics are also shaped through the relationship to significant others, that is, peers or family members. Social interactions can implicitly or explicitly support or undermine gender stereotypes (Levanon and Grusky 2016). During adolescence, young people are reframing their preferences and making decisions about their future, so this phase of life is of particular interest in regard to STEM choices. The way peers adhere to gender roles or sanction atypical behavior will likely affect individuals' behavior.

Measuring peer effects, however, comes with conceptual challenges. Most importantly, identifying the relevant peers is not trivial. Students' most important peers are likely their classmates, because they spend the majority of their time in school and interact there with others of the same age and in the same life situation. Thus, a lot of studies conceptualize the peer effect as an aggregate of characteristics of the classroom context (Legewie and DiPrete 2014a; Rjosk et al. 2014; van Ewijk and Sleegers 2010). Although these studies theoretically consider that individuals are influenced by significant others on the micro level, the methodological approach typically considers only the classroom context through utilization of aggregates, often due to lack of data on within-classroom relations. Friendship network data allow researchers to explicitly consider particular peers. Indeed, evidence shows that "some are more peer than others," suggesting one should focus on peers "subjectively meaningful to the individual" when researching peer effects (Lomi et al. 2011). In our study, we focus on two kinds of peers who are subjectively relevant to individuals: friends and others in the classroom. We investigate the extent to which each contributes to social explanations of the leaky pipeline model. If friends and peers drop out of STEM careers together, should the leaky pipeline be considered a social pipeline?

Friend Influence Effects

Friends have long been considered relevant in theories of educational success. The influential Wisconsin model of status attainment assumes students are influenced by "significant" peers' expectations, implicitly differentiating close friends from classmates (Carolan 2016; Salikutluk 2016; Sewell, Haller, and Portes 1969) .

Homophily, the tendency for friends to be similar in multiple regards (e.g., in their gender or sex category, age, attitudes, and cultural taste) is widely documented (McPherson, Smith-Lovin, and Cook 2001). This can be due to friend selection, that is, the tendency to befriend others who are similar, but, in the case of changeable characteristics, it can also be due to social influence. Research on friendship networks documents this tendency in regard to many outcomes (Cheadle, Walsemann, and Goosby 2015; DeLay et al. 2016). We propose that when it comes to favorite subjects in school, similar dynamics apply. Youths are likely to value their friends' opinions, and when they interact, they are likely to discuss their preferences for subjects. Friends tend to select or influence each other on such changeable characteristics, so they are likely to share general attitudes and tastes, support the same ideas, and be attracted to the same challenges and contents school subjects can offer (i.e., "value homophily"; Goel, Mason, and Watts 2010; Lazarsfeld and Merton 1954; Lazer et al. 2010). We thus hypothesize the following:

Hypothesis 1: Students adopt their friends' subject preferences over time (friend influence effect).

Given that boys and girls show different subject preferences in school, and their friendship patterns tend to be somewhat different (Rose and Rudolph 2006), they might also be subject to different peer effects. Therefore, we will test whether there are gender differences in the extent to which boys and girls are susceptible to friend influence. We further control for the possibility that students may select their friends based on shared subject preferences.

Peer Exposure Effects

Evidence shows that friends tend to be a more determinative frame of reference in socialization compared to others in the same context, such as in the classroom (Lomi et al. 2011), but it is important to consider effects of those other peers. Students are not likely to discuss subject preferences in the same detail with all others in their class, but we propose that they are likely aware of classmates' preferences regarding subjects. This can happen, for example, through observing others' enthusiasm during class or by overhearing discussions.

Considering the politics of gender norms, we expect same-gender others' behavior to be particularly crucial. The reasoning for this is rooted in the nature of norms themselves as well as in previous research on exposure to gender-typed behavior. First, research in developmental psychology has found that adolescents are sensitive to the behavior of others in the same social category, that is, others of the same gender or sex category and the same age. The extent of exposure to same-gender peers is positively correlated with the extent of gender-typed behavior individuals exhibit (Martin and Fabes 2001). Second, social norms are highly dependent on the context in which they are applied (Bicchieri 2006); they can be guiding or even restrictive, due to sanctions that can be applied. Importantly, a norm is salient only when the vast majority of others adheres to it. Indeed, results from observational studies and behavioral experiments suggest a dynamic interplay of social surroundings and the existence of norms in the particular social context (Block, Heathcote, and Burnett Heyes 2018; Efferson et al. 2016).

Based on this, we propose that the extent to which gender norms are upheld by others in a classroom likely matters for an individual, even if the others are not friends, because others are nevertheless in a position to exert sanctions. Adolescence is a vulnerable phase, when students feel a need to belong to the school community (Osterman 2000). Because adolescents tend to adhere to gender roles (ter Bogt et al. 2010), classmates likely sanction nonconforming gender-typed behavior and preferences. We argue that the costs of nonconformity, however, will become lower (or even disappear) the more individuals exhibit non-gender-typed preferences: either this social norm becomes more and more deconstructed or sanctions, such as excluding individuals from the community, have a much smaller effect, because otherwise isolated individuals will have each other.

We thus propose that gender roles are more salient the more girls adhere to and support them. The more girls behave in a non-gender-conforming way, the less salient this norm will become, and hence, the less influence it will have on others. If this is the case, girls' STEM preferences should be more stable and more likely to appear in environments where girls have an overall tendency to like STEM.

> **Hypothesis 2:** Exposure to girls' non-gender-conforming subject preferences in a classroom influences other girls to adopt these preferences (peer exposure effect).

