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Selection homophily and peer influence for adolescents' smoking and vaping norms and outcomes in high and middle-income settings

The MECHANISMS study investigates how social norms for adolescent smoking and vaping are transmitted through school friendship networks, and is the first study to use behavioral economics methodology to assess smoking-related social norms. Here, we investigate the effects of selection homophily (the tendency to form friendships with similar peers) and peer influence (a social process whereby an individual's behavior or attitudes are affected by peers acting as reference points for the individual) on experimentally measured smoking and vaping norms, and other smoking outcomes, in adolescents from high and middle-income settings. Full school year groups in six secondary schools in Northern Ireland (United Kingdom) and six secondary schools in Bogotá (Colombia) participated ($n = 1344/1444$, participation = 93.1%, target age 12–13 years). Over one semester, pupils received one previously tested school-based smoking prevention program (ASSIST or Dead Cool). Outcomes included experimentally measured smoking/vaping norms, self-report and objectively measured smoking behavior, and self-report smoking norms, intentions, susceptibility, attitudes, and psycho-social antecedents. We investigated selection homophily and peer influence using regressions and SIENA modeling. Regression results demonstrate lagged and contemporaneous selection homophily (odds ratios [ORs] = 0.87–1.26, $p \leq 0.01$), and peer influence effects for various outcomes from average responses of friends, school classes, or school year groups (standardized coefficients [βs] = 0.07–0.55, ORs = 1.14–1.31, $p \leq 0.01$). SIENA models showed that comparable proportions of smoking/vaping-based similarity between friends were due to selection homophily (32.8%) and peer influence (39.2%). A higher percentage of similarity between friends was due to selection homophily and/or peer influence for ASSIST schools compared to Dead Cool. Selection homophily was also more important in Bogotá, whilst peer influence was stronger in Northern Ireland. These findings support using social norms strategies in adolescent smoking prevention interventions. Future research should consider selection homophily and social influence jointly, and examine whether these findings translate to other high and low-middle-income settings with varying cultures and norms.

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Introduction

Every year, over seven million people die from tobacco consumption and 1.2 million die from second-hand smoke (World Health Organization, 2020). Smoking rates are declining in high-income countries, but remain high in low- and middle-income countries (LMICs), with over 80% of the world's 1.3 billion tobacco users living in LMICs (World Health Organization, 2020). Smokers usually start during adolescence when social influences (from observing others' smoking behaviors, attitudes, and norms) are prevalent (Allen and Feigl, 2017; Littlecott et al., 2019). The risk of developing smoking-related diseases increases as the number of smoking years and cigarettes smoked per day increases (Difranza and Richmond, 2008). E-cigarettes are also gaining popularity, particularly amongst adolescents (Perikleous et al., 2018; Schneider and Diehl, 2016). While adult smokers are more likely to use e-cigarettes as a smoking cessation aid (Chan et al., 2021), they are typically used for experimentation amongst adolescents, similar to how adolescents typically use conventional cigarettes and could serve as a "gateway to smoking" (Perikleous et al., 2018; Soneji et al., 2017). Smoking prevention programs usually target younger adolescents (12–13 years), and many use social norms-based approaches or attempt to leverage peer influences (Campbell et al., 2008; Thomas et al., 2015).

Peer influence is a social process by which a focal individual's behavior or attitudes are affected by peers acting as reference points for the individual within social networks (Montgomery et al., 2020; Steglich et al., 2012). Whether it is due to peer influence or selection homophily processes (the tendency for individuals to form friendships with others of similar characteristics and behaviors (Krupka et al., 2016; Steglich et al., 2012)), research shows that adolescent smokers usually have more smoking friends, whilst non-smokers have more non-smoking friends (Liu et al., 2017; Steglich et al., 2012). This correlation between an individual's smoking and the smoking behaviors of their peers has been shown to differ according to cultural characteristics (i.e., to be stronger for adolescent samples drawn from collectivistic, versus individualistic, cultures) (Liu et al., 2017). In general, high-income countries such as those in the United States, United Kingdom (UK), and Europe, tend to be more individualistic, whilst LMICs including those in Latin America tend to be more collectivistic (Peng and Paletz, 2011; Weiss et al., 2019). Schools are appropriate settings for delivering interventions attempting to adjust health behaviors by shaping peer norms and interactions. Most children can be reached through schools, tobacco education fits naturally into school activities, and schools are important determinants of adolescent friendship formation (Thomas et al., 2015). In a 2015 meta-analysis, school-based smoking prevention programs combining social influence and social competence components were most effective (Thomas et al., 2015). However, only four of the 50 included trials were conducted in non-high-income settings (Thomas et al., 2015). In a 2012 review conducted in LMICs, only three of the included interventions incorporated social influence components, and the evidence was inconclusive for whether they were effective in reducing smoking uptake and progression to regular smoking (Munabi-Babigumira et al., 2012). The authors highlighted the need for rigorous studies to be conducted in LMICs, incorporating delivery strategies of interventions that have been successful in high-income settings, and appropriately adapted to account for local contextual factors and culture (Munabi-Babigumira et al., 2012). A more recent review of school-based smoking prevention programs for adolescents in developing countries found only seven articles meeting the eligibility criteria but concluded that peer education programs were effective and could be tailored to the conditions of the country (Huriah and Dwi Lestari, 2020).

Interventions targeting groups of people and social networks may be more effective at reducing health inequalities than those focusing on individuals (Hunter et al., 2019, 2020; Montgomery et al., 2020). The A Stop Smoking in Schools Trial (ASSIST) intervention works by identifying influential pupils in school year groups to promote anti-smoking norms amongst school peers, by aligning a peer-focused education program with social network-based principles (Campbell et al., 2008). Such group or social network-based interventions frequently act, at least partly, by changing social norms (Hunter et al., 2020). Social norms are defined as rules and standards understood by members of a social group, which guide or constrain social behavior without enforcement by law (Cialdini and Trost, 1998). Injunctive norms are shared perceptions about behaviors that are associated with social approval or acceptance (e.g., peer approval of smoking), while descriptive norms are shared perceptions about behaviors that are undertaken by others in a social group in any given situation (e.g., peer engagement in smoking) (Cialdini and Trost, 1998; Mackie et al., 2015). Whilst social network structures affect how social norms spread, social norms also derive from shared understandings between individuals within social networks (Hunter et al., 2020; Panter-Brick et al., 2006). Therefore, interventions targeting social norms span different levels of the Socio-Ecological Model of behavior change since they rely on individual perceptions of the consequences of non-compliance (at the individual level), and on others' behavior within the social network (at the social environmental level) (Bronfenbrenner, 1977; Hunter et al., 2020; Panter-Brick et al., 2006).

Public health research has traditionally relied on self-report assessments of norms, however, such methods are often charged with being susceptible to social desirability biases (Mackie et al., 2015; Murray et al., 2020). Experimental methods of eliciting social norms, drawn from behavioral economics and game theory, can deepen our understanding of the mechanisms of norms-based public health interventions since they mitigate social desirability bias and provide rich information regarding the distribution of acceptability of various actions (i.e., norms) (Kimbrough and Vostroknutov, 2016, 2018; Krupka and Weber, 2013; Murray et al., 2020). For example, Krupka and Weber used financially incentivized co-ordination games to elicit social norms for choices in a standard dictator game (Krupka and Weber, 2013). The Mechanisms of Networks and Norms Influence on Smoking in Schools (MECHANISMS) study is the first to use these behavioral economics methods (Kimbrough and Vostroknutov, 2016, 2018; Krupka and Weber, 2013) to elicit social norms for adolescent smoking and vaping behaviors (Hunter et al., 2020; Murray et al., 2020). The study aims to investigate the mechanisms through which social norms for adolescent smoking and vaping are transmitted through school friendship networks (Hunter et al., 2020; Murray et al., 2020). To do this we have elicited social norms (for various adolescent smoking and vaping behaviors and actions) (Kimbrough and Vostroknutov, 2016, 2018; Krupka and Weber, 2013) and friendship networks pre- and post-implementation of two different types of school-based smoking prevention programs with proven effectiveness in previous cluster randomized controlled trials: ASSIST and Dead Cool (Campbell et al., 2008; Thurston et al., 2019). The incentivized experimental methods applied in the MECHANISMS study reduce social desirability bias when measuring social norms since they require participants to guess how peers in their school year group would answer. Specifically, participants are provided with monetary incentives to try to 'match' their own response to the most common response in their school year group. Injunctive norms, for example, are measured by asking participants to guess how their peers would rate the social appropriateness of "a parent smoking in front of young children". Participants are told that they will be paid a fixed amount if their response to a randomly selected question "is the same as the most common response provided in your school year group". The modal answer is elicited as the social norm for the school year group. Since participants are encouraged to think about how peers will respond rather than providing personal opinions the need for social desirability, which affects commonly used self-report assessment methods, is mitigated (Burks and Krupka, 2012). Introducing incentives to guess how most others are guessing, provides further reason to report beliefs truthfully.

This paper aims to investigate selection homophily and peer influence effects for these novel experimental measures of smoking and vaping norms. Previous norms-based public health studies have relied on limited self-report methods of measuring social norms, and have not attempted to empirically measure these effects directly (Hunter et al., 2020). The underpinning methodology will also have broader relevance for studying other health-related behaviors in the future (Hunter et al., 2020). Our study is also novel in that it includes data from schools in two different settings (a high-income setting, and a middle-income setting). Northern Ireland (NI) is a high-income country in the United Kingdom (UK) (The World Bank, 2020b), with approximately 2 million inhabitants (Northern Ireland Statistics and Research Agency, 2019), and current cigarette consumption rates of 4% for adolescents aged 11–16 years (12% report having smoked tobacco at least once) (Foster et al., 2017). Current e-cigarette consumption rates were 4.9% for adolescents aged 11–18 years across the UK in 2019 (15.4% had tried vaping at least once) (Action on Smoking and Health (ASH), 2019). Bogotá is the capital city of Colombia, an upper-middle-income country (The World Bank, 2020a), with over 7 million inhabitants (National Administrative Department of Statistics, 2019), and current cigarette consumption rates of 13.1% for adolescents aged 12–18 years (25.0% of adolescents aged 13–15 years report having smoked at least once) (Ministry of Health and Social Protection, 2020; Ministry of Justice and Law et al., 2016). In 2017, 15.4% of adolescents aged 13–15 years across Colombia reported that they had tried e-cigarettes at least once (Ministry of Health and Social Protection, 2020). Since e-cigarettes are growing in popularity among adolescents, norms for smoking and vaping were both considered in the MECHANISMS study (Perikleous et al., 2018; Schneider and Diehl, 2016). Studying norms for adolescent smoking and vaping in two different settings is an important aspect of the MECHANISMS study since most of the world's tobacco users now live in LMICs, and previous studies have highlighted a lack of relevant research in LMIC settings (Huriah and Dwi Lestari, 2020; Munabi-Babigumira et al., 2012; Thomas et al., 2015).

Our paper also presents an overview of selection homophily and peer influence effects for a broad range of smoking-related psychosocial antecedents that may lead to smoking behavior (e.g., attitudes, self-efficacy, and perceived risks and benefits), and objectively measured smoking behavior. Previous studies examining peer influence and peer selection homophily in adolescent smoking have mostly limited their focus to examining social network processes for smoking behavior, intentions, or susceptibility, and very few have incorporated psychological characteristics. For example, Go et al., examined selection homophily and peer influence processes using mixed-effects logistic regression with propensity score modeling and found both processes explained the association between peer smoking and adolescent smoking initiation (Go et al., 2012). Hoffman et al., modeled peer influence and selection homophily using cross-lagged panel structural equation models (CLPMs) and found that whilst both effects were occurring simultaneously, peer influence was a more salient predictor of adolescents' 'ever smoking' than peer selection (Hoffman et al., 2007). However, a longitudinal social network analysis in the original ASSIST trial found that smoking-based selection of friends explained a greater proportion of smoking behavior similarity over time than peer influence (Mercken et al., 2012). The authors recommended that future adolescent smoking prevention research should not focus solely on social influence, but should also consider selection homophily (Mercken et al., 2012). In a recent paper, Chu et al., used agent-based models to describe cigarette and e-cigarette use with data from the state of Pennsylvania in the United States (children and adults), which showed declines in cigarette, e-cigarette, and total nicotine use when implementing a program of e-cigarette education and policies (Chu et al., 2020). The authors also developed a model that considered a social contagion factor where schools functioned as a transmission vector, but they did not attempt to explore selection homophily and peer influence (Chu et al., 2020).

Selection homophily and peer influence are both mechanisms producing homogeneity of peer networks (Go et al., 2012), and disentangling the two processes has been recognized as challenging (Ragan et al., 2019; Shalizi and Thomas, 2010). This paper aims to explore the behavioral mechanisms underlying the influence of social norms on adolescent smoking and vaping by examining whether changes in the experimentally elicited norms measures over time are correlated amongst friendship cliques, and broadly within the larger school community (e.g., school classes and school year groups). Our statistical approach draws upon the work of Krupka et al. (2016), who studied selection homophily and peer influence effects for university freshmen's economic preferences (and related self-report outcomes), and our study's power calculation was also based on the work of Krupka et al., to detect changes in these effects (Hunter et al., 2020). Specifically, we examine selection homophily processes using mixed-effects logistic regressions to investigate whether similarity with another pupil on the smoking and vaping outcomes increases the likelihood of nominating them as a friend (objective 1). Peer influence effects (from the average responses of pupils' friendship networks and broader social communities within school classes and school year groups) are examined using ordinary least square regressions (objective 2). Previous health-related and behavioral economics studies have used similar regression-based approaches to investigate selection homophily and social influence (Flashman and Gambetta, 2014; Fowler and Christakis, 2008; Go et al., 2012; Hoffman et al., 2007; Miething et al., 2016; Parkinson et al., 2018; Rohrer et al., 2021). To examine selection homophily and peer influence effects simultaneously, we also conducted longitudinal CLPMs examining cross-lagged and auto-regressive effects between adolescent and friends' smoking and vaping outcomes between baseline and follow-up (objective 3). This is similar to the approach adopted by Hoffman et al., to examine peer influence and selection homophily for adolescent smoking behavior (Hoffman et al., 2007). Finally, we compared the results of our regressions and CLPMs with simulation investigation for empirical network analysis (SIENA) models, which simultaneously estimate selection homophily and peer influence effects, whilst accounting for network dynamics, network structure, and the characteristics of the actors in the network (Mercken et al., 2009, 2012; Ripley et al., 2022; Steglich et al., 2010) (objective 4). This is similar to the approach of Ragan et al. who compared estimates of selection homophily and peer influence effects derived from conventional regression methods to estimates from SIENA models for adolescents' deviance and school performance and found no evidence that the regression methods tended to be biased toward overestimating peer influence compared to SIENA (Ragan et al., 2019). For the SIENA models, we also investigated differences across subgroups of schools defined by setting (NI versus Bogotá), and intervention program (ASSIST versus Dead Cool; objective 4). In previous work, our group combined Latent Transition Analysis (LTA) with Separable Temporal Random Graph Models (STERGMs) to examine selection homophily and peer influence processes in terms of the MECHANISMS study experimental measures of smoking and vaping norms (Montes et al., 2023). In the LTA, pupils were classified into unobserved ("latent") groups characterized by whether they changed their smoking/vaping injunctive and descriptive norms ("favorable towards smoking" or "against smoking") between baseline and follow-up. The STERGM showed that pupils were more likely to be friends with others who had social norms against smoking, but that pupils with social norms favorable towards smoking had more friends with similar views than the pupils with perceived norms against smoking. Subgroup analyses also showed that the proportion of pupils who changed their norms to be "against smoking" was higher for ASSIST schools compared to Dead Cool (Montes et al., 2023). The current paper adds to our previous work by providing a broader overview of selection homophily and peer influence for our experimental smoking and vaping norms measures (in terms of pupils' observed scores on the scales, and individual 'norms' items), comparing statistical methods used to address these questions in behavioral economics (regression, e.g., Krupka et al., 2016) and network sciences (SIENA, e.g., Mercken et al., 2012), examining peer influence from proximal (e.g., nominated friends) versus distal (e.g., school classes and school year groups) peers, and also examining selection homophily and peer influence for our study's other (self-report) smoking outcomes and objectively measured smoking behavior.