We assume the two types of peer effects exist at the same time. Given that during adolescence, students mostly have same-sex friends, the two mechanisms should often overlap. Modeling them together, we are able to disentangle them from one another.

MEETING THE CHALLENGE OF STUDYING PEER EFFECTS THROUGH DYNAMIC NETWORK ANALYSIS

In this study, we consider both friend influence and peer exposure effects. Both conceptualizations have been researched in the past, and both have methodological or conceptual limitations. We aim to overcome these limits by including both types of peer effects in our analysis at the same time and by utilizing the novel approach of random-coefficient multilevel stochastic actor-oriented models (SAOMs), a statistical framework for the analysis of dynamic social networks across multiple classrooms.

First, as argued earlier, it is more exact to use social network data than classroom-level aggregates when researching peer effects. When considering the effect of friends, however, it is important to consider how friendships change over time. This is necessary to distinguish a peer influence effect, that is, changing behavior because of an existing friendship, from a peer selection effect, that is, befriending someone who is similar. Regression-based analyses considering the effect of friends (e.g., Carbonaro and Workman 2016; Raabe and Wölfer forthcoming) can associate friends' characteristics with those of the individual over time, but they cannot account for these different friendship processes. SAOMs that apply longitudinal social network analysis, however, are able to do so (Steglich, Snijders, and Pearson 2010) and have been applied, for instance, to detect friendship selection and social influence on academic achievement (Flashman 2012; Kretschmer, Leszczensky, and Pink 2018).

Second, until recently, it has been challenging to study multiple groups (e.g., school classes, as in our study) in the SAOM framework, which is necessary to draw generalizable conclusions. Several methods have been proposed to analyze multiple groups together (e.g., meta-analysis, multigroup analysis; see Ripley et al. 2018), but they often prove suboptimal due to lack of statistical power (Stadtfeld et al. 2018) or strong statistical assumptions (Ripley et al. 2018). The recently developed random-coefficient multilevel network models are able to rectify those shortcomings. They simultaneously estimate the entire group of networks and take between-group differences into account. These models use the available information in the data more efficiently and thus struggle less with issues of statistical power. At the same time, they are able to account for multilevel dynamics (Boda 2018; Koskinen and Snijders 2015). Random-coefficient multilevel SAOMs are implemented in a Bayesian framework.

Our study contributes to previous research in four ways. First, we are able to capture the theoretically relevant peer dimension, friends, through utilization of social network data. Second, we simultaneously consider exposure to classmates, in line with previous research using classroom-level aggregates. Thus, we are able to show friend influence net of peer exposure, and vice versa. Third, we are able to control for friendship selection due to shared preferences. Fourth, we use random-coefficient multilevel network models to analyze a large group of networks from a large and generalizable data set, allowing us to account for multilevel dynamics.

DATA AND METHODS

Data

We use the Swedish subset of the first two waves of the Children of Immigrants Longitudinal Survey in Four European Countries (CILS4EU) data set (Kalter et al. 2014, 2015). This project, which is funded by several European research councils (New Opportunities for Research Funding Agency Cooperation in Europe), followed adolescents in England, Germany, the Netherlands, and Sweden over three waves in three years; the first wave was collected when students were in eighth grade and mostly 14 or 15 years old. The sampling design took a two-step cluster approach, first selecting schools (oversampling schools with a high proportion of immigrant students) and then randomly drawing two classes within each school (for further information, see the technical report [CILS4EU 2014] and the sociometric field report [Kruse and Jacob 2014]). In Sweden, 5,025 students from 251 classes in 129 schools participated in the survey (Kalter et al. 2014, 2015). Social network data were collected as part of the youth survey; they contain information on several types of social relations, including friendship networks.

We focus on the Swedish subset of the data for conceptual and technical reasons. Conceptually, Sweden's nontracked education system means students in our sample should structurally have the same choices and prospects; in the Netherlands and Germany, where the education system is tracked, this is not the case. Additionally, in the Netherlands, longitudinal network analysis is almost impossible, due to students being sorted into field of study after wave 1, which involves a restructuring of classes. England has a nontracked education system, as well, but there are some inconsistencies in its collection of network data (Kruse and Jacob 2014).

With Sweden, we focus on one of the more gender-equal European countries, due to, for example, government policies aimed at equalizing effects of childbearing on labor market chances (Duvander and Andersson 2006) and high postmaterialist value orientation (Inglehart 2008). Nevertheless, gender differences in the proportion of women scientists and engineers is still substantial in Sweden although less pronounced than in other European countries (European Commission 2016). This points to the limited influence of a gender-egalitarian ideology on educational and occupational choices, and it suggests that gendered pathways to STEM and differential mechanisms identified in a country like Sweden are also likely to apply in less gender-equal countries.

Variables

We measure preferences for STEM subjects as favorite subjects. The survey item this measure is built on asks, "What is your favorite subject at school?"; multiple answers were possible. Most respondents answered with one subject; nobody indicated more than two subjects. Answers were grouped and recoded into 17 categories (Swedish comprehensive schools use a multisubject curriculum): art, biology, chemistry, English, handicrafts, history, home economics, mathematics, music, natural science, other foreign languages, physical education, physics, religious studies, social studies, Swedish, and technology. Of these, we consider chemistry, mathematics, natural science, physics, and technology to be STEM subjects. Biology is not included in this list, following a strand of literature that considers biology a "soft science," which thus has different implications (Gabay-Egozi, Shavit, and Yaish 2014; Smith 2011). For each classroom, data about subject preferences are represented as a "two-mode network" in which students are linked to their favorite subjects (subject affiliation network).