Thus, the aim of this paper is primarily to investigate selection homophily and peer influence effects for our experimental measures of smoking and vaping norms (that is, how norms for different smoking/vaping-related actions are diffused through school friendship networks). As a secondary aim, we have also investigated selection homophily and peer influence for related self-report outcomes (including self-report smoking norms, behavior, intentions, knowledge, attitudes, and other psychosocial antecedents), and objectively measured smoking behavior.

Methods

Study design. The MECHANISMS study is a pre-post quasi-experimental study (Hunter et al., 2020). Twelve schools ($N = 6$ NI, $N = 6$ Bogotá; participation = 93.1%, $n = 1344/1444$ pupils) participated in the MECHANISMS study between January and November 2019 (Hunter et al., 2020). Study procedures have previously been described in the study protocol and related publications (Hunter et al., 2020; Murray et al., 2020; Sánchez-Franco et al., 2021). We recruited full school year groups (NI Year 9, Bogotá Year 7; target age 12–13 years). In NI, schools were recruited for the full phase of the MECHANISMS study between November 2018 and January 2019. Schools were prioritized if they were non-selective secondary education schools not already enrolled in the Dead Cool program, mixed gender, had over 100 pupils in Year 9, were of higher deprivation levels, and ranged in geographical location (urban, rural) and sector (controlled, maintained, integrated). In Bogotá, schools were recruited between March and May 2019. A list of 40 private and public schools was prioritized based on health risks outlined by the Education and Health secretaries. From this list, 13 schools were invited to participate according to the following criteria: schools in urban areas; mixed gender; having enrolled between 90 and 150 students in 7th year (equivalent of Year 9 in NI). Only six schools accepted the invitation and were selected for the final sample. Schools were assigned to one of two smoking prevention programs: ASSIST (which is specifically designed to leverage peer influence) or Dead Cool (which is based on more conventional classroom pedagogy) (Campbell et al., 2008; Thurston et al., 2019). In a pre-post design, pupils participated in incentivized (monetary) norms elicitation experiments, designed on behavioral economics and game theory principles (Kimbrough and Vostroknutov, 2016, 2018; Krupka and Weber, 2013), and completed a self-report survey over one semester.

Ethics approval was granted from Queen's University Belfast in September 2018 (reference 18:43) and Universidad de los Andes in July 2018 (reference 937/2018). Prior to the baseline assessment, each school was provided with Teacher information sheets, Pupil information sheets, Parent/guardian information sheets, Pupil consent forms, and Parent/guardian opt-out forms. All pupils were required to complete written consent forms indicating whether they agreed or declined to participate. Parents/guardians who did not wish their child to take part were asked to return completed opt-out forms. The experimental protocol, and all data collection procedures, were carried out in accordance with institutional guidelines for research involving human participants and with the Declaration of Helsinki. Experiments and surveys were delivered via Qualtrics (Qualtrics, Provo, UT, USA) and completed on tablet computers. Participants were instructed not to communicate with classmates during data collection. Prior to implementation in Bogotá, all study materials were culturally adapted, including translation into Spanish language (Sánchez-Franco et al., 2021). Further details on study procedures are available in the Supplementary Information (see the Supplementary Methods, 'Study Procedures' subsection, the study flow diagram in Supplementary Fig. S1, and participants' baseline characteristics in Supplementary Table S1).

Incentivized experiments. The game theory experiments included several incentivized tasks (Kimbrough and Vostroknutov, 2016, 2018; Krupka and Weber, 2013). Part 1 included a rule-following task measuring individuals' social norms sensitivities (Kimbrough and Vostroknutov, 2016, 2018). Participants were given five minutes to allocate 50 balls across two buckets following an arbitrary rule with explicit monetary costs: "The rule is to put the balls in the blue bucket". Individuals' norms sensitivities were elicited as the number of balls allocated to the rule-following bucket ('Rule-following').

Parts 2–3 included incentivized co-ordination games to elicit injunctive and descriptive norms for smoking and vaping in whole school year groups (Krupka and Weber, 2013). Participants were informed they would receive a payment if their response to a randomly selected question matched the most common answer in their school year group. The financial incentives are included to encourage participants to match their ratings/estimates to others in their school year group instead of providing personal opinions. Injunctive norms, reflecting shared beliefs about what actions people ought to take (Krupka and Weber, 2013), were assessed by asking participants to 'co-ordinate' with others in their school year group (as described above) to rate the social appropriateness of eight smoking- and vaping-related scenarios (P2S2–P2S9). The scenarios included: a parent smoking in their own home in front of children under the age of 5 (P2S2); an adult smoking in a car with children under the age of 16 in the car (P2S3); someone selling cigarettes to a teenager who looks younger than 16 without requesting proof of age (P2S4); in a recent superhero movie the lead actor is seen smoking in the opening scene (P2S5); an older student from school is smoking outside school, for example, at a bus stop (P2S6); a pupil from school is using an e-cigarette while walking to school (P2S7); a pupil from school shares a photograph of him/herself using an e-cigarette on social media

(P2S8), and; a pupil from school is chewing tobacco (P2S9). Pupils provided their ratings on a six-point scale ("extremely socially inappropriate" to "extremely socially appropriate"). Descriptive norms, reflecting shared beliefs about what actions people actually do take (Krupka and Weber, 2013), were assessed with two items asking participants to 'co-ordinate' with others in their school year group to estimate the proportion of their school year group who would be accepting of a close friend smoking (P3Q1) or vaping (P3Q2). Pupils provided their ratings on a six-point scale ("none of my peers" to "all of my peers"). For each situation, the 'norm' was elicited as the modal response in the school year group.

Part 4 assessed participants' willingness to pay to support anti-smoking norms. Participants were informed that they would receive ten virtual tokens of equal monetary value, asked how many they wanted to donate to the organization responsible for delivering the smoking prevention program in their school, and informed that they would receive a payment equal to the amount not donated. The extent of a participant's willingness to incur a cost to make a higher donation to a smoking prevention program reveals their support for creating anti-smoking norms ('Donation to ASSIST/Dead Cool').

Participants received participation fees of £5.00 (NI; COP$5000 Bogotá), and could earn money in each part of the experiment (maximum £30 NI, COP$50,000 Bogotá) depending on their answers and answers provided by others in their school year group. Payments were received after the follow-up experiment. See the 'Game Theory Experiments' and 'English and Spanish language versions of the experimental protocol' subsections of the Supplementary Methods. Supplementary Table S2 shows the assessed smoking- and vaping-related scenarios, and numerical coding of responses.

Self-report survey and carbon monoxide measurements. A survey was used to collect socio-demographics (gender, age, ethnicity, socio-economic status), friendship networks, self-report smoking outcomes, personality characteristics, and wellbeing. In NI, socio-economic status was based on the Northern Ireland Multiple Deprivation Measure (NIMDM2017) (Northern Ireland Statistics and Research Agency, 2017). The NIMDM2017 ranks NI postcodes based on seven domains of deprivation (Northern Ireland Statistics and Research Agency, 2017). In Bogotá, socio-economic status was determined as the socio-economic level index provided by the Colombian National Administrative Department of Statistics (National Administrative Department of Statistics, 2021).

Survey items were previously validated and adopted from studies of similar-aged participants (Hunter et al., 2020). Self-report injunctive smoking norms (IN1–IN7) were assessed with seven items enquiring about perceived approval of smoking from groups of important others, including "most of the people who are important to me" (IN1), "my mother" (IN2), "my father" (IN3), "my brother(s)" (IN4), "my sister(s)" (IN5), "my friends" (IN6), and "my best friend" (IN7). Pupils provided their answers on a five-point scale ("think(s) that I definitely should smoke" to "think(s) that I definitely should not smoke") (Cremers et al., 2012). Self-report descriptive smoking norms were assessed with two scales (DN1.1–DN1.5; DN2.1–DN2.3) (Cremers et al., 2012). The first scale consisted of five items enquiring about how often groups of important others engaged in smoking behavior, including "best friend" (DN1.1), "mother" (DN1.2), "father" (DN1.3), "brother(s)" (DN1.4), and "sister(s)" (DN1.5). Pupils provided their answers on a five-point scale ("very often" to "never"/"don't know"). The second scale consisted of three items enquiring about the proportion of groups of important others who are smokers, including "friends" (DN2.1), "other family members" (DN2.2), and "classmates" (DN2.3). Pupils provided their answers on a five-point scale ("almost all of them" to "almost none of them"/"don't know"). Other self-report smoking outcomes included past/current smoking behavior (Dunne et al., 2016; Fuller and Hawkins, 2012), smoking intentions and susceptibility (Dunne et al., 2016; Mazanov and Byrne, 2007; Pierce et al., 1998), smoking knowledge (Cremers et al., 2012), attitudes towards smoking (Ganley and Rosario, 2013), self-efficacy (emotional, friends, and opportunity subscales) (Condiotte and Lichtenstein, 1981; Lawrance, 1989), perceived risks (physical, social, and addiction subscales) (Aryal et al., 2013; Halpern-Felsher et al., 2004; Song et al., 2009), perceived benefits (Aryal et al., 2013; Halpern-Felsher et al., 2004; Song et al., 2009), perceived behavioral control (easy to quit smoking) (Smith et al., 2006), and perceived behavioral control (to avoid smoking) (Smith et al., 2006).

Pupils had their smoking behavior in the last 24 h objectively measured using hand-held carbon monoxide monitors (PICOAdvantage Smokerlyzer, Bedfont) (Bedfont Scientific Ltd., 2018), which measure expelled air carbon monoxide in parts per million (Bedfont Scientific Ltd., 2018). Objectively measured smoking behavior was analyzed as a continuous variable (Thurston et al., 2019). Details of all measurement instruments are available in Supplementary Table S2.

Social networks data. School friendship networks were assessed by asking pupils to name up to ten of their closest friends in their school year group (Dunne et al., 2016). The social network data was anonymized by matching participants' nominations to class rosters containing unique study IDs, using the 'agrep' function in R (R Core Team, 2022). The 'agrep' function automatically matched 90% of nominations. The remaining 10% were independently hand-matched by two researchers, with discussion to resolve disagreements. Throughout this paper, references to 'friendship networks' mean all of the nominated closest friends in the school year group for each focal participant (up to 10).

Statistical analysis. Analyses were conducted using Stata 13 (StataCorp, 2013) and R version 4.2.1 (R Core Team, 2022). Due to multiple testing, we have discussed our results with reference to a significance level of $p \leq 0.01$. Throughout the results tables and supplementary tables, we have also highlighted which results would have attained statistical significance ($p \leq 0.05$) after using the Holm–Bonferroni procedure to adjust the p-values for multiple testing (Holm, 1979). Means and standard deviations were computed, and histograms were graphed to visualize distributions. Cronbach's alpha coefficients for individual scales and Wilcoxon matched-pairs signed-ranks tests (Wilcoxon, 1945) examining pre-post intervention changes in outcomes are reported in Table 1.

For objectives 1–4, we investigated selection homophily and peer influence processes in terms of our smoking and vaping outcomes, namely: experimentally measured injunctive smoking and vaping norms (P2S2–P2S9), experimentally measured descriptive smoking and vaping norms (P3Q1–P3Q2), number of tokens donated to ASSIST/Dead Cool, self-report injunctive norms (IN1–IN7), self-report descriptive norms scale 1 (DN1.1–DN1.5), self-report descriptive norms scale 2 (DN2.1–DN2.3), self-report smoking behavior, self-report smoking intentions, smoking knowledge, attitudes towards smoking, self-efficacy (emotional, friends, and opportunity subscales), perceived risks (physical, social, and addiction subscales), perceived benefits, perceived behavioral control (easy to quit), perceived behavioral control (easy to avoid), objectively measured

Table 1 Baseline and follow-up summary statistics and Wilcoxon signed-rank tests on pre-post intervention differences.

	Northern Ireland (*N* = 6)*		Bogotá (*N* = 6)*		All schools (*N* = 12)*		Wilcoxon signed-rank tests	
	Baseline	**Follow-up**	**Baseline**	**Follow-up**	**Baseline**	**Follow-up**	**No. of −/+/0 signs**	***z*-statistic, *p*-value**
Experiment, *n*	625	620	646	631	1271	1251		
Survey, *n*	630	590	644	619	1274	1209		
Carbon monoxide readings, *n*	591	591	648	620	1239	1211		
Experiment Part 1 (rule-following)								
Balls allocated to blue rule-following bucket (0–50)	29.4 (19.2)	29.1 (20.3)	32.6 (16.6)	32.9 (17.8)	31.0 (18.0) [30]	31.0 (19.2) [33]	−ve: 409; +ve: 425; 0: 359	$z = 0.27$, $p = 0.79$
Experiment Part 2 (injunctive social norms; α = 0.78; −1 = "extremely socially inappropriate" to +1 = "extremely socially appropriate")								
P2S2: Parent smoking in their own home in front of children under age of 5	−0.8 (0.3)	−0.8 (0.4)	−0.9 (0.2)	−0.9 (0.2)	−0.9 (0.3) [−1]	−0.8 (0.3) [−1]	−ve: 120; +ve: 214; 0: 857	**$z = 5.12$, $p < 0.001$†**
P2S3: An adult smoking in a car with children under the age of 16 in the car	−0.7 (0.4)	−0.7 (0.4)	−0.7 (0.3)	−0.7 (0.3)	−0.7 (0.4) [−0.6]	−0.7 (0.3) [−0.6]	−ve: 292; +ve: 318; 0: 582	$z = 1.11$, $p = 0.27$
P2S4: Someone selling cigarettes to a teenager who looks younger than 16 without requesting proof of age.	−0.9 (0.3)	−0.8 (0.3)	−0.9 (0.3)	−0.8 (0.3)	−0.9 (0.3) [−1]	−0.8 (0.3) [−1]	−ve: 158; +ve: 306; 0: 726	**$z = 6.62$, $p < 0.001$†**
P2S5: In a recent superhero movie the lead actor is seen smoking in the opening scene	−0.3 (0.4)	−0.3 (0.4)	−0.4 (0.4)	−0.4 (0.4)	−0.4 (0.4) [−0.2]	−0.3 (0.4) [−0.2]	−ve: 304; +ve: 377; 0: 512	**$z = 2.95$, $p = 0.003$**
P2S6: An older student from school is smoking outside school, for example, at a bus stop	−0.5 (0.4)	−0.5 (0.4)	−0.5 (0.4)	−0.5 (0.4)	−0.5 (0.4) [−0.6]	−0.5 (0.4) [−0.6]	−ve: 288; +ve: 418; 0: 483	**$z = 4.77$, $p < 0.001$†**
P2S7: A pupil from school is using an e-cigarette while walking to school	−0.5 (0.4)	−0.5 (0.4)	−0.5 (0.4)	−0.5 (0.4)	−0.5 (0.4) [−0.6]	−0.5 (0.4) [−0.6]	−ve: 312; +ve: 399; 0: 480	**$z = 3.08$, $p = 0.002$**
P2S8: A pupil from school shares a photograph of him/herself using an e-cigarette on social media	−0.5 (0.4)	−0.5 (0.4)	−0.4 (0.4)	−0.4 (0.4)	−0.5 (0.4) [−0.6]	−0.5 (0.4) [−0.6]	−ve: 300; +ve: 386; 0: 506	**$z = 3.03$, $p = 0.002$**
P2S9: A pupil from school is chewing tobacco	−0.8 (0.4)	−0.7 (0.4)	−0.8 (0.3)	−0.7 (0.3)	−0.8 (0.3) [−1]	−0.7 (0.4) [−1]	−ve: 201; +ve: 350; 0: 641	**$z = 6.29$, $p < 0.001$†**
Experimental injunctive norms scale (average P2S2 to P2S9)	−0.6 (0.3)	−0.6 (0.3)	−0.7 (0.2)	−0.6 (0.2)	−0.6 (0.2) [−0.7]	−0.6 (0.3) [−0.6]	−ve: 448; +ve: 610; 0: 123	**$z = 5.74$, $p < 0.001$†**
*Experiment Part 3 (descriptive social norms; α = 0.85; −1 = "none of my peers" to +**1** = "all of my peers")*								
P3Q1: Proportion of school year group accepting of a close friend smoking	−0.5 (0.5)	−0.3 (0.5)	−0.5 (0.5)	−0.3 (0.5)	−0.5 (0.5) [−0.6]	−0.3 (0.5) [−0.6]	−ve: 249; +ve: 481; 0: 463	**$z = 8.68$, $p < 0.001$†**
P3Q2: Proportion of school year group accepting of a close friend vaping	−0.3 (0.6)	−0.2 (0.6)	−0.4 (0.5)	−0.3 (0.6)	−0.4 (0.6) [−0.6]	−0.2 (0.6) [−0.2]	−ve: 255; +ve: 523; 0: 414	**$z = 9.18$, $p < 0.001$†**

Table 1 (continued)

	Northern Ireland ($N = 6$)*		Bogotá ($N = 6$)*		All schools ($N = 12$)*		Wilcoxon signed-rank tests	
	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up	No. of −/+/0 signs	*z*-statistic, *p*-value
Experimental descriptive norms scale (average P3Q1 to P3Q2)	−0.4 (0.5)	−0.3 (0.5)	−0.5 (0.5)	−0.3 (0.5)	−0.4 (0.5) [−0.6]	−0.3 (0.5) [−0.4]	−ve: 311; +ve: 622; 0: 259	**$z = 9.96$, $p < 0.001$**†
Experiment Part 4 (willingness to pay to support anti-smoking norms; 0 = "0 tokens donated to ASSIST/Dead Cool" to 10 = "10 tokens donated to ASSIST/Dead Cool")								
Donation to ASSIST/Dead Cool (0 to 10).	3.5 (3.1)	3.0 (2.8)	3.9 (2.6)	3.6 (2.4)	3.7 (2.9) [4]	3.3 (2.6) [3]	−ve: 445; +ve: 333; 0: 413	**$z = -4.37$, $p < 0.001$**†
Survey: Self-report injunctive social norms ($\alpha = 0.75$; −2 = "think(s) that I definitely should smoke" to +2 = "think(s) that I definitely should not smoke")								
IN1: Most of the people who are important to me	1.7 (0.7)	1.7 (0.7)	1.8 (0.7)	1.7 (0.8)	1.7 (0.7) [2]	1.7 (0.7) [2]	−ve: 131; +ve: 116; 0: 902	$z = -1.05$, $p = 0.30$
IN2: Mother	1.9 (0.3)	1.9 (0.4)	1.9 (0.4)	1.9 (0.5)	1.9 (0.4) [2]	1.9 (0.4) [2]	−ve: 54; +ve: 44; 0: 1053	$z = -1.04$, $p = 0.30$
IN3: Father	1.8 (0.6)	1.8 (0.6)	1.7 (0.7)	1.7 (0.7)	1.7 (0.7) [2]	1.7 (0.7) [2]	−ve: 93; +ve: 83; 0: 971	$z = -0.76$, $p = 0.45$
IN4: Brother(s)	1.4 (0.9)	1.4 (0.9)	1.4 (0.9)	1.5 (0.8)	1.4 (0.9) [2]	1.4 (0.9) [2]	−ve: 138; +ve: 159; 0: 850	$z = 1.29$, $p = 0.20$
IN5: Sister(s)	1.4 (0.9)	1.4 (0.9)	1.3 (0.9)	1.4 (0.9)	1.4 (0.9) [2]	1.4 (0.9) [2]	−ve: 116; +ve: 139; 0: 893	$z = 1.50$, $p = 0.14$
IN6: Friends	1.5 (0.9)	1.5 (0.9)	1.3 (0.9)	1.3 (0.9)	1.4 (0.9) [2]	1.4 (0.9) [2]	−ve: 197; +ve: 221; 0: 731	$z = 1.09$, p = 0.27
IN7: Best friend	1.7 (0.7)	1.7 (0.8)	1.5 (0.9)	1.5 (0.9)	1.6 (0.8) [2]	1.6 (0.8) [2]	−ve: 169; +ve: 155; 0: 826	$z = -0.64$, $p = 0.53$
Self-report injunctive norms scale (average IN1–IN7)	1.6 (0.5)	1.6 (0.5)	1.5 (0.5)	1.6 (0.5)	1.6 (0.5) [1.7]	1.6 (0.5) [1.7]	−ve: 322; +ve: 351; 0: 470	$z = 1.13$, $p = 0.26$
Survey: Self-report descriptive social norms 1 ($\alpha = 0.54$; 1 = "smoke(s) very often" to 5 = "never smoke(s)"/"don't know")								
DN1.1: Best friend	4.8 (0.8)	4.7 (0.8)	4.9 (0.6)	4.8 (0.6)	4.8 (0.7) [5]	4.8 (0.7) [5]	−ve: 88; +ve: 59; 0: 1005	$z = -2.34$, $p = 0.02$
DN1.2: Mother	4.2 (1.4)	4.3 (1.3)	4.6 (0.9)	4.6 (0.9)	4.4 (1.2) [5]	4.5 (1.1) [5]	−ve: 90; +ve: 107; 0: 956	$z = 1.24$, $p = 0.21$
DN1.3: Father	4.1 (1.4)	4.2 (1.4)	4.4 (1.1)	4.5 (1.1)	4.3 (1.3) [5]	4.3 (1.3) [5]	−ve: 101; +ve: 120; 0: 931	$z = 1.27$, $p = 0.20$

Table 1 (continued)

	Northern Ireland (*N* = 6)*		Bogotá (*N* = 6)*		All schools (*N* = 12)*		Wilcoxon signed-rank tests	
	Baseline	**Follow-up**	**Baseline**	**Follow-up**	**Baseline**	**Follow-up**	**No. of −/+/0 signs**	***z*-statistic, *p*-value**
DN1.4: Brother(s).	4.7 (0.9)	4.7 (0.9)	4.7 (0.8)	4.7 (0.9)	4.7 (0.8) [5]	4.7 (0.9) [5]	−ve: 75; +ve: 50; 0: 1027	$z = -2.31$, $p = 0.02$
DN1.5: Sister(s)	4.8 (0.7)	4.8 (0.8)	4.8 (0.7)	4.8 (0.7)	4.8 (0.7) [5]	4.8 (0.7) [5]	−ve: 40; +ve: 35; 0: 1077	$z = -0.59$, $p = 0.56$
Self-report descriptive norms scale 1 (average DN1.1–DN1.5)	4.5 (0.7)	4.5 (0.7)	4.7 (0.5)	4.7 (0.5)	4.6 (0.6) [5]	4.6 (0.6) [5]	−ve: 251; +ve: 227; 0: 672	$z = -1.04$, $p = 0.30$
Survey: Self-report descriptive social norms 2 (α = 0.53; 1 = "almost all of them smoke" to 5 = "almost none of them smoke"/"don't know")								
DN2.1: Friends	4.7 (0.7)	4.6 (0.8)	4.7 (0.6)	4.7 (0.7)	4.7 (0.7) [5]	4.7 (0.8) [5]	−ve: 155; +ve: 108; 0: 890	**$z = -2.92$, $p = 0.004$**
DN2.2: Other family members	4.1 (1.0)	4.1 (1.1)	4.4 (0.9)	4.5 (0.9)	4.3 (1.0) [5]	4.3 (1.0) [5]	−ve: 213; +ve: 201; 0: 738	$z = -0.56$, $p = 0.57$
DN2.3: Classmates	4.7 (0.7)	4.6 (0.7)	4.8 (0.5)	4.8 (0.6)	4.8 (0.6) [5]	4.7 (0.7) [5]	−ve: 139; +ve: 100; 0: 914	**$z = -2.56$, $p = 0.01$**
Self-report descriptive norms scale 2 (average DN2.1–DN2.3)	4.5 (0.6)	4.5 (0.7)	4.7 (0.5)	4.6 (0.5)	4.6 (0.5) [4.7]	4.6 (0.6) [4.7]	−ve: 322; +ve: 261; 0: 569	**$z = -2.50$, $p = 0.01$**
Survey: Self-report smoking behavior (1 = "sometimes smoke" to 4 = "never smoked")								
Smoking behavior	3.8 (0.6)	3.8 (0.7)	3.7 (0.7)	3.6 (0.7)	3.8 (0.6) [4]	3.7 (0.7) [4]	−ve: 105; +ve: 56; 0: 1003	**$z = -3.91$, $p < 0.001$†**
Survey: Self-report smoking intentions (α = 0.77)								
Intentions (to quit smoking; 1 = "definitely remain a smoker" to 6 = "I don't smoke")	5.9 (0.5)	5.9 (0.7)	5.9 (0.6)	5.8 (0.7)	5.9 (0.5) [6]	5.8 (0.7) [6]		
Intentions (to try smoking; yes/don't know), *n* (%)	117 (18.6%)	122 (20.7%)	204 (31.7%)	233 (37.7%)	321 (25.2%)	355 (29.4%)		
Intentions (friends; 1 = "definitely yes" to 5 = "definitely not")	4.6 (0.8)	4.5 (0.9)	4.6 (0.9)	4.4 (1.0)	4.6 (0.9) [5]	4.4 (0.9) [5]		
Intentions (1 = "I am a smoker" to 6 = "definitely remain a non-smoker")	5.7 (0.8)	5.7 (0.9)	5.5 (1.1)	5.3 (1.3)	5.6 (1.0) [6]	5.5 (1.1) [6]	−ve: 188; +ve: 113; 0: 856	**$z = -4.30$, $p < 0.001$†**
Survey: Self-report smoking susceptibility (0 = "not susceptible to commencing smoking"; 1 = "susceptible to commencing smoking")								
Susceptible to commencing smoking, *n* (%)	199 (31.6%)	199 (33.7%)	259 (40.2%)	315 (50.9%)	458 (35.9%)	514 (42.5%)		
Survey: Self-report smoking knowledge and attitudes								
Knowledge (0 = "0 correct" to 6 = "6 correct")	3.0 (1.5)	3.3 (1.5)	2.2 (1.4)	2.5 (1.5)	2.6 (1.5) [3]	2.9 (1.5) [3]	−ve: 327; +ve: 503; 0: 328	**$z = 6.31$, $p < 0.001$†**

Table 1 (continued)

	Northern Ireland ($N = 6$)*		Bogotá ($N = 6$)*		All schools ($N = 12$)*		Wilcoxon signed-rank tests	
	Baseline	**Follow-up**	**Baseline**	**Follow-up**	**Baseline**	**Follow-up**	**No. of −/+/0 signs**	***z*-statistic, *p*-value**
Attitudes (1 = "least anti-smoking" to 5 = "most anti-smoking"; $\alpha = 0.81$)	4.0 (0.6)	4.0 (0.6)	3.9 (0.7)	3.9 (0.7)	3.9 (0.6) [4]	3.9 (0.7) [4]	−ve: 507; +ve: 540; 0: 90	$z = 0.23$, $p = 0.82$
Survey: Self-report psycho-social antecedents								
Self-efficacy (Emotional; 1 = "least self-efficacy to resist smoking" to 6 = "greatest self-efficacy to resist smoking"; $\alpha = 0.97$)	5.7 (0.8)	5.7 (0.9)	5.6 (0.8)	5.4 (0.9)	5.6 (0.8) [6]	5.5 (0.9) [6]	−ve: 306; +ve: 198; 0: 645	**z = −5.16, p < 0.001**†
Self-efficacy (Friends; 1 = "least" to 6 = "greatest"; $\alpha = 0.96$)	5.7 (0.8)	5.7 (0.8)	5.6 (0.7)	5.5 (0.9)	5.6 (0.8) [6]	5.6 (0.8) [6]	−ve: 323; +ve: 225; 0: 605	**z = −4.48, p < 0.001**†
Self-efficacy (Opportunity; 1 = "least" to 6 = "greatest"; $\alpha = 0.98$)	5.8 (0.6)	5.8 (0.6)	5.7 (0.6)	5.6 (0.8)	5.8 (0.6) [6]	5.7 (0.7) [6]	−ve: 222; +ve: 146; 0: 786	**z = −4.15, p < 0.001**†
Perceived physical risks (0% ="lowest perceived risk" to 100% ="highest perceived risk"; $\alpha = 0.87$)	62.5 (21.6)	66.0 (20.4)	59.4 (26.5)	62.9 (25.3)	60.9 (24.2) [62.9]	64.4 (23.1) [67.4]	−ve: 488; +ve: 631; 0: 28	**z = 4.65, p < 0.001**†
Perceived social risks (0% ="lowest" to 100%="highest"; $\alpha = 0.71$)	75.1 (22.0)	75.9 (22.2)	61.5 (29.1)	63.8 (26.8)	68.1 (26.8) [72.7]	69.7 (25.4) [73.3]	−ve: 500; +ve: 556; 0: 98	$z = 2.01$, $p = 0.04$
Perceived addiction risks (0% ="lowest" to 100%="highest"; $\alpha = 0.49$)	43.4 (24.9)	47.5 (24.0)	27.7 (24.9)	30.2 (25.1)	35.2 (26.1) [33.3]	38.9 (26.1) [37.3]	−ve: 473; +ve: 540; 0: 72	**z = 3.36, p < 0.001**†
Perceived benefits (0%="lowest perceived benefit" to 100% ="highest perceived benefit"; $\alpha = 0.79$)	23.4 (22.1)	24.0 (20.9)	23.8 (21.1)	23.7 (22.0)	23.6 (21.5) [19.8]	23.8 (21.5) [20.0]	−ve: 514; +ve: 525; 0: 51	$z = 0.18$, $p = 0.86$
Perceived behavioral control (easy to quit; 1 = "strongly disagree" to 5 = "strongly agree")	2.5 (1.4)	2.4 (1.4)	3.5 (1.3)	3.5 (1.3)	3.0 (1.4) [3]	3.0 (1.5) [3]	−ve: 376; +ve: 359; 0: 414	$z = -0.63$, $p = 0.53$
Perceived behavioral control (to avoid smoking; 1 = "strongly disagree" to 5 = "strongly agree")	4.3 (1.1)	4.3 (1.0)	4.0 (1.3)	4.0 (1.3)	4.2 (1.2) [5]	4.2 (1.2) [5]	−ve: 302; +ve: 276; 0: 575	$z = -0.91$, $p = 0.37$
Objectively measured smoking behavior (expelled air carbon monoxide readings)								
Parts per million (0–30)	1.5 (1.4)	2.0 (1.0)	3.4 (1.5)	3.5 (1.7)	2.5 (1.7) [3]	2.8 (1.6) [2]	−ve: 363; +ve: 506; 0: 268	**z = 5.64, p < 0.001**†