Sex category (only female or male possible) is defined based on self-reports. We control for two exogenous factors that could be related to STEM preferences: socioeconomic status and cognitive ability. Socioeconomic status is measured as parents' highest educational attainment, using four categories: no school-leaving certificate, degree from lower-secondary school, degree from upper-secondary school, and university degree. This information is drawn from the parental questionnaire; where possible, missing data due to parental nonparticipation were replaced by information from the youth questionnaire. Cognitive ability is based on a language-free test, aimed at measuring analytic skills, which is part of the CILS4EU data; it is measured in wave 1. Further information on this test can be found in the technical report (CILS4EU 2014) and the codebook (CILS4EU 2016). Appendix Table A1 shows descriptive statistics for all variables, along with a number of classroom-level descriptives.

Network Descriptives

Friendship relations are measured through the survey item "Who are your best friends in class?" Respondents could nominate up to five others. Table 1 presents network-level descriptives of friendship networks (who is friends with whom) and subject affiliation networks (the two-mode network indicating students' favorite subject). The descriptives and all subsequent analyses are based on a subsample of 218 school classes. Of the 251 school classes, we excluded 33 due to estimation issues in the RSiena estimation routine.[2] Descriptive comparisons indicate that the

Table 1. Network Descriptives.

Variable	Min.	Max.	*M*	*SD*
Friendship networks				
Size	9	34	22.86	3.67
Density	0	0.24	0.13	0.04
Degrees	0	5.00	2.74	1.85
Average degree	0	4.70	2.71	0.73
Clustering	0.25	0.88	0.57	0.11
Jaccard indices	0	0.58	0.33	0.11
Same-gender ties (T1)	0.54	1.00	0.90	0.08
Same-gender ties (T2)	0.51	1.00	0.87	0.10
Subject networks				
Density	0.03	0.08	0.05	0.01
Degrees	0	2	0.89	0.42
Average degree	0.48	1.39	0.89	0.13
Jaccard indices	0.05	0.56	0.27	0.09

Note: T1 = time point 1; T2 = time point 2.

excluded networks are not very different from the 218 classes in the sample, but they tend to be somewhat smaller, which is likely the cause of the estimation problems (see Appendix Table A2 for details). Each table includes the range, mean, and standard deviation of a number of indexes. Class size ranges from 9 to 34 students; the mean number of students per class is 22.9.

Network densities are defined by the number of relations over the maximum possible number of relations (e.g., if everybody was friends with everybody else in a particular class, the density of the friendship network would be 1). On average, density is 13 percent for friendship networks (individuals indicate that they are friends with 13 percent of their classmates) and 5 percent for subject affiliation networks. Students indicate 0.9 favorite subjects, on average, and 2.7 friends. Friendship networks have an average clustering coefficient of 0.57. This means 57 percent of all two-paths (i nominates j, j nominates h) are transitively closed (i also nominates h). Both networks are similarly stable, indicated by average Jaccard coefficients of 33 percent (friendship) and 27 percent (subject affiliation). The Jaccard coefficient is the proportion of ties persistent in the two waves (stable ties) over the number of ties that exist in either or both data collection waves. It ranges from 0 to 1, where 1 indicates the network does not change at all. Some friendship networks have a Jaccard coefficient of 0, because in some classes no friendship information was collected in the second wave and the networks thus appear empty; because we have information in the favorite subject networks, these classes still carry usable information for our multilevel analysis. Classrooms also show strong gender homophily, which is typical of adolescent friendship networks: 90 percent of friendships are same sex in wave 1 and 87 percent in wave 2.

METHOD AND ANALYTICAL STRATEGY

For our analysis, we use SAOMs (Snijders 2011, 2017; Steglich et al. 2010). These models require longitudinal (panel) data and use simulations to infer the social mechanisms behind observed tie changes in networks. Network changes are represented as sequences of many small changes, such as in agent-based simulation models. In each step, one randomly selected actor has a chance to change (create or terminate) an outgoing tie or to keep the network unchanged. The first data wave serves as a starting point for modeling this process, eventually leading to the second wave. During the simulation, actors make choices about whom they want to be connected to based on theoretically assumed effects, which serve as independent variables in the model. The dependent variables of a SAOM are the changes between subsequent network observations.

In the SAOM framework, one can model the coevolution of one-mode and two-mode networks

(Snijders, Lomi, and Torló 2013; Stadtfeld et al. 2016). The model thus has two dependent variables: the change within the one-mode network (the friendship network) and the change in the two-mode network (the subject affiliation network). In a one-mode network, all nodes are of the same type (here, students), and ties can exist between pairs of these nodes. In a two-mode network, relations connect nodes of two different node sets (here, students and school subjects). Visualizations of several sample classrooms are presented in the section on descriptive results.

We assume that students make decisions about their friendship ties and their favorite subjects through time. By including explanatory variables that are concerned with the respective other network, it is possible to express interdependencies between the two levels. For example, we can test whether friendship is more likely between students who prefer the same subjects. The simultaneous modeling of two dependent variables has two major advantages. First, it allows us to distinguish between selection (friendship choice based on favorite subject) and influence (favorite subject choice based on friendship) processes. Second, it allows us to separate both selection and influence effects of friendship or favorite subject choices from endogenous network effects.[3]

The networks can be further specified through variables or covariates. We can thus test under which circumstances female students (a nodal covariate of students), for example, are more or less likely to prefer a STEM subject (a nodal covariate of the subject). We can further control for the tendency of students with higher analytic cognitive skills being more likely to choose STEM subjects, which may require analytic reasoning more than languages or subjects in the humanities. Whereas traditional regression-based methods consider observations (i.e., social ties or favorite subjects) to be independent, social network models, such as SAOMs, capture and statistically model these dependencies, controlling for them when estimating the rest of the parameters.