Reported results are mean (standard deviation) [median] unless otherwise stated.
*There were 1266 participants who nominated at least one friend at baseline (5 had no identifiable nominations), and 1200 who nominated at least one friend at follow-up (3 had no identifiable nominations). There were 9538 friendship nominations at baseline (9403 [98.6%] were identifiable) and 8476 friendship nominations at follow-up (8404 [99.2%] were identifiable). At baseline 6473/9403 (68.8%) nominations were of friends from the same school class. At follow-up 5692/8404 (67.7%) nominations were of friends from the same school class. At baseline, 5124/9403 (54.5%) identifiable friend nominations were reciprocated (follow-up: $n = 4598/8404$ [54.7%]). On average, participants made 7.5 identifiable friend nominations at baseline, and 7.0 at follow-up (based on participants providing at least one identifiable friend nomination). The average school class size was 28.3 with a standard deviation (SD) of 6.8 (NI: mean = 24.5, SD = 5.0; Bogotá: mean = 32.1, SD = 6.2). The average school year group size was 125.7 with an SD of 26.7 (NI: mean = 127.1, SD = 32.0; Bogotá: mean = 124.4, SD = 20.0). Each network had one component.
†Retained statistical significance at the 5% level after using the Holm–Bonferroni procedure to correct the *p*-values for multiple testing ($p \leq 0.05$; based on all tests reported in Table 1).
Bold values show the results meeting the significance level of $p \leq 0.01$.

smoking behavior, and smoking susceptibility (a binary outcome variable coded 1 if the individual was susceptible to commencing smoking and 0 if they were not susceptible to commencing smoking). To investigate selection homophily and peer influence for individual norms items, models were run treating the norms outcomes from the experiment and survey as individual items (experimental injunctive norms P2S2-P2S9, experimental descriptive norms P3Q1–P3Q2, self-report injunctive norms IN1–IN7, and self-report descriptive norms DN1.1–DN1.5 and DN2.1–DN2.3). These analyses were repeated including the average of each scale as the outcome variable. For the SIENA models, only the scale averages were considered for the experimental injunctive norms, experimental descriptive norms, self-report injunctive norms, and self-report descriptive norms scales (objective 4).

The statistical methods used to address objectives 1 to 4 have been summarized below, and more detailed descriptions of the methods have been provided in the Supplementary Methods ('Statistical analysis' subsection). Detailed examples of the syntax used to generate the results for objectives 1–4 have also been provided in the Supplementary Methods.

Objective 1: Friendship networks at baseline and follow-up were graphed for each school, and network descriptive statistics were calculated. Descriptive statistics included: the number of edges, network density, dyadic reciprocity, edgewise reciprocity, reciprocated ties, transitive ties, transitivity, transitive triplets, number of actors at distance two, number of three-cycles, and Jaccard similarity indices. See the 'Glossary' subsection of the Supplementary Methods for definitions.

Selection homophily was examined using mixed-effects logistic regressions with binary outcome variables indicating whether the focal participant: (1) nominated the individual as a friend at baseline; (2) added the individual as a friend between baseline and follow-up; or (3) dropped the individual as a friend between baseline and follow-up. The predictor variable was the absolute difference between focal participant outcome scores, and outcome scores of potential friends on the smoking/vaping-related outcomes, at baseline or follow-up. Models included random intercepts at the individual participant level. Standard errors (SEs) were also clustered at the individual level, similar to Krupka et al. (2016). Odds ratios (ORs), SEs, and intraclass correlation coefficients were extracted for each model. To provide comparable effect size estimates for variables with different scales, the mixed-effects logistic regressions were repeated, with the smoking and vaping outcomes re-scaled (0–10), before computing absolute differences. Mixed-effects logistic regressions were also run with binary predictor variables indicating whether the focal participant and potential friend had matching smoking susceptibility statuses.

Previous health-related and behavioral economics studies have used similar approaches, based on logistic or probit regressions, to investigate selection homophily (Flashman and Gambetta, 2014; Parkinson et al., 2018; Rohrer et al., 2021), and our study's power calculation was specifically conducted to detect changes in these effects, based on the work of Krupka et al. (Hunter et al., 2020; Krupka et al., 2016).

Objective 2: Ordinary least square (OLS) regressions with robust (Huber–White) SEs (Huber, 1967; White, 1980) were used to examine peer influence effects for focal participant outcomes at follow-up from the average responses of: (1) their nominated friends; (2) other pupils in their school class, and; (3) other pupils in their school year group (Krupka et al., 2016).

Whilst an individual's current social context may be the most prominent, it may also take an extended amount of time or sustained exposure for influence to occur (Krupka et al., 2016). All models were conducted with peer-group averages at baseline (to examine influence effects from the social context at baseline) and were repeated with peer-group averages at follow-up (to examine influence effects from the contemporaneous social context at follow-up).

Covariate selection was determined using established criteria (Supplementary Fig. S2) (Ferguson et al., 2020; VanderWeele, 2019). The final set of baseline covariates for each focal participant included: gender, age, intervention, ethnicity, socio-economic status, and baseline values of the outcome. Variance inflation factors (VIFs) were calculated to examine the impact of multi-collinearity (Johnston et al., 2018). VIFs for 'setting' were high for many of the models examining average school class or school year group responses as predictors. Results of models examining average friends' responses are presented before and after adjusting for setting (0 = NI; 1 = Bogotá).

Unstandardized (b) and standardized (β) regression coefficients are reported. Positive coefficients indicated positive influence effects ($p \leq 0.01$). Logistic regressions were run with focal participants' smoking susceptibility as the outcome, and robust (Huber White) SEs (Huber, 1967; White, 1980). ORs > 1.00 indicated positive influence effects ($p \leq 0.01$). Ordered categorical dependent variables (with at least four categories) were treated as continuous variables (Hayashi et al., 2011). In sensitivity analyses, models including ordered categorical dependent variables with six or less categories were repeated using ordered logistic regressions. Analyses were repeated to examine the influence effects from reciprocated friend nominations (where the nominated friend also listed the focal individual as a friend).

Previous health-related and behavioral economics studies have used similar regression-based approaches to investigate peer influence (Fowler and Christakis, 2008; Go et al., 2012; Hoffman et al., 2007; Miething et al., 2016). One of the advantages of the regression models is that they allow us to make important observations in terms of the differences in social influence processes from proximal peers (e.g., close friends) versus distal peers (e.g., members of your school class and school year group). This approach is also similar to previous work conducted by our study's co-investigators, who investigated selection homophily and peer influence effects for university freshmen's economic preferences, comparing influence effects from individuals' friends with their broader network community (Krupka et al., 2016). Our study's power calculation was specifically conducted to detect changes in these effects (Hunter et al., 2020; Krupka et al., 2016).

A common critique of using regression techniques to model selection homophily and peer influence is that they cannot account for endogenous network processes and the inherent non-independence of network data (Ragan et al., 2019). Peer influence operates between all friendship connections within a network simultaneously, and is inherently a network phenomenon. Using regression techniques to model peer influence ignores this endogeneity by assuming independence among units (i.e., the covariation between focal participant outcomes and friends' outcomes is treated as the isolated product of influence in one direction from a discrete group of friends to one actor) (Ragan et al., 2019). Regression models of peer influence also do not control for selection homophily processes or the structure of the network. This can lead to inflated estimates of peer influence. To overcome these limitations, statistical methods designed for the analysis of network data (e.g., SIENA models) which simultaneously estimate selection homophily and peer influence effects in the same model, whilst accounting for network dynamics, network structure, and the characteristics of the actors in the network, are recommended (Mercken et al., 2009, 2012; Ripley et al., 2022; Steglich et al., 2010). In a study conducted by Ragan et al., the authors specifically set out to compare peer influence estimates from SIENA models, which explicitly address network

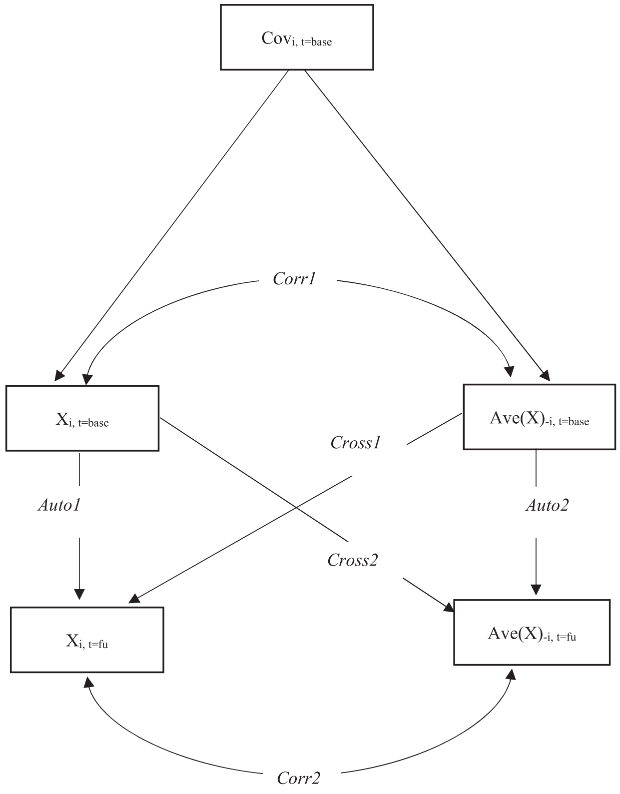

Fig. 1 Cross-lagged panel structural equation models simultaneously examining peer influence and selection homophily effects, with cross-lagged and auto-regressive effects between focal participant scores and the average scores of their nominated friends between baseline and follow-up. $X_{i,\ t=\text{base}}$: Focal participant (*i*) scores on the outcome at baseline. $X_{i,\ t=\text{fu}}$: Focal participant (*i*) scores on the outcome at follow-up. Ave$(X)_{-i,\ t=\text{base}}$: Average of nominated friends' (−*i*) scores on the outcome at baseline. Ave$(X)_{-i,\ t=\text{fu}}$: Average of nominated friends' (-*i*) scores on the outcome at follow-up. Cov$_{i,\ t=\text{base}}$: Focal participant (*i*) baseline covariates (gender, age, ethnicity, and socio-economic status). *Cross1*: Cross-lagged path from Ave$(X)_{-i,\ t=\text{base}}$ to $X_{i,\ t=\text{fu}}$. This path represents the peer influence effect. *Cross2*: Cross-lagged path from $X_{i,\ t=\text{base}}$ to Ave$(X)_{-i,\ t=\text{fu}}$. This path represents the selection homophily effect. *Auto1*: Auto-regressive path from $X_{i,\ t=\text{base}}$ to $X_{i,\ t=\text{fu}}$. *Auto2*: Auto-regressive path from Ave$(X)_{-i,\ t=\text{base}}$ to Ave$(X)_{-i,\ t=\text{fu}}$. *Corr1*: Correlation path between $X_{i,\ t=\text{base}}$ and Ave$(X)_{-i,\ t=\text{base}}$. *Corr2*: Correlation path between $X_{i,\ t=\text{fu}}$ and Ave$(X)_{-i,\ t=\text{fu}}$.

processes, with more "conventional" regression models (such as we have used under objective 2). However, the authors found no evidence that results from the regression models were biased toward overestimating peer influence, relative to SIENA. They argued that there is no perfect way to model peer influence, and that approaches like SIENA are still subject to limitations (e.g., omitted variable bias) (Ragan et al., 2019). In the current paper, we also aimed to compare the results of regression-based analyses of selection homophily and peer influence for our adolescent smoking/vaping outcomes (objectives 1–3) with estimates derived from SIENA models (objective 4).

Objective 3: CLPMs were used to examine cross-lagged and auto-regressive effects between outcomes reported by the focal participant at baseline and follow-up, and the average outcome reported by their nominated friends at baseline and follow-up. CLPMs aim to examine causal (i.e., directional) influences between variables by examining reciprocal relationships between variables over time (Allen, 2017; Preacher, 2015). Figure 1 shows the structure of our CLPMs. Since peer influence occurs when adolescents smoke because their friends smoke, it is represented by the association from average friends' responses at baseline to the focal participant's outcomes at follow-up (path "cross1" in Fig. 1). Selection homophily occurs when adolescents select friends due to similar attributes and is represented by the association from the focal participant's outcomes at baseline to their average friends' responses at follow-up (path "cross2" in Fig. 1). Gender, age, ethnicity, and socio-economic status were included as baseline covariates for focal participants' outcomes at baseline and for average friends' responses at baseline (Hoffman et al., 2007). CLPMs were specified with the 'lavaan' package in R (Rosseel, 2012) using maximum-likelihood estimation with robust (Huber–White) (Huber, 1967; White, 1980) SEs and imputation of missing data using full information maximum likelihood (FIML). CLPMs with the binary variable smoking susceptibility as the outcome was specified using the diagonally weighted least-squares estimator. Model fit indices were extracted, including the model chi-square test, comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR). CFI values of ≥0.96, RMSEA values of ≤0.06, and SRMR values of ≤0.09 indicated good model fit (Hooper et al., 2008; Hu and Bentler, 1999). Unstandardized and standardized parameter estimates were extracted.

The CLPMs add to the regressions conducted under objectives 1 and 2 as they investigate selection homophily and peer influence processes simultaneously (i.e., each effect estimate is controlled for the other, in the same model), within the regression-based framework. Hoffman et al., previously modeled peer influence and selection homophily effects for adolescents' smoking behavior using a similar CLPM strategy which showed that both effects were occurring simultaneously (Hoffman et al., 2007).

Objective 4: We also modeled selection homophily and peer influence processes in terms of our smoking/vaping outcomes using SIENA models. SIENA models were conducted using the 'RSiena' package in R (Ripley et al., 2022). SIENA is a statistical modeling technique designed for the analysis of longitudinal network data collected in a panel study with two or more time-points (Mercken et al., 2009, 2012; Ripley et al., 2022; Snijders et al., 2007; Steglich et al., 2010). SIENA can be used to simultaneously estimate selection homophily and peer influence effects in the same model, whilst accounting for network dynamics (e.g., endogenous network processes and the interdependence inherent in network data), network structure, and the characteristics and behaviors of the actors in the network (Mercken et al., 2009, 2012; Ripley et al., 2022; Steglich et al., 2010). The statistical procedure models probabilistic changes in friendship ties and behaviors using a large number of repeated simulations of the co-evolution of the network and behavior variable from one wave to the next (Ripley et al., 2022). The 'behaviors' investigated in the SIENA models are our smoking/vaping outcomes. The mathematical specification and statistical estimation procedures for SIENA models of the co-evolution of networks and a behavioral dependent variable have been previously described (Snijders et al., 2007; Steglich et al., 2010). Prior to running SIENA models, smoking/vaping outcomes were categorized as described on the righthand side of Supplementary Table S2 (Ripley et al., 2022).

Each model consisted of two parts: a 'Friendship network evolution' part modeling probabilities of changes in network ties, and a 'Smoking/vaping outcome evolution' part modeling probabilities of changes in the smoking/vaping outcome. Each part of the model was specified with a number of effects hypothesized to be associated with the evolution of the friendship network or smoking/vaping outcomes (including the main "peer selection homophily" and "peer influence" effects, in addition to a number of control effects). All effects included in the SIENA models are described in Table 2.

SIENA models were estimated for each school using the Method of Moments, with SEs estimated using the score function, and 10,000 iterations in phase three (Schweinberger and Snijders, 2007; Snijders et al., 2007). Maximum-likelihood estimation has been noted to produce more efficient estimates, particularly when estimating complex models in smaller networks. When analyzing larger networks, the efficiency advantage is negligible and there is no reason not to use the Method of Moments, which is less computationally intensive and time-consuming (Mercken et al., 2009; Ripley et al., 2022; Snijders et al., 2007). For some SIENA models, various parameters were constrained due to non-convergence or multi-collinearity issues. Score tests for fixed parameters were all non-significant ($p > 0.05$) indicating the goodness-of-fit of the models was not decreased (Schweinberger, 2012).

Estimates and SEs for each effect parameter in the SIENA models for individual schools were then combined in a meta-analysis, using the multilevel network analysis method of Snijders and Baerveldt (2003). Previous studies using SIENA modeling to investigate the co-evolution of network ties and smoking behavior, and more recently published Stochastic Actor-Oriented Models have used similar meta-analytic procedures to combine estimates across different networks (Block, 2018; Hooijsma et al., 2020; la Roi et al., 2020; Leszczensky and Pink, 2020; Mercken et al., 2009, 2012; Steglich et al., 2012; Windzio, 2021; Zhang et al., 2020). For each effect, the overall null hypothesis that the effect was 0 in all schools was tested using Fisher's combination of one-sided tests procedure with two one-sided tests (Fisher, 1925; Hedges and Olkin, 1985). To control for multiple (left and right) testing, there was deemed to be sufficient evidence for a significant effect if a one-sided test produced a p-value of $p \leq 0.005$. The null hypothesis that the effect parameter estimates are constant across schools ("heterogeneity across schools" test) was tested using the methods of Cochran (1954), adapted for social network analysis by Snijders and Baerveldt (Cochran, 1954; Snijders and Baerveldt, 2003). A p-value ≤ 0.01 indicated significant differences across schools.

For each outcome, meta-analyses were repeated for subgroups of schools, and the null hypothesis that effect parameter estimates are constant across subgroups ("heterogeneity across subgroups" test for NI versus Bogotá, and ASSIST versus Dead Cool), was tested using methods described in the Cochrane Handbook (Higgins and Thomas, 2022). A p-value ≤ 0.01 indicated significant differences across subgroups. For the peer selection and peer influence effects, we have also highlighted which results would have attained statistical significance after using the Holm–Bonferroni procedure to adjust the p-values for multiple testing ($p \leq 0.025$ for Fisher's tests, $p \leq 0.05$ for heterogeneity tests across schools or subgroups) (Holm, 1979).

The relative contribution of peer selection effects, peer influence effects, and control or alternative explaining mechanisms, to similarities in each of the smoking/vaping outcomes between friends was calculated based on the decomposition of the mean Moran's I statistic from networks simulated under different model specifications in each school: (1) including both peer selection and peer influence effects ("Full"); (2) excluding peer selection effects ("Excluding PS"); (3) excluding peer influence effects ("Excluding PI"), and; (4) excluding peer selection and peer influence effects ("Excluding PS and PI"). For each model specification, 500 networks were simulated from the SIENA model results on the observed networks in each school (24,000 simulated networks in total for outcomes with all 12 schools included). Moran's I is a spatial autocorrelation coefficient measuring the similarity of individuals linked in a network on variables of interest (Cliff and Ord, 1981; Moran, 1950). The percentage of network autocorrelation attributable to peer selection, peer influence, undetermined (either peer selection or peer influence, but not able to distinguish which), and control (or alternative explaining mechanisms), was calculated by comparing the average Moran's I across the simulated networks in each school under model specifications (1)–(4). Violin plots were used to plot the distributions of Moran's I statistics from the simulated networks in each school under each model specification (1)–(4), and stacked bar charts were used to show the relative contribution of peer selection effects, peer influence effects, and control (or alternative explaining mechanisms) to similarities between friends for each of the smoking/vaping outcomes. Further information on the statistical terms and methods used in the SIENA models is available in the 'Glossary' subsection of the Supplementary Methods.

Results

Descriptive statistics and distributions of variables are shown in Table 1, Supplementary Figs. S3–S49, and Supplementary Table S3). Baseline network graphs and statistics for friendship networks collected in each school at baseline and follow-up are shown in Figs. 2 and 3, and Table 3. Supplementary Figs. S50–S73 show network graphs at baseline and follow-up for each school. Supplementary Table S4 shows Moran's I statistics for each of the smoking/vaping outcomes calculated from the observed networks in each school at baseline and follow-up. Supplementary Table S5 shows descriptive statistics for average friend response variables. Throughout the results section, results are reported for models showing significant associations ($p \leq 0.01$). Throughout the results tables and supplementary tables, we have also highlighted which results would have attained statistical significance ($p \leq 0.05$) after using the Holm–Bonferroni procedure to adjust the p-values for multiple testing (Holm, 1979).

Objective 1: Selection homophily effects estimated using mixed-effects logistic regressions. Mixed-effects logistic regressions examining selection homophily effects are reported in Table 4. Throughout the following paragraphs, ORs are reported for models including the comparable re-scaled predictor variables (0–10).

Predictors of friendship nominations at baseline. The odds of a friendship nomination at baseline were significantly reduced with a one-unit increase in absolute difference between the focal participant and a potential friend for the following outcomes at baseline: experimentally measured injunctive norms P2S7, P2S8, and the experimental injunctive norms scale (average of P2S2–P2S9); experimentally measured descriptive norms P3Q1, P3Q2, and the experimental descriptive norms scale (average of P3Q1–P3Q2); donations to ASSIST/Dead Cool; self-report injunctive norms IN2, IN3, IN5–IN7, and the self-report injunctive norms scale (average of IN1–IN7); self-report descriptive norms DN1.1–DN1.3, DN2.1, DN2.3, and the self-report descriptive norms scales 1 and 2 (averages of DN1.1–DN1.5 and DN2.1–DN2.3 respectively); self-report smoking behavior, intentions, attitudes, self-efficacy (emotional, friends, opportunity), perceived risks (physical and social), perceived behavioral control (easy to quit); and objectively measured smoking behavior [ORs = 0.87–0.99, $p \leq 0.003$]. The odds of a friendship nomination at baseline were significantly increased if the focal participant and potential friend had matching susceptibility statuses at baseline [OR = 1.20, $p < 0.001$].

Baseline predictors for adding friends between baseline and follow-up. The odds of adding a potential friend between baseline and

Table 2 Effects included in SIENA models for modeling the co-evolution of friendship ties and smoking/vaping outcomes.

Effects		**Description**
Friendship network evolution		
Constant friendship rate (period 1)	Rate effect.	A constant term representing the dependence of friendship nominations on the period (i.e., the rate of changing friendship ties in period 1).
Smoking/vaping outcome alter[a]	Peer selection effects	The sum of the smoking/vaping outcome over all actors to whom ego is tied. Represents the association between the smoking/vaping outcome level and the tendency to be nominated as a friend.
Smoking/vaping outcome squared alter[a,b]		The sum of the squared (centered) smoking/vaping outcome over all actors to whom ego is tied. Represents the marginal association between the smoking/vaping outcome level and the tendency to be nominated, controlling for the previous effect.
Smoking/vaping outcome ego[a]		Ego's outdegree (number of friendship nominations) weighted by his/her value of the smoking/vaping outcome. Represents the association between the smoking/vaping outcome level and the tendency to nominate friends.
Smoking/vaping outcome similarity (peer selection homophily)[a]		**The sum of centered similarity scores on the smoking/vaping outcome between ego and the other actors to whom ego is tied (higher similarity scores indicate greater similarity between ego and the actors to whom ego is tied). Represents the tendency to select a friend based on similarity on the smoking/vaping outcome**.
Outdegree (density)	Control effects	Ego's out-degree (number of friendship nominations). Represents the general tendency to nominate friends (i.e., the density of the network).
Reciprocity		The number of ego's reciprocated ties. Represents the tendency to return friendship nominations.
Transitive ties		The number of actors to whom ego is directly as well as indirectly tied. Represents the tendency to select a friend who is already friends with one of an adolescent's other friends.
Transitive triplets		The number of transitive patterns in ego's relations (i.e., ordered pairs of actors, both of whom are tied to ego, and also tied to each other). Represents the tendency to select further friends of friends in addition to the first such friend, which is represented by the previous "transitive ties" effect.
Number of actors at distance 2		The number of actors to whom ego is indirectly tied, through at least one intermediary. Represents the tendency to be indirectly (through one of your friends) instead of directly connected to others.
Three-cycles		Ego's number of three cycles. Represents a generalized form of reciprocity, or the tendency to stay indirectly tied to other actors within a closed triad (actor 'a' nominates actor 'b', actor 'b' nominates actor 'c', actor 'c' nominates actor 'a'). A significant negative "Three-cycles" effect, in addition to positive "Transitive ties" or "Transitive triplets" effects, may be interpreted as a tendency towards local hierarchy within the network.
Gender alter		Tendency for girls/PNTS to be selected as friends more often compared to boys.
Gender ego		Tendency for girls/PNTS to select more friends compared to boys.
Gender similarity		Tendency to select a friend based on similar gender.
Age alter		Tendency for older pupils to be selected as friends more often compared to younger pupils.
Age ego		Tendency for older pupils to select more friends compared to younger pupils.
Age similarity		Tendency to select a friend based on similar age.
SES alter[c]		Tendency for pupils with higher SES to be selected as friends more often compared to pupils with lower SES.
SES ego[c]		Tendency for pupils with higher SES to select more friends compared to pupils with lower SES.
SES similarity[c]		Tendency to select a friend based on similar SES.
School class similarity		The number of ties ego has to all other actors in the same school class. Represents the tendency to nominate a friend based on being in the same school class.
Smoking/vaping outcome evolution		
Rate smoking/vaping outcome (period 1)	Rate effect.	A constant term representing the dependence of the level of smoking/vaping outcome on the period (i.e., the tendency for individuals to change their values of the smoking/vaping outcome in period 1).
Smoking/vaping outcome friends (peer influence)[a]	Peer influence effects.	**Average similarity effect. The average of centered similarity scores on the smoking/vaping outcome between ego and the other actors to whom ego is tied (higher similarity scores indicate greater similarity between ego and the actors to whom ego is tied). Represents the tendency for ego to change his/her value of the smoking/vaping outcome to become similar to current friends**.
Linear shape	Control effects.	Ego's value of the smoking/vaping outcome. Represents the general trend of the smoking/vaping outcome variable.
Quadratic shape[b]		Ego's squared value of the smoking/vaping outcome. Represents the effect of the smoking/vaping outcome on itself, controlling for the previous effect (where the attractiveness of further increases/decreases in the smoking/vaping outcome depends on the actor's current value of the outcome).

Table 2 (continued)

Effects	Description
Effect from ego's gender	Effect of ego's gender on ego's own value of the smoking/vaping outcome (higher values indicate girls/PNTS tend to have higher values of the smoking/vaping outcome compared to boys).
Effect from ego's age	Effect of ego's age on ego's own value of the smoking/vaping outcome (higher values indicate older pupils tend to have higher values of the smoking/vaping outcome compared to younger pupils).
Effect from ego's SES[c]	Effect of ego's SES on ego's own value of the smoking/vaping outcome (higher values indicate pupils with higher SES tend to have higher values of the smoking/vaping outcome compared to pupils with lower SES).

PNTS prefer not to say, *SES* socio-economic status, *SIENA* simulation investigation for empirical network analysis.
[a]Smoking/vaping outcomes examined in SIENA models are experimental injunctive norms scale, experimental descriptive norms scale, experimental donation to ASSIST/Dead Cool, self-report injunctive norms scale, self-report descriptive norms scale 1, self-report descriptive norms scale 2, self-report smoking behavior, intentions, knowledge, attitudes, self-efficacy (emotional, friends, and opportunity subscales), perceived risks (physical, social, and addiction subscales), perceived benefits, perceived behavioral control (easy to quit), perceived behavioral control (to avoid smoking), objectively measured smoking behavior, and smoking susceptibility (see details in Supplementary Table S2).
[b]The "Smoking/vaping outcome squared alter" and "Quadratic shape" effects are not included for the outcome "Smoking susceptibility" (which is a binary outcome variable), as these effects are only relevant for outcomes with three or more categories (Ripley et al., 2022; p. 51).
[c]SES effects are not included for school 3 (all actors in the network had the same value of the SES covariate).
The rows highlighted in bold indicate the main "peer selection homophily" and "peer influence" effects.

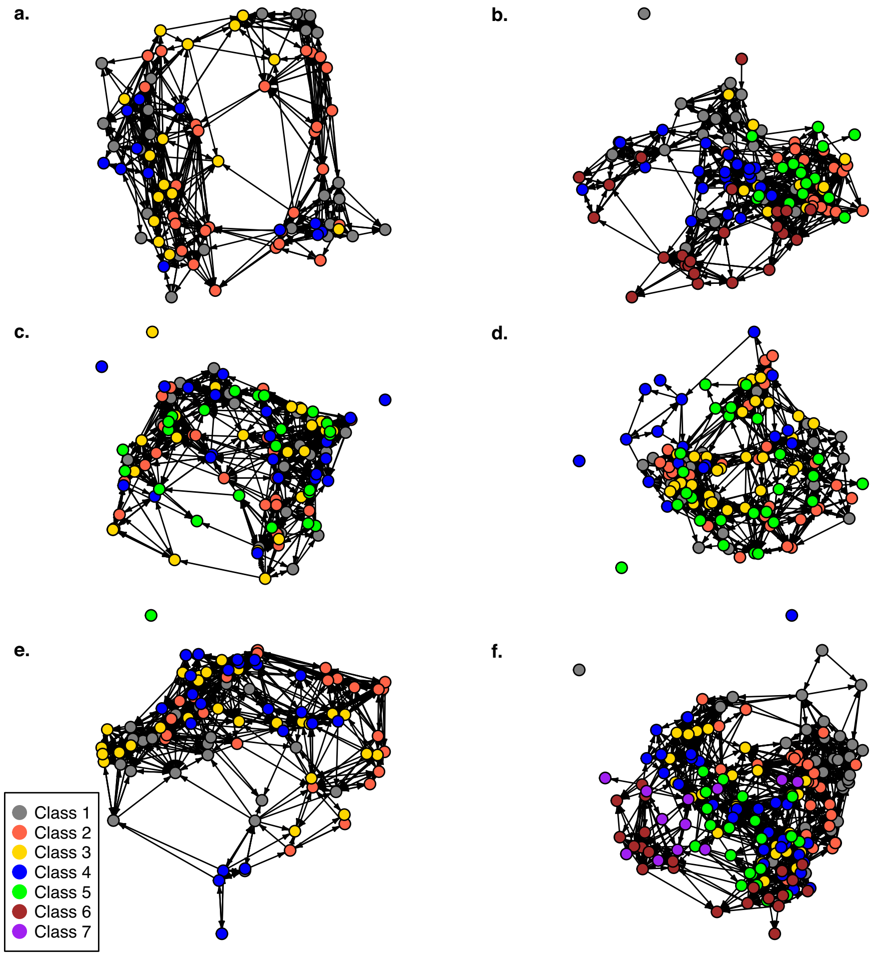

Fig. 2 Baseline friendship networks for Northern Ireland schools. Note: different colored nodes indicate different school classes. **a** School 1 (Northern Ireland Dead Cool school). **b** School 2 (Northern Ireland ASSIST school). **c** School 3 (Northern Ireland Dead Cool school). **d** School 4 (Northern Ireland ASSIST school). **e** School 5 (Northern Ireland Dead Cool school). **f** School 6 (Northern Ireland ASSIST school).

follow-up were significantly reduced with a one-unit increase in absolute difference between the focal participant and a potential friend for the following outcomes at baseline: experimentally measured injunctive norms P2S2, P2S7, P2S8, and the experimental injunctive norms scale (average of P2S2–P2S9); donations to ASSIST/Dead Cool; perceived physical risks; and objectively measured smoking behavior [ORs = 0.90–0.97, $p \leq 0.01$]. The odds of adding a potential friend between baseline and follow-up were significantly increased if the focal participant and potential friend had matching susceptibility statuses at baseline [OR = 1.16, $p = 0.001$].