A methodological challenge in education research is its multilevel nature. Researchers need to aggregate classroom-level results to global estimates while accounting for classroom-level effects, for example, peers' behavior. To capture the complex multilevel structures and network dependencies in our sample, we apply a new methodological addition to SAOMs that allows us to fit random-coefficient multilevel network models. These SAOMs can be imagined as analogous to the hierarchical linear model for multilevel analysis in the non-network framework (Snijders and Bosker 2011), but they additionally model network dependencies. The method uses a Bayesian estimation technique; details are provided in Appendix Section A1. Our analyses were carried out in R version 3.2.2, using the package RSienaTest version 1.2-2 on a large-scale computer cluster.

Model Specifications

To test the friend influence hypothesis, we include an effect that models the tendency of individuals to choose (start liking or keep liking) the same subjects as their friends: friend influence.[4] Friend influence regarding a subject is more pronounced the more friends like it. We control for subject homophily in friendship selection, that is, the tendency to become or remain friends with others who have the same favorite subject: shared favorite subject of ego and alter. The cross-sectional scenarios are similar—both feature triadic configurations in which friends are connected to the same subjects—but in the case of friend influence, the dependent variable relates to the subject network, and in case of subject homophily, the dependent variable relates to the friendship network. Because we are interested in whether these tendencies vary by sex category, we interact each of the two effects with the covariate female ego.

To test the peer exposure hypothesis, we include three main effects and their interactions in the favorite subject network part of the model (resulting in three two-way interactions and two three-way interactions). The main effects are

a. female ego (0 if male, 1 if female): girls are more/less likely to choose favorite subjects (compared to boys);
b. STEM subject (0 if not STEM, 1 if STEM): STEM subjects are chosen more/less in general (compared to other subjects); and
c. subject popularity among girls (number of girls liking a subject; a square-routed version is used so every additional girl matters less): subjects liked by more girls are chosen more/less in general (compared to subjects liked by fewer girls).

Given that effects a and c are interacted in the model, c in itself directly expresses how a subject's popularity among girls affects boys' preferences about the given subject. To test how this popularity influences other girls' preferences, we consider the interaction a × c. Compared to the main effect of c, this interaction shows the additional effect of the subject's popularity among girls on the preferences of female egos (male ego is the reference category). The sum of main effect c and interaction a × c will show the total effect of a subject's popularity among girls on the choices of female students in the classroom. We apply a joint test to see whether this sum is statistically significant.[5] Compared to the main effect c, this interaction shows the additional effect of the non-STEM subject's popularity among girls on the preferences of female egos (male ego is the reference category). The sum of main effect c and interaction a × c will then show the total effect of a non-STEM subject's popularity among girls on the choices of female students in the classroom.

To consider how peer exposure is different for STEM subjects, we look at additional variables. Interacting each c and a × c with main effect b, we get a two-way (b × c) and a three-way (a × b × c) interaction. Following our argument in the above paragraph, effect b × c will directly capture whether girls influence boys more about a subject when that subject is STEM compared to other subjects; a positive parameter means stronger influence. Similarly, the sum (b × c) + (a × b × c) will express this STEM effect for girls influencing other girls. If this sum is positive, girls influence other girls' preference for STEM more strongly than for other subjects; if this is negative, the influence is weaker.

In our model, we also include the main effect capturing a subject's popularity among male students and its interactions with main effects b and c, creating an analogue set of variables to the one described above. This way, we can look at the effect of boys' preferences on the preferences of other students. We present these sums in the results tables in the main text; full results containing the individual effects can be found in the Appendix.

Apart from the effects that relate to our hypotheses, our models include a number of controls, for endogenous network processes and for alternative explanations that might relate to differential STEM preferences. We follow state-of-the-art model specifications (Block 2015; Ripley et al. 2018; Snijders 2017). For a more elaborate discussion, see Appendix Section A2; full descriptions of all effects included are given in Appendix Table A3.

Based on visual inspection, the model shows good convergence. Following Gelman and colleagues (2013) and Koskinen and Snijders (2015), we calculated a convergence statistic, which indicated good overall convergence for our model.

DESCRIPTIVE RESULTS

Figure 1 shows six exemplary combined networks (friendship and subject affiliation networks) from wave 1 of the data. Individuals are shown in the center of the plots (girls as triangles, boys as circles), and subjects are squares in the periphery. A line between two individuals indicates that at least one considers the other a friend (for visual simplicity, the direction of friendship is not shown, but it is considered in the dynamic analyses with SAOMs); an arrow between an individual and a subject indicates a favorite subject nomination. From the visual representation, gender homophily (a higher tendency of friendship between same-sex individuals) and transitivity (the tendency to form small groups) appear to be important social forces that explain change in friendship networks. These friendship networks are characterized by many triadic structures (friends of friends being friends) and a high proportion of same-sex relations. Subject affiliation seems to be partly shaped by a tendency toward degree centralization (many students share the same preferences for subjects, thus some have a particularly high indegree), considering the large number of potential subjects in relation to number of students in the classroom. The SAOM models test whether we find evidence for dynamic processes explaining the emergence of such structures.