Follow-up predictors for adding friends between baseline and follow-up. The odds of adding a potential friend between baseline

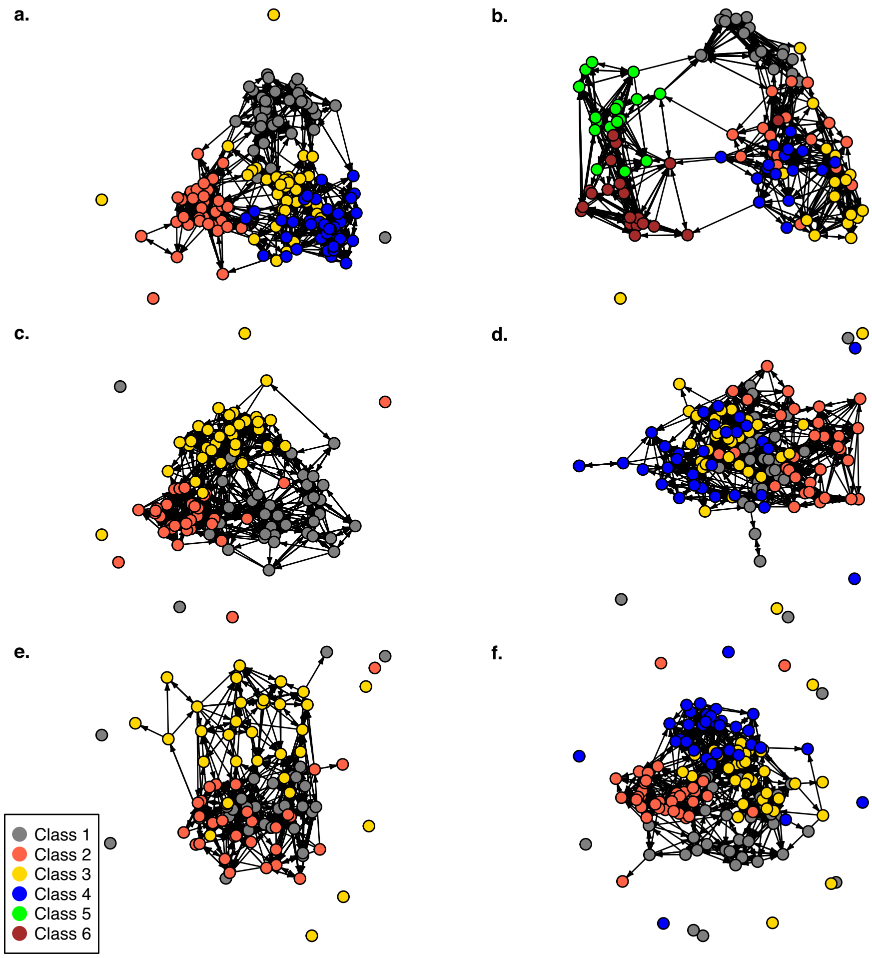

Fig. 3 Baseline friendship networks for Bogotá schools. Note: Different colored nodes indicate different school classes. **a** School 7 (Bogotá ASSIST school). **b** School 8 (Bogotá Dead Cool school). **c** School 9 (Bogotá Dead Cool school). **d** School 10 (Bogotá ASSIST school). **e** School 11 (Bogotá ASSIST school). **f** School 12 (Bogotá Dead Cool school).

and follow-up were significantly reduced with a one-unit increase in absolute difference between the focal participant and a potential friend for experimentally measured injunctive norm P2S8 at follow-up [$OR = 0.96$, $p = 0.001$], and significantly increased if the focal participant and potential friend had matching susceptibility statuses at follow-up [$OR = 1.26$, $p < 0.001$].

Baseline predictors for dropping friends between baseline and follow-up. The odds of dropping a baseline friend at follow-up were significantly increased with a one-unit increase in an absolute difference between the focal participant and the friend for the following outcomes at baseline: self-report injunctive norms IN3, IN6, IN7, and the self-report injunctive norms scale (average of IN1–IN7); self-report descriptive norms DN1.1, DN1.5, DN2.1, and the self-report descriptive norms scale 2 (average of DN2.1–DN2.3); self-report smoking behavior, self-efficacy (emotional, friends, opportunity), and perceived social risks [$ORs = 1.04–1.10$, $p \leq 0.004$].

Follow-up predictors for dropping friends between baseline and follow-up. The odds of dropping a baseline friend at follow-up were significantly increased with a one-unit increase in absolute difference between the focal participant and the friend for the following outcomes at follow-up: experimentally measured injunctive norm P2S7; experimentally measured descriptive norms P3Q1, P3Q2, and the experimental descriptive norms scale (average of P3Q1–P3Q2); self-report injunctive norms IN3, IN6, IN7, and the self-report injunctive norms scale (average of IN1–IN7); self-report descriptive norms DN1.1, and DN2.1; self-report smoking behavior, intentions, attitudes, self-efficacy (emotional, friends, opportunity), perceived social risks; and objectively measured smoking behavior [$ORs = 1.03–1.19$, $p \leq 0.007$].

Objective 2: Peer influence effects estimated using ordinary least square regressions. Peer influence effects are reported in Table 5. Throughout the following paragraphs, the word "friends" in parentheses denotes an influence effect from the average responses of the focal participant's friendship network, "class" denotes an influence effect from the average responses of the focal participant's school class, and "year" denotes an influence effect from the average responses of the focal participant's school year group. References to 'positive' influence effects mean that focal participant outcomes were positively associated with the outcomes of friends, school classes, or school year groups, and not necessarily that outcomes were changing in a more favorable (anti-smoking) direction. Throughout the following paragraphs, standardized regression coefficients (β) are reported.

Peer influence effects from average baseline responses of friends, school classes, and school year groups. There were positive influence effects from average baseline responses for the following

Table 3 School friendship networks descriptive statistics.

Setting	School	Year group size (nodes)	Time-point[a]	Participants with identifiable nominations	Edges	Mean (SD) nominations[b]	Network density[c]	Dyadic reciprocity[d]	Edgewise reciprocity[d]	Number of reciprocated ties[d]	Total number of transitive ties[e]	Mean (SD) number of transitive ties[e]	Transitivity[f]	Transitive triplets[f]	Mean (SD) number of actors at distance 2[g]	Mean (SD) proportion of network at distance 2[g]	Three-cycles[h]	Jaccard index[i]
NI	1	83	Base	73	537	7.36 (2.40)	0.079	0.45	0.62	167	536	6.00 (3.15)	0.45	1513	14 (8)	0.17 (0.10)	430	0.4435
			FU	70	524	7.49 (2.64)	0.077	0.40	0.58	151	524	5.82 (3.62)	0.40	1300	15 (9)	0.18 (0.11)	318	
	2	120	Base	105	849	8.09 (2.53)	0.059	0.40	0.57	243	838	6.41 (3.60)	0.42	2656	17 (11)	0.15 (0.09)	722	0.4033
			FU	95	755	7.95 (2.49)	0.053	0.38	0.55	208	745	5.51 (3.75)	0.43	2269	15 (10)	0.13 (0.09)	575	
	3	115	Base	101	851	8.43 (2.32)	0.065	0.41	0.58	247	848	6.63 (3.54)	0.44	2825	18 (11)	0.16 (0.10)	748	0.4556
			FU	88	756	8.59 (1.88)	0.058	0.41	0.58	218	750	5.97 (3.77)	0.45	2316	15 (11)	0.13 (0.10)	599	
	4	125	Base	102	787	7.72 (2.57)	0.051	0.35	0.52	205	779	5.58 (3.77)	0.37	2015	17 (10)	0.13 (0.08)	494	0.3996
			FU	98	740	7.55 (2.60)	0.048	0.31	0.47	173	732	5.10 (3.69)	0.34	1575	16 (12)	0.13 (0.10)	322	
	5	97	Base	85	706	8.31 (2.41)	0.076	0.41	0.58	204	702	6.72 (3.45)	0.44	2192	18 (10)	0.19 (0.11)	550	0.5552
			FU	93	787	8.46 (2.20)	0.085	0.45	0.62	243	782	7.67 (2.79)	0.45	2876	20 (10)	0.21 (0.10)	796	
	6	178	Base	157	1230	7.83 (2.42)	0.039	0.41	0.58	355	1224	6.09 (3.33)	0.38	3376	20 (12)	0.11 (0.07)	939	0.4173
			FU	140	1015	7.25 (2.63)	0.032	0.32	0.49	247	998	4.84 (3.57)	0.41	2293	13 (10)	0.08 (0.06)	470	
Bogotá	7	148	Base	135	957	7.09 (2.71)	0.044	0.32	0.48	232	950	5.56 (3.27)	0.38	2366	17 (9)	0.11 (0.06)	559	0.3433
			FU	133	796	5.98 (2.62)	0.037	0.41	0.58	232	787	4.51 (3.04)	0.40	1770	13 (8)	0.09 (0.05)	504	
	8	107	Base	103	703	6.83 (2.68)	0.062	0.38	0.55	193	698	5.76 (3.01)	0.39	1757	16 (7)	0.15 (0.06)	465	0.4238
			FU	100	651	6.51 (2.57)	0.057	0.41	0.58	190	645	5.33 (3.03)	0.37	1510	15 (7)	0.14 (0.07)	423	
	9	106	Base	97	743	7.66 (2.71)	0.067	0.34	0.51	190	741	6.09 (3.28)	0.31	1624	23 (10)	0.22 (0.10)	420	0.4108
			FU	95	641	6.75 (2.84)	0.058	0.34	0.51	163	639	5.09 (3.26)	0.33	1289	17 (10)	0.16 (0.10)	341	
	10	133	Base	120	828	6.90 (2.50)	0.047	0.38	0.55	227	821	5.20 (2.91)	0.33	1820	19 (12)	0.14 (0.09)	498	0.327
			FU	119	775	6.51 (2.50)	0.044	0.40	0.57	221	768	4.98 (3.02)	0.37	1746	16 (10)	0.12 (0.08)	473	
	11	92	Base	75	473	6.31 (2.80)	0.056	0.35	0.52	122	463	4.32 (3.17)	0.36	991	13 (9)	0.14 (0.10)	255	0.2623
			FU	63	374	5.94 (2.80)	0.045	0.40	0.57	107	367	3.36 (3.12)	0.46	859	8 (8)	0.09 (0.09)	218	
	12	140	Base	108	739	6.84 (2.69)	0.038	0.31	0.48	177	731	4.22 (3.44)	0.32	1416	16 (12)	0.12 (0.08)	348	0.3772
			FU	103	590	5.73 (2.42)	0.030	0.33	0.49	146	584	3.34 (2.95)	0.33	939	11 (9)	0.08 (0.06)	233	

NI Northern Ireland, *SD* standard deviation.

[a]Base: baseline; FU: follow-up.

[b]Mean (SD) friendship nominations based on pupils who provided at least one identifiable friend nomination. There were 1266 participants who nominated at least one friend at baseline (5 had no identifiable nominations), and 1200 who nominated at least one friend at follow-up (3 had no identifiable nominations). There were 9538 friendship nominations at baseline (9403 [98.6%] were identifiable) and 8476 friendship nominations at follow-up (8404 [99.2%] were identifiable). At baseline 6473/9403 (68.8%) nominations were of friends from the same school class. At follow-up 5692/8404 (67.7%) nominations were of friends from the same school class. At baseline, 5124/9403 (54.5%) identifiable friend nominations were reciprocated (follow-up: $n = 4598/8404$ [54.7%]). On average, participants made 7.5 identifiable friend nominations at baseline, and 7.0 at follow-up (based on participants providing at least one identifiable friend nomination). The average school class size was 28.3 with a standard deviation (SD) of 6.8 (NI: mean = 24.5, SD = 5.0; Bogotá: mean = 32.1, SD = 6.2). The average school year group size was 125.7 with an SD of 26.7 (NI: mean = 127.1, SD = 32.0; Bogotá: mean = 124.4, SD = 20.0). Each network had one component.

[c]The ratio of observed edges to the total number of possible edges.

[d]In directed networks, reciprocity occurs when an actor receives a tie from another actor, and sends a tie back to the same actor. Dyadic reciprocity refers to the proportion of dyads that are symmetric (i.e., the ratio of mutuals to non-null dyads). Edgewise reciprocity refers to the proportion of edges in the network that are reciprocated. The number of reciprocated ties in the network is calculated as 0.5*(Edgewise reciprocity)*(Number of edges in the network).

[e]The total number of transitive ties refers to the number of edges where there is a direct (friendship nomination) as well as an indirect connection (through a mutual friend). The mean (SD) number of transitive ties is based on the total number of nodes in the network.

[f]Transitivity is the ratio of transitive triads to (transitive plus intransitive triads). Transitive triplets refer to the total number of transitive triads in the network. A transitive triad occurs when if actor 'a' is connected to actor 'b' and actor 'b' is connected to actor 'c', then actor 'a' is connected to actor 'c'. The Transitivity and Transitive triplets statistics account for 'weak-form' transitivity (i.e., actor 'a' nominates actor 'b', actor 'b' nominates actor 'c', and actor 'a' nominates actor 'c').

[g]Mean (SD) number of actors tied to each node through at least one intermediary (i.e., number of actors at geodesic distance 2), and mean (SD) proportion of the network tied to each node through at least one intermediary. Calculated based on directed networks.

[h]Total number of three-cycles in the network (i.e., closed triads in which actor 'a' nominates actor 'b', actor 'b' nominates actor 'c', and actor 'c' nominates actor 'a').

[i]Jaccard similarity index measures the degree of similarity between the friendship networks at baseline and follow-up in each school. It is computed for each school as: (the number of edges that are common to the baseline and follow-up network)/(the total number of edges in at least one of the networks [baseline or follow-up]). Range: 0 (completely dissimilar) to 1 (completely similar).

Table 4 Results of mixed-effects logistic regressions investigating selection homophily effects: (1) for friendship nominations at baseline; (2) for adding friends between baseline and follow-up; or (3) for dropping friends between baseline and follow-up.

Outcomes	Time-point	(1) Baseline friend nominations					(2) Adding friends from the school year group					(3) Dropping friends from the school year group				
		Original scale			Re-scaled (0–10)	ICC[c]	Original scale			Re-scaled (0–10)	ICC[c]	Original scale			Re-scaled (0–10)	ICC[c]
		n	OR (SE)[a]	*p*-value	OR (SE)[b]		*n*	OR (SE)[a]	*p*-value	OR (SE)[b]		n	OR (SE)[a]	*p*-value	OR (SE)[b]	
Experiment Part 2: Injunctive norms for smoking/vaping (−1 = "extremely socially inappropriate" to +1 = "extremely socially appropriate").																
P2S2	*t* = base	106,804	0.99 (0.04)	0.78	0.998 (0.008)	0.015	99,869	**0.81 (0.07)**	**0.01**	**0.96 (0.02)**	**0.081**	6935	0.78 (0.08)	0.02	0.95 (0.02)	0.140
	t = fu						100,298	0.91 (0.06)	0.20	0.98 (0.01)	0.079	6858	0.86 (0.08)	0.10	0.97 (0.02)	0.130
P2S3	*t* = base	106,644	0.98 (0.04)	0.55	0.995 (0.008)	0.015	99,723	0.93 (0.06)	0.29	0.99 (0.01)	0.083	6921	1.04 (0.09)	0.68	1.007 (0.02)	0.142
	t = fu						100,455	1.04 (0.07)	0.52	1.009 (0.01)	0.080	6865	1.12 (0.10)	0.21	1.02 (0.02)	0.132
P2S4	*t* = base	106,804	0.99 (0.03)	0.77	0.998 (0.006)	0.015	99,869	0.94 (0.05)	0.30	0.99 (0.01)	0.082	6935	1.01 (0.07)	0.89	1.002 (0.01)	0.142
	t = fu						100,087	0.96 (0.06)	0.51	0.99 (0.01)	0.080	6847	1.14 (0.09)	0.12	1.03 (0.02)	0.130
P2S5	*t* = base	106,804	0.94 (0.03)	0.07	0.99 (0.007)	0.015	99,869	0.90 (0.06)	0.08	0.98 (0.01)	0.082	6935	1.17 (0.08)	0.04	1.03 (0.02)	0.142
	t = fu						100,455	0.94 (0.06)	0.32	0.99 (0.01)	0.080	6865	1.19 (0.09)	0.02	1.04 (0.02)	0.132
P2S6	*t* = base	106,478	0.92 (0.03)	0.02	0.98 (0.007)	0.015	99,578	0.93 (0.05)	0.20	0.99 (0.01)	0.083	6900	0.88 (0.06)	0.07	0.97 (0.01)	0.145
	t = fu						100,061	0.94 (0.06)	0.30	0.99 (0.01)	0.081	6847	0.999 (0.07)	0.99	0.9998 (0.01)	0.132
P2S7	*t* = base	106,804	**0.81 (0.03)**	**<0.001[f]**	**0.96 (0.007)**	**0.015**	99,869	**0.84 (0.05)**	**0.004**	**0.97 (0.01)**	**0.082**	6935	0.98 (0.07)	0.75	0.995 (0.01)	0.142
	t = fu						100,298	0.94 (0.06)	0.30	0.99 (0.01)	0.080	6858	**1.31 (0.10)**	**0.001**	**1.06 (0.02)**	**0.129**
P2S8	*t* = base	106,804	**0.82 (0.03)**	**<0.001[f]**	**0.96 (0.007)**	**0.015**	99,869	**0.73 (0.05)**	**<0.001[f]**	**0.94 (0.01)**	**0.082**	6935	1.01 (0.08)	0.89	1.002 (0.02)	0.142
	t = fu						100,455	**0.82 (0.05)**	**0.001**	**0.96 (0.01)**	**0.080**	6865	0.97 (0.08)	0.74	0.99 (0.02)	0.132
P2S9	*t* = base	106,804	0.92 (0.04)	0.04	0.98 (0.008)	0.015	99,869	0.89 (0.06)	0.05	0.98 (0.01)	0.082	6935	0.95 (0.08)	0.56	0.99 (0.02)	0.142
	t = fu						100,298	0.90 (0.06)	0.14	0.98 (0.01)	0.080	6858	1.16 (0.10)	0.08	1.03 (0.02)	0.134
Experimental injunctive norms scale (average P2S2–P2S9)	*t* = base	106,318	**0.80 (0.05)**	**0.001**	**0.96 (0.01)**	**0.015**	99,432	**0.66 (0.08)**	**0.001**	**0.92 (0.02)**	**0.082**	6886	0.95 (0.13)	0.71	0.99 (0.03)	0.144
	t = fu						99,387	0.82 (0.09)	0.06	0.96 (0.02)	0.079	6815	1.32 (0.19)	0.05	1.06 (0.03)	0.131
Experiment Part 3: Descriptive norms for smoking/vaping (−1 = "none of my peers" to +1 = "all of my peers").																
P3Q1	*t* = base	106,804	**0.84 (0.03)**	**<0.001[f]**	**0.97 (0.006)**	**0.014**	99,869	0.89 (0.04)	0.03	0.98 (0.01)	0.081	6935	1.06 (0.07)	0.35	1.01 (0.01)	0.143
	t = fu						100,455	0.96 (0.04)	0.34	0.99 (0.009)	0.080	6865	**1.20 (0.07)**	**0.002**	**1.04 (0.01)**	**0.132**
P3Q2	*t* = base	106,644	**0.85 (0.02)**	**<0.001[f]**	**0.97 (0.006)**	**0.014**	99,712	0.98 (0.05)	0.69	0.996 (0.009)	0.082	6932	1.02 (0.06)	0.75	1.004 (0.01)	0.143
	t = fu						100,455	0.93 (0.04)	0.11	0.99 (0.009)	0.080	6865	**1.19 (0.07)**	**0.003**	**1.04 (0.01)**	**0.133**
Experimental descriptive norms scale (average P3Q1–P3Q2)	*t* = base	106,644	**0.82 (0.03)**	**<0.001[f]**	**0.96 (0.007)**	**0.014**	99,712	0.94 (0.05)	0.25	0.99 (0.01)	0.081	6932	0.99 (0.07)	0.87	0.998 (0.01)	0.142
	t = fu						100,455	0.93 (0.05)	0.17	0.99 (0.01)	0.080	6865	**1.18 (0.08)**	**0.009**	**1.03 (0.01)**	**0.133**
Experiment Part 4: Willingness to pay to support anti-smoking norms (Donations to ASSIST/Dead Cool; 0 = "0 tokens donated" to 10 = "10 tokens donated")																
Donation to ASSIST/ Dead Cool	*t* = base	106,640	**0.97 (0.006)**	**<0.001[f]**	**0.97 (0.006)**	**0.016**	99,718	**0.97 (0.009)**	**0.006**	**0.97 (0.009)**	**0.083**	6922	0.999 (0.01)	0.91	0.999 (0.01)	0.143
	t = fu						100,218	0.98 (0.01)	0.03	0.98 (0.01)	0.080	6854	1.02 (0.01)	0.15	1.02 (0.01)	0.131
Self-report injunctive smoking norms (−2 = "think(s) that I definitely should smoke" to +2 = "think(s) that I definitely should not smoke").																
IN1	*t* = base	113,380	0.96 (0.02)	0.02	0.98 (0.007)	0.017	106,099	1.0009 (0.03)	0.98	1.0004 (0.01)	0.082	7281	1.06 (0.04)	0.11	1.02 (0.01)	0.139
	t = fu						105,871	0.998 (0.02)	0.92	0.999 (0.01)	0.081	7263	1.06 (0.03)	0.06	1.02 (0.01)	0.135
IN2	*t* = base	113,642	**0.92 (0.02)**	**0.001**	**0.97 (0.01)**	**0.017**	106,348	1.04 (0.05)	0.34	1.02 (0.02)	0.081	7294	1.07 (0.06)	0.28	1.03 (0.02)	0.139
	t = fu						105,952	0.99 (0.04)	0.75	0.995 (0.01)	0.080	7276	1.10 (0.05)	0.04	1.04 (0.02)	0.133
IN3	*t* = base	113,320	**0.94 (0.01)**	**<0.001[f]**	**0.98 (0.006)**	**0.016**	106,056	0.995 (0.03)	0.86	0.998 (0.01)	0.081	7264	**1.13 (0.04)**	**0.001**	**1.05 (0.01)**	**0.134**
	t = fu						105,786	1.01 (0.02)	0.54	1.006 (0.01)	0.080	7266	**1.09 (0.03)**	**0.007**	**1.03 (0.01)**	**0.134**
IN4	*t* = base	113,044	0.97 (0.01)	0.05	0.99 (0.005)	0.017	105,786	1.008 (0.02)	0.72	1.003 (0.009)	0.082	7258	1.04 (0.03)	0.23	1.01 (0.01)	0.140
	t = fu						105,786	0.996 (0.02)	0.87	0.998 (0.009)	0.081	7266	1.06 (0.03)	0.04	1.02 (0.01)	0.136
IN5	*t* = base	113,218	**0.95 (0.01)**	**<0.001[f]**	**0.98 (0.005)**	**0.016**	105,953	0.97 (0.02)	0.19	0.99 (0.009)	0.083	7265	1.03 (0.03)	0.33	1.01 (0.01)	0.140
	t = fu						105,786	0.99 (0.02)	0.66	0.996 (0.009)	0.080	7266	1.02 (0.03)	0.58	1.006 (0.01)	0.136
IN6	*t* = base	113,480	**0.92 (0.01)**	**<0.001[f]**	**0.97 (0.006)**	**0.016**	106,205	0.96 (0.02)	0.07	0.98 (0.009)	0.082	7275	**1.12 (0.03)**	**<0.001[f]**	**1.05 (0.01)**	**0.136**
	t = fu						105,786	0.98 (0.02)	0.49	0.99 (0.009)	0.081	7266	**1.14 (0.04)**	**<0.001[f]**	**1.05 (0.01)**	**0.131**
IN7	*t* = base	113,480	**0.94 (0.01)**	**<0.001[f]**	**0.98 (0.006)**	**0.017**	106,205	0.97 (0.02)	0.24	0.99 (0.009)	0.082	7275	**1.17 (0.03)**	**<0.001[f]**	**1.07 (0.01)**	**0.135**
	t = fu						105,952	0.97 (0.02)	0.17	0.99 (0.009)	0.080	7276	**1.15 (0.03)**	**<0.001[f]**	**1.06 (0.01)**	**0.130**

Table 4 (continued)