In general, we find gender differences in favorite subjects that are in line with our expectations (see Appendix Figure A1). Subjects like arts, Swedish, and English are more popular among girls; physics and technology are more popular among boys. Physical education is very popular in general but is named by substantially more boys than girls. We see some variations between waves 1 and 2. Math, for example, is equally popular among boys and girls in wave 1 but is named by more boys in wave 2.

STEM subjects become less popular between waves 1 and 2; this decrease in popularity is stronger for girls. In wave 1, 21 percent of boys' and 19 percent of girls' favorite subject is a STEM

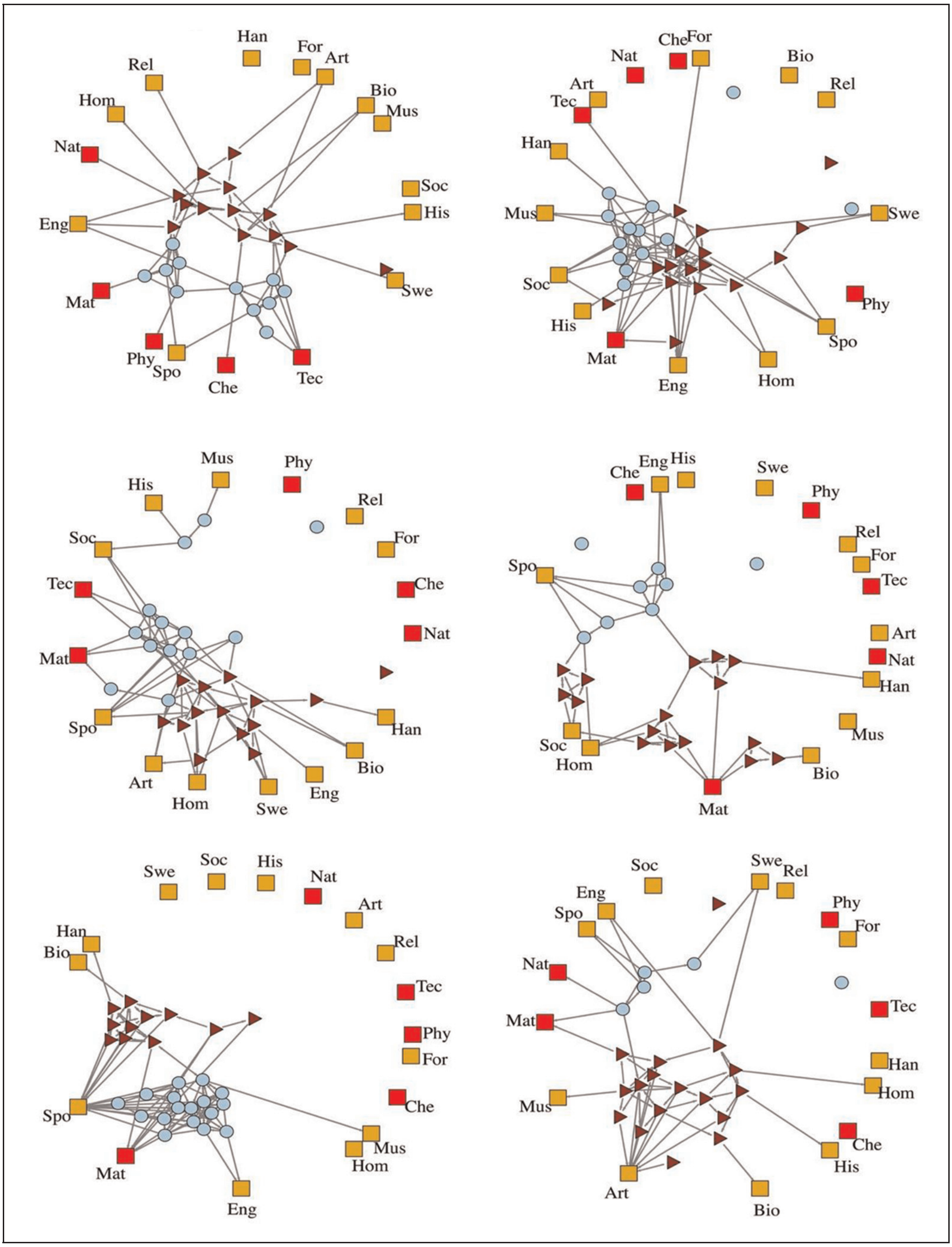

Figure 1. Combination of one-mode and two-mode plots, six sample classrooms.
Note: Triangles represent girls; circles, boys. Art = art; Bio = biology; Che = chemistry; Eng = English; Han = handicrafts; His = history; Hom = home economics; Mat = mathematics; Mus = music; Nat = natural science; For = foreign language; Spo = physical education; Phy = physics; Rel = religious studies; Soc = social studies; Swe = Swedish; Tec = technology.

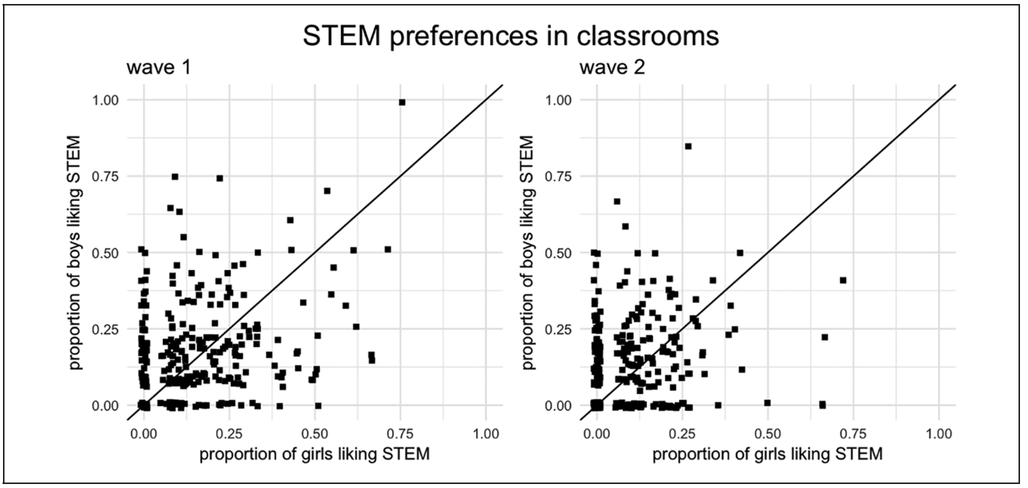

Figure 2. Proportion of students in each classroom who have a STEM-favorite subject in wave 1; proportion split up by gender.
Note: STEM = science, technology, engineering, and mathematics.

subject. This difference is only marginally statistically significant (p = .07), but in wave 2, the gap grows to 20 percent of boys and 15 percent of girls having a STEM-favorite subject; this is a highly significant difference ($p < .0001$). In other words, between waves 1 and 2, approximately 21 percent of girls "leak" from the STEM pipeline; in the same amount of time, only 5 percent of boys "leak." More detailed information can be found in Appendix Table A15. This descriptive finding is in line with the leaky pipeline model.

Figure 2 shows how STEM preferences differ between school classes from wave 1 to wave 2. The same overall picture applies: STEM preferences decrease in general, and they do so more for girls. Additionally, the figure shows that STEM subjects are differentially popular in different classrooms, and the extent to which this varies by sex category is not uniform. This warrants the application of a multilevel framework.

Results from Multilevel Network Models

As discussed earlier, we analyze peer effects on favorite subjects by modeling the coevolution of students' friendships and subject choices. Therefore, our model consists of two parts: one that relates to friendship dynamics and one that relates to dynamics in the favorite subject network. In this section, we report only the variables relevant for our hypotheses (see Table 2); the whole model, including the detailed model of friendship dynamics, can be found in Appendix Table A4. However, for interpretation of each parameter in the model, it is important to consider that friendship selection processes were also taken into account.

As stated in Hypothesis 1, we expect friends to influence each other's favorite subjects (friend influence effect). Our analysis confirms this hypothesis: the friend influence variable shows that the more friends someone has who prefer a certain subject, the more likely the person is to also choose that subject as a favorite ($\beta = 0.820$, $p < .001$).[6] Because boys and girls might be susceptible to friend influence to a different extent, we tested whether this effect is the same for both sex categories. We find a negative interaction effect between friend influence and sex category ($\beta = -0.310$, $p < .001$): girls (coded as 1, boys as 0) are influenced by their peers but significantly less so than boys. Table 2 displays linear combinations of the relevant effects to show the differential friend influence on boys' and girls' subject preferences.

According to Hypothesis 2, the more female students who already prefer STEM subjects in a class, the more likely a girl will choose a STEM subject as her favorite (exposure peer effect). In contrast to Hypothesis 1, we now consider all other girls in the classroom, not just

Table 2. Results, Random-coefficient Multilevel SAOMs; Main Model, Both Peer Effects, with Covariate Controls.

	Posterior		Credible	
Variable	β	*SD*	From	To
Favorite subject part				
Peer exposure effect				
Influence of boys' preferences in the classroom				
Effect of general preferences				
On boys	0.513	(0.120)***	0.270	0.747
On girls	–0.279	(0.101)**	–0.468	–0.050
Additional effect of STEM preferences				
On boys	–0.247	(0.211)	–0.643	0.130
On girls	–0.121	(0.312)	–0.334	0.109
Influence of girls' preferences in the classroom				
Effect of general preferences				
On boys	–0.044	(0.131)	–0.297	0.209
On girls	0.133	(0.115)	–0.091	0.337
Additional effect of STEM preferences				
On boys	0.303	(0.272)	−1.000	0.734
On girls	0.457	(0.100)***	0.226	0.674
Friend influence effect				
Influence of friends' subject preferences				
In general	0.815	(0.094)***	0.654	0.991
Additional effect for girls	0.506	(0.052)***	0.391	0.598

Note: This model controls for friendship selection, endogenous network effects in the friendship, and the favorite subject part as well as effects from cognitive ability and parental education on favorite subject. For the peer exposure effects, linear combinations of the relevant main effects and interaction effects are presented. For full results, see Appendix Table A4. Significance levels refer to the posterior probability for the parameter to be positive or negative. SAOM = stochastic actor-oriented model; STEM = science, technology, engineering, and mathematics.
*$p < .05$. **$p < .01$. ***$p < .001$.

friends. The effect of other girls on girls' subject preferences could exist for all subjects to some extent, but we specifically expect this for STEM, because liking STEM subjects is an expression of preferences not necessarily supported by gender norms in the outside society. This is indeed what we find. In comparison to the influence of girls' general subject preferences on other girls' general subject preferences, which is positive but not significant (β = 0.133, p = .25), the effect of girls' STEM preferences on other girls' STEM preferences is larger and highly significant (β = 0.457, $p <$ .001). Considering the mirrored effect for boys, as well as opposite-sex influence, our results show that the hypothesized peer exposure effect is a particular case: boys are not influenced by other boys' STEM preferences in the same way, and opposite-sex peer exposure does not affect individual STEM preferences. This means other girls' preferences in the classroom are of particular importance when they counter mainstream gender norms in society. This provides strong evidence for Hypothesis 2.

Beyond the effects described above, we did not find evidence that boys like STEM subjects more or less than other subjects, as indicated by the STEM subject variable (β = 0.089, p = .89). Girls, however, appear to like STEM subjects significantly less than other subjects, as indicated by the sum of the STEM subject variable and its interaction with the female ego variable (β = −0.876, $p <$ .001). This negative tendency to develop a new preference for a STEM subject, and to maintain existing STEM preferences, is true even beyond our hypotheses on the friend influence effect, given that both hypothesized processes were analyzed in the same model.

Robustness Checks

We carried out several robustness checks to validate our results. First, to capture differential popularity of specific subjects (e.g., physical education), we repeated our main analysis with subject dummies in the two-mode network part. Results can be found in Appendix Table A5; there are no substantive differences from the results we are discussing.

We also tested both peer effects separately, with and without subject dummies (see Appendix Tables A6 through A9). In all models, the substantive results are the same: we find clear evidence for peer exposure and peer influence effects on subject preferences.

The design of the CILS4EU includes an oversampling of immigrants, which could affect our results. We are unable to include this in our analysis, because it would require interacting every variable related to our hypotheses with an immigrant ego variable, which would lead to several additional three-way interactions as well as four-way interactions that are not implemented in RSiena. There is no obvious reason to assume that the social mechanisms we are testing here apply differently to migrants, but we can investigate descriptively the distribution of STEM preferences among students with and without a migration background. At wave 1, there is no substantial gender gap among children with a migration background; in wave 2, 20.56 percent of girls and 24.73 percent of boys with a migration background name a STEM subject as their favorite (see Appendix Table A14). In general, migrants are more likely to have a STEM-favorite subject, but we still see a more pronounced decrease of STEM preferences for girls.

DISCUSSION

In this article, we aimed to understand the growing gender gap in adolescents' school subject preferences over the life course. We find evidence for two mechanisms related to the effect of peers on students' favorite subjects: favorite-subject preferences are affected by friends' preferences (friend influence) and classroom peers' preferences (peer exposure). We thus captured two substantively different ways in which adolescents' social surroundings affect their subject preferences while considering potentially important exogenous factors, such as parental education and cognitive ability. Both types of peer effects represent social mechanisms that contribute to our understanding as to why more women than men drop out of a STEM career trajectory. High school is an important formative period; preferences cemented during this time will likely be followed up during tertiary education and further career steps. We thus contribute to a set of social explanations to the leaky pipeline model that is relevant at other career stages, because people who drop out during this time are unlikely to be able to join again later.

Both boys and girls are influenced by their friends regarding their favorite subjects, but girls are influenced by their friends to a lesser extent than boys. Notably, this applies to all subjects, not just STEM subjects. To grasp the full significance of the friend influence documented here, it has to be interpreted together with the observed gender homophily in friendship networks and with the preexisting gender differences in subject preferences at the first observation.

As is typical of adolescent friendship networks, friendship in our sample was highly segregated by sex: 90 percent of friendships in wave 1 were same sex, and 87 percent in wave 2. This means social influence mostly comes from same-sex friends, that is, girls will mostly be influenced by girls, and boys will mostly be influenced by boys. Preexisting gender differences may be amplified through these sex-specific influence processes. Indeed, in the first wave of data, we already see a discrepancy in subject preferences between boys and girls: 19 percent of girls and 21 percent of boys had a STEM subject as a favorite subject. In wave 2, 20 percent of boys still had a favorite STEM subject (5 percent decrease), compared to only 15 percent of girls (21 percent decrease). As mentioned earlier, this creates a statistically significant difference in wave 2. Compared to girls, boys are more likely to have a STEM subject as a favorite subject. This means general social influence on favorite subject among boys will lean toward STEM subjects, and this influence affects mostly boys. Because girls are less likely to have a STEM subject as their favorite, the general social influence will be comparatively less likely to direct girls toward STEM. Additionally, we find that social influence on favorite subjects is stronger among boys, which also contributes to social influence amplifying gender differences in STEM preferences. Consequently, friend influence not only produces gender differences in subject preferences because it works differently for boys and girls, but it reinforces different patterns for the two sex categories.

We show that exposure to female classmates who have a STEM-favorite subject has a significantly stronger effect on girls' individual STEM preferences compared to the general effect of girls' favorite subjects on girls' individual subject preferences. We did not find similar tendencies for boys or for opposite-sex peer exposure. This implies that the salience of gender norms in the classroom specifically affects girls in their subject preferences. We argue that the more girls who exhibit non-gender-normative preferences in a class, the lower the costs of and risk for sanctioning. Moreover, the effect of having other girls in a class who like STEM is potentially stronger than it first seems, given that girls in these classes should, on average, also be more likely to have friends who like STEM. Therefore, in such cases, friends could have a more encouraging effect on girls' STEM preferences. Peer exposure is thus a social mechanism that can help protect girls from sanctions against non-gender-conforming behavior.

Our study has several limitations. First, although we controlled for the most important alternative explanations, there are a few we were not able to consider. For instance, the observed peer exposure effect might be a teacher effect. A science teacher who can encourage many girls in a classroom to engage and like the subject can likely motivate additional girls, as well. Furthermore, it could be an effect of the teacher's sex category, gender stereotypes, or different expectations for girls and boys. Our data, however, do not contain information about specific subject teachers, only the main classroom teacher; we were thus unable to account for this possibility. Similarly, school programs promoting STEM subjects could be of relevance. Unfortunately, we do not have information on this. Nevertheless, we are able to control for general subject popularity in the classroom, which captures these kinds of tendencies to some extent. Although we cannot make causal claims, both our interpretation of the results and this alternative explanation suggest that an encouraging classroom atmosphere for girls regarding STEM subjects is important and will likely influence female students. This could lead to girls not being discouraged from following their initial interest in STEM subjects.

Second, we focus only on Sweden, for technical and conceptual reasons: data quality and a non-tracked education system. Nevertheless, we believe our results likely represent relevant tendencies in other countries, too. Sweden has a relatively small gender gap in the proportion of science and technology jobs, yet we still find evidence for two social processes that lead to sex segregation in STEM preferences. Gender homophily can be observed in virtually all adolescent friendship networks, so gender differences in STEM preferences are likely more pronounced in other countries. Indeed, this is the case in the other three countries in our data (England, Germany, and the Netherlands; see Appendix Table A15). There is no reason to assume the mechanisms exacerbating these differences in Sweden work differently in other countries. Nevertheless, more research is needed to investigate other national contexts, beyond Sweden and other European countries. Furthermore, to have a more complete view of the leaky pipeline, which assumes a life course approach, it would be valuable to replicate this study for different age groups.

Finally, we could not test whether the friend influence effect varies by subject and thus operates differently for STEM. Similarly, we could not separately test influences from friends of specific sex categories: to date, necessary effects for these tests are not implemented for the joint analysis of one-mode and two-mode networks in SAOMs. This is necessary, however, to capture interdependencies of specific subject preferences. Nevertheless, both notions would be interesting paths to follow, once these tests are possible.

Our results emphasize peers' effect on individual subject preferences. Although policy makers can do little about the friend influence we document here, awareness is valuable, and evidence for the peer exposure effect has potential in this regard. The peer exposure effect suggests it is beneficial for girls to be exposed to other girls who are interested in STEM subjects. Our analysis is not able to identify a threshold, such as the minimum number of girls who like STEM in a classroom that is needed to sufficiently lower associated costs. Future research could provide insights into beneficial class compositions.

CONCLUSION

Through application of a new and powerful method of multilevel longitudinal network analysis, our study demonstrates the importance of peers in explaining why girls' preferences for STEM subjects decline, which contributes to the explanation of why women drop out from STEM careers at a higher rate than men. We identify two social processes that simultaneously contribute to the social reality of youths in the classroom, in which girls' and boys' subject preferences are shaped.

First, both boys and girls are influenced to like what their friends like. Because students mostly have same-sex friends, gender-specific tendencies of influence will emerge. Boys, who have higher probabilities to like STEM to begin with (in our observed time period), are likely to be further influenced toward STEM because their friends are likely to be boys, who are, again, more likely to have preexisting STEM preferences. Girls, having lower probabilities to like STEM already, are likely further influenced by other girls, who are also less likely to prefer STEM. However, these are just general tendencies. Depending on the particular friends one might have, individual implications can also be different (e.g., cases where girls are friends with more boys than with girls, or with girls who like STEM).

Second, regarding STEM subjects, other girls' preferences in the classroom matter. Having other female students in a class who prefer STEM can protect girls from being discouraged from STEM subjects. This implies that along with friends' subject preferences, the negotiation of gender politics in the classroom is also important for girls' STEM preferences. Our findings suggest the STEM pipeline model should be conceived as a social pipeline model, in which effects of peer exposure and friend influence are considered important factors in female dropout from STEM careers.

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SUPPLEMENTAL MATERIAL

The Appendices are available in the online version of the journal.

NOTES

1. We are aware of the distinction of sex category and gender, which pertains to the difference between displaying and recognizing "socially regulated external insignia of sex" (West and Zimmerman 2009:113) and "being accountable to current cultural conceptions . . . compatible with the 'essential natures' of a woman or a man" (West and Zimmerman 2009:114). We use the appropriate term whenever possible, but to ease readability and to refer to widely used terms (e.g., "gender gap," "gender homophily"), we may on occasion still use *gender* instead of *sex category*. In our study, gender is measured through self-reports, but it was possible to name only two categories (boy and girl).
2. With some smaller classes included, the sienaBayes estimation routine (package RSienaTest, version 1.2-2) threw an error. This error could not be linked to inconsistencies between data and the model. The package maintainer is aware of this problem. The authors will provide details on the error messages and the current workaround on request.
3. Examples of endogenous effects are transitive closure in friendship networks (i.e., friends of friends being friends) and Matthew effects in the subject network (i.e., school subjects might become even more popular in the future purely due to their past popularity).
4. Names in italics are used in the results tables. A full overview of all effects included in the analysis, as well as the internal RSiena shortnames, is given in Appendix Table A3.
5. We applied joint tests to test the statistical significance of combinations of parameters in the model. For this, we calculated Mahalanobis distances of the elements of the posterior sample from the posterior mean for linear combinations of multiple effects. The p value is the relative frequency that these are greater than the distance between the tested value and the posterior mean.
6. Given that an interaction with gender is part of this model, the parameter actually refers to the differential tendency of boys to be influenced. A model without a gender interaction effect (not reported here, but see Appendix Tables A10 and A11 [with subject dummies]) confirms that we find evidence for friend influence irrespective of gender.

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