Outcomes	Time-point	(1) Baseline friend nominations					(2) Adding friends from the school year group					(3) Dropping friends from the school year group				
		Original scale			Re-scaled (0–10)	ICC[c]	Original scale			Re-scaled (0–10)	ICC[c]	Original scale			Re-scaled (0–10)	ICC[c]
		n	OR (SE)[a]	*p*-value	OR (SE)[b]		*n*	OR (SE)[a]	*p*-value	OR (SE)[b]		n	OR (SE)[a]	*p*-value	OR (SE)[b]	
Self-report injunctive norms scale (average IN1–IN7)	*t* = base	113,480	**0.94 (0.01)**	**<0.001[f]**	**0.94 (0.01)**	**0.016**	105,390	0.997 (0.05)	0.95	0.999 (0.02)	0.082	7234	**1.25 (0.08)**	**<0.001[f]**	**1.09 (0.03)**	**0.135**
	t = fu						105,622	0.99 (0.04)	0.86	0.997 (0.02)	0.081	7254	**1.21 (0.07)**	**0.001**	**1.08 (0.02)**	**0.133**
Self-report descriptive smoking norms (DN1: 1 = "smoke(s) very often" to 5 = "never smoke(s)"/"don't know"; DN2: 1 = "almost all of them smoke" to 5 = "almost none of them smoke"/"don't know").																
DN1.1	*t* = base	113,544	**0.94 (0.02)**	**<0.001[f]**	**0.97 (0.007)**	**0.016**	106,253	0.98 (0.02)	0.41	0.99 (0.01)	0.081	7291	**1.21 (0.05)**	**<0.001[f]**	**1.08 (0.02)**	**0.135**
	t = fu						106,201	0.98 (0.02)	0.30	0.99 (0.009)	0.080	7285	**1.18 (0.04)**	**<0.001[f]**	**1.07 (0.01)**	**0.136**
DN1.2	*t* = base	113,806	**0.96 (0.01)**	**<0.001**	**0.98 (0.004)**	**0.017**	106,505	0.97 (0.02)	0.09	0.99 (0.007)	0.081	7301	1.009 (0.02)	0.67	1.004 (0.009)	0.140
	t = fu						106,201	1.001 (0.02)	0.96	1.0004 (0.007)	0.081	7285	1.02 (0.02)	0.47	1.01 (0.01)	0.135
DN1.3	*t* = base	113,642	**0.97 (0.009)**	**0.001**	**0.99 (0.004)**	**0.017**	106354	1.006 (0.02)	0.72	1.002 (0.006)	0.081	7288	0.98 (0.02)	0.37	0.99 (0.008)	0.140
	t = fu						106,201	1.004 (0.02)	0.80	1.002 (0.006)	0.081	7285	1.002 (0.02)	0.94	1.0007 (0.008)	0.135
DN1.4	*t* = base	113,544	0.99 (0.01)	0.40	0.996 (0.005)	0.017	106,253	0.99 (0.02)	0.67	0.996 (0.009)	0.082	7291	1.03 (0.03)	0.36	1.01 (0.01)	0.139
	t = fu						106,201	0.98 (0.02)	0.38	0.99 (0.008)	0.080	7285	1.02 (0.03)	0.40	1.008 (0.01)	0.135
DN1.5	*t* = base	113,544	0.995 (0.01)	0.73	0.998 (0.005)	0.017	106,253	1.02 (0.02)	0.41	1.008 (0.01)	0.082	7291	**1.09 (0.03)**	**0.004**	**1.04 (0.01)**	**0.138**
	t = fu						106,201	1.02 (0.02)	0.38	1.008 (0.009)	0.080	7285	1.06 (0.04)	0.07	1.02 (0.01)	0.134
Self-report descriptive norms scale 1 (average DN1.1–DN1.5)	*t* = base	113,120	**0.86 (0.02)**	**<0.001[f]**	**0.94 (0.009)**	**0.017**	105,852	0.92 (0.04)	0.03	0.97 (0.02)	0.081	7268	1.08 (0.06)	0.14	1.03 (0.02)	0.138
	t = fu						106,201	0.98 (0.03)	0.46	0.99 (0.01)	0.080	7285	1.10 (0.06)	0.07	1.04 (0.02)	0.134
DN2.1	*t* = base	113806	**0.88 (0.02)**	**<0.001[f]**	**0.95 (0.007)**	**0.016**	106505	1.02 (0.03)	0.55	1.006 (0.01)	0.081	7301	**1.26 (0.05)**	**<0.001[f]**	**1.10 (0.02)**	**0.137**
	t = fu						106,201	0.98 (0.03)	0.43	0.99 (0.01)	0.081	7285	**1.15 (0.04)**	**<0.001[f]**	**1.06 (0.02)**	**0.134**
DN2.2	*t* = base	113,806	0.97 (0.01)	0.03	0.99 (0.005)	0.017	106,505	1.002 (0.02)	0.92	1.0009 (0.009)	0.081	7301	1.03 (0.03)	0.25	1.01 (0.01)	0.140
	t = fu						106,045	0.97 (0.02)	0.15	0.99 (0.008)	0.081	7275	0.97 (0.03)	0.37	0.99 (0.01)	0.135
DN2.3	*t* = base	113,806	**0.90 (0.02)**	**<0.001[f]**	**0.96 (0.008)**	**0.016**	106,505	0.97 (0.03)	0.31	0.99 (0.01)	0.081	7301	1.04 (0.04)	0.37	1.02 (0.02)	0.140
	t = fu						106,201	0.95 (0.03)	0.08	0.98 (0.01)	0.080	7285	0.999 (0.04)	0.97	0.999 (0.02)	0.135
Self-report descriptive norms scale 2 (average DN2.1–DN2.3)	*t* = base	113,806	**0.85 (0.02)**	**<0.001[f]**	**0.94 (0.01)**	**0.016**	106,505	0.96 (0.04)	0.30	0.98 (0.02)	0.081	7301	**1.24 (0.07)**	**<0.001[f]**	**1.09 (0.02)**	**0.137**
	t = fu						106,045	0.94 (0.04)	0.09	0.97 (0.01)	0.081	7275	1.08 (0.06)	0.17	1.03 (0.02)	0.135
Self-report smoking behavior, intentions, knowledge, attitudes, and psycho-social antecedents, and objectively measured smoking behavior[d]																
Self-report smoking behavior (1– 4)	*t* = base	114,672	**0.91 (0.02)**	**<0.001[f]**	**0.97 (0.006)**	**0.016**	107326	0.98 (0.03)	0.52	0.99 (0.009)	0.081	7346	**1.23 (0.05)**	**<0.001[f]**	**1.07 (0.01)**	**0.136**
	t = fu						107,326	1.02 (0.03)	0.49	1.006 (0.008)	0.082	7346	**1.25 (0.05)**	**<0.001[f]**	**1.07 (0.01)**	**0.133**
Intentions (1–6)	*t* = base	113,856	**0.95 (0.01)**	**<0.001[f]**	**0.97 (0.006)**	**0.016**	106,569	1.01 (0.02)	0.59	1.005 (0.009)	0.082	7287	1.04 (0.03)	0.11	1.02 (0.01)	0.138
	t = fu						106,791	0.98 (0.02)	0.17	0.99 (0.008)	0.081	7311	**1.10 (0.03)**	**<0.001[f]**	**1.05 (0.01)**	**0.136**
Knowledge (0–6)	*t* = base	114,328	0.98 (0.01)	0.12	0.99 (0.006)	0.017	107,005	0.98 (0.02)	0.15	0.99 (0.01)	0.082	7323	1.002 (0.02)	0.93	1.001 (0.01)	0.139
	t = fu						106,489	0.97 (0.02)	0.12	0.98 (0.01)	0.082	7303	0.98 (0.02)	0.40	0.99 (0.01)	0.135
Attitudes (1– 5)	*t* = base	111,298	**0.87 (0.02)**	**<0.001[f]**	**0.95 (0.01)**	**0.016**	104,152	0.98 (0.04)	0.54	0.99 (0.01)	0.079	7146	0.99 (0.05)	0.87	0.997 (0.02)	0.140
	t = fu						105,353	1.009 (0.04)	0.80	1.004 (0.01)	0.080	7241	**1.21 (0.06)**	**<0.001[f]**	**1.08 (0.02)**	**0.129**
Self-efficacy (Emotional; 1–6)	*t* = base	113,720	**0.91 (0.01)**	**<0.001[f]**	**0.95 (0.008)**	**0.016**	106,438	0.97 (0.02)	0.28	0.99 (0.01)	0.082	7282	**1.10 (0.04)**	**0.003**	**1.05 (0.02)**	**0.137**
	t = fu						105,675	0.99 (0.02)	0.76	0.997 (0.01)	0.080	7229	**1.19 (0.03)**	**<0.001[f]**	**1.09 (0.02)**	**0.131**
Self-efficacy (Friends; 1–6)	*t* = base	114,078	**0.91 (0.01)**	**<0.001[f]**	**0.96 (0.007)**	**0.016**	106,765	0.98 (0.02)	0.54	0.99 (0.01)	0.082	7313	**1.11 (0.04)**	**0.003**	**1.05 (0.02)**	**0.136**
	t = fu						106,156	0.98 (0.03)	0.46	0.99 (0.01)	0.081	7262	**1.17 (0.04)**	**<0.001[f]**	**1.08 (0.02)**	**0.131**
Self-efficacy (Opportunity; 1–6)	*t* = base	113,900	**0.90 (0.02)**	**<0.001[f]**	**0.95 (0.01)**	**0.016**	106,600	0.97 (0.03)	0.32	0.98 (0.02)	0.082	7300	**1.18 (0.05)**	**<0.001[f]**	**1.09 (0.02)**	**0.136**
	t = fu						106,512	0.997 (0.03)	0.91	0.999 (0.01)	0.081	7290	**1.17 (0.04)**	**<0.001[f]**	**1.08 (0.02)**	**0.129**
Perceived physical risks (0–100%)	*t* = base	112,428	**0.995 (0.0007)**	**<0.001[f]**	**0.95 (0.007)**	**0.017**	105,222	**0.997 (0.001)**	**0.008**	**0.97 (0.01)**	**0.082**	7206	1.003 (0.001)	0.02	1.03 (0.01)	0.132
	t = fu						105,979	1.0002 (0.001)	0.86	1.002 (0.01)	0.082	7285	1.002 (0.001)	0.11	1.02 (0.01)	0.134
Perceived social risks (0–100%)	*t* = base	113,404	**0.997 (0.0006)**	**<0.001[f]**	**0.97 (0.006)**	**0.016**	106,128	0.999 (0.0009)	0.19	0.99 (0.009)	0.082	7276	**1.004 (0.001)**	**0.001**	**1.04 (0.01)**	**0.133**
	t = fu						106,492	1.0003 (0.001)	0.72	1.003 (0.01)	0.081	7304	**1.005 (0.001)**	**<0.001[f]**	**1.05 (0.01)**	**0.133**
	t = base	109,822		0.06	0.99 (0.006)	0.016	102,800	0.998 (0.001)	0.12	0.98 (0.01)	0.079	7022	1.002 (0.001)	0.23	1.02 (0.01)	0.137

Table 4 (continued)

Outcomes	Time-point	(1) Baseline friend nominations					(2) Adding friends from the school year group					(3) Dropping friends from the school year group				
		Original scale			Re-scaled (0–10)	ICC[c]	Original scale			Re-scaled (0–10)	ICC[c]	Original scale			Re-scaled (0–10)	ICC[c]
		n	OR (SE)[a]	*p*-value	OR (SE)[b]		*n*	OR (SE)[a]	*p*-value	OR (SE)[b]		n	OR (SE)[a]	*p*-value	OR (SE)[b]	
Perceived addiction risks (0–100%)			0.999 (0.0006)													
	$t = \text{fu}$						96,488	1.00005 (0.001)	0.97	1.0005 (0.01)	0.080	6666	0.999 (0.001)	0.51	0.99 (0.01)	0.134
Perceived benefits (0–100%)	$t = \text{base}$	104,778	0.998 (0.0007)	0.02	0.98 (0.007)	0.017	98,117	0.997 (0.001)	0.02	0.97 (0.01)	0.083	6661	1.002 (0.002)	0.14	1.02 (0.02)	0.128
	$t = \text{fu}$						101,366	0.999 (0.001)	0.32	0.99 (0.01)	0.080	6982	1.0006 (0.001)	0.69	1.006 (0.01)	0.135
PBC (easy to quit; 1–5)	$t = \text{base}$	113,238	**0.97 (0.01)**	**0.003**	**0.99 (0.004)**	**0.017**	105,978	0.97 (0.02)	0.10	0.99 (0.007)	0.082	7260	1.01 (0.02)	0.54	1.01 (0.009)	0.138
	$t = \text{fu}$						106,289	0.99 (0.02)	0.41	0.99 (0.007)	0.080	7271	1.04 (0.02)	0.06	1.02 (0.009)	0.136
PBC (to avoid smoking; 1- 5)	$t = \text{base}$	113,998	0.98 (0.01)	0.11	0.99 (0.004)	0.017	106,687	1.003 (0.02)	0.87	1.001 (0.007)	0.082	7311	1.04 (0.02)	0.08	1.02 (0.009)	0.137
	$t = \text{fu}$						106,084	1.01 (0.02)	0.48	1.005 (0.007)	0.080	7268	1.05 (0.03)	0.03	1.02 (0.01)	0.133
Objectively measured smoking behavior (0–30)	$t = \text{base}$	104,680	**0.93 (0.01)**	**<0.001[f]**	**0.87 (0.02)**	**0.015**	97,935	**0.94 (0.02)**	**0.001**	**0.90 (0.03)**	**0.080**	6745	1.02 (0.02)	0.39	1.03 (0.04)	0.135
	$t = \text{fu}$						104,927	0.97 (0.02)	0.16	0.95 (0.03)	0.083	7231	**1.10 (0.03)**	**<0.001**	**1.19 (0.06)**	**0.135**
Smoking susceptibility (binary)[e]	$t = \text{base}$	113,856	**1.20 (0.03)**	**<0.001[f]**	-	**0.017**	106,569	**1.16 (0.05)**	**0.001**	-	**0.082**	7287	0.93 (0.05)	0.17	-	0.138
	$t = \text{fu}$						106791	**1.26 (0.06)**	**<0.001[f]**	-	**0.081**	7311	0.96 (0.05)	0.46	-	0.138

[a]Results are odds ratios, standard errors, and *p*-values from mixed-effects logistic regressions. In each model, the outcome variable is a binary variable representing whether the focal participant had: (1) nominated an individual from the school year group as a friend at baseline [0 = no friend nomination; 1 = friend nomination]; (2) added a potential friend from the school year group between baseline and follow-up [0 = potential friend not added; 1 = potential friend added]; or (3) dropped a friend from the school year group between baseline and follow-up [0 = baseline friend not dropped; 1 = baseline friend dropped]. The predictor variable is the absolute difference (on the original scale) between the focal participant and the individual on the smoking-related outcome variable at baseline ($t = \text{base}$) or follow-up ($t = \text{fu}$). Odds ratios represent the multiplicative change in odds of nominating/adding/dropping friends for a one-unit increase in the absolute difference between the focal participant and the individual on the smoking-related outcome variable (original scale) at baseline ($t = \text{base}$) or follow-up ($t = \text{fu}$). Random intercepts were included at the individual participant level, with cluster-robust standard errors. Analyses are based on participants providing network data at the two timepoints. OR: odds ratio; SE: standard error; ICC: intraclass correlation coefficient; PBC: perceived behavioral control.

[b]For comparability between predictor variables measured on different scales, the mixed-effects logistic regressions were repeated with the smoking-related outcome measures re-scaled to run between 0 and 10. Odds ratios represent the multiplicative change in odds of nominating/adding/dropping friends with a one-unit increase in the absolute difference between the focal participant and the individual on the smoking-related outcome variable (re-scaled) at baseline ($t = \text{base}$) or follow-up ($t = \text{fu}$). Random intercepts were included at the individual participant level, with cluster-robust standard errors. *p*-values remain the same as those extracted from the original model.

[c]Intraclass correlation coefficients (ICCs) are defined as the ratio of the between-cluster variance to the total between-cluster and within-cluster variance (Killip et al., 2004).

[d]Higher numerical values represent higher self-report anti-smoking outcomes, apart from objectively measured smoking behavior (higher numerical values represent higher levels of smoking behavior).

[e]The predictor variable is a binary variable representing whether the focal participant had the same smoking susceptibility status (0 = not susceptible to commencing smoking; 1 = susceptible to commencing smoking) as the individual at baseline ($t = \text{base}$) or follow-up ($t = \text{fu}$). Odds ratios represent the multiplicative change in odds of nominating/adding/dropping friends for matching susceptibility statuses compared to non-matching susceptibility statuses at baseline ($t = \text{base}$) or follow-up ($t = \text{fu}$). Random intercepts were included at the individual participant level, with cluster-robust standard errors.

[f]Retained statistical significance at the 5% level after using the Holm–Bonferroni procedure to correct the *p*-values for multiple testing ($p \leq 0.05$; based on all tests reported in Table 4).

Bold values show the results meeting the significance level of $p \leq 0.01$.

outcomes: experimentally measured injunctive norms P2S2 (friends, class, school), P2S5 (friends, class, school), P2S6 (class), P2S7 (friends, class), P2S8 (friends, class, school), P2S9 (class, school), and the experimental injunctive norms scale (average of P2S2–P2S9; friends, class, school); experimentally measured descriptive norm P3Q2 (friends, class, school), and the experimental descriptive norms scale (average of P3Q1–P3Q2; friends, class); self-report injunctive norms IN6 (friends, school), and IN7 (school); self-report descriptive norms DN1.1 (friends, school), DN1.2 (friends), DN2.2 (friends, class, school), DN2.3 (friends, class, school), and the self-report descriptive norms scale 2 (average of DN2.1–DN2.3; friends, class, school); self-report smoking behavior (school), intentions (class, school), knowledge (friends, class, school), attitudes (friends), self-efficacy emotional subscale (class, school), self-efficacy opportunity subscale (class), perceived social risks (friends, class, school), perceived addiction risks (friends, class, school), perceived behavioral control (easy to quit; friends, class, school), perceived behavioral control (to avoid smoking; class, school); and objectively measured smoking behavior (friends, class, school) [friends: βs = 0.07–0.27, $p \le 0.007$; class: βs = 0.07–0.26, $p \le 0.01$; school: βs = 0.08–0.37, $p \le 0.009$]. The odds of being classified as susceptible to commencing smoking at follow-up were significantly increased with a 10% increase in the number of friends classified as susceptible to commencing smoking at baseline (OR = 1.14, $p < 0.001$).

Peer influence effects from average follow-up responses of friends, school classes, and school year groups. There were positive influence effects from average follow-up responses for the following outcomes: experimentally measured injunctive norms P2S2 (class, school), P2S4 (class), P2S5 (friends, class, school), P2S6 (friends, class, school), P2S7 (friends, class), P2S8 (friends, class, school), P2S9 (friends, class), and the experimental injunctive norms scale (average of P2S2–P2S9; friends, class); experimentally measured descriptive norms P3Q1 (class), P3Q2 (friends, class), and the experimental descriptive norms scale (average of P3Q1–P3Q2; class); donations to ASSIST/Dead Cool (friends, class, school); self-report injunctive norms IN6 (friends, class, school), IN7 (friends), and the self-report injunctive norms scale (average of IN1–IN7; friends); self-report descriptive norms DN1.1 (friends, school), DN2.1 (friends), DN2.2 (school), DN2.3 (friends, class, school), and the self-report descriptive norms scale 2 (average of DN2.1–DN2.3; class, school); self-report smoking behavior (friends, class, school), intentions (friends, school), knowledge (friends, class, school), attitudes (friends), self-efficacy emotional subscale (friends, school), self-efficacy friends subscale (friends), perceived social risks (class, school), perceived addiction risks (friends, class, school), perceived behavioral control (easy to quit; friends, class, school), perceived behavioral control (to avoid smoking; school); and objectively measured smoking behavior (friends, class, school) [friends: βs = 0.08–0.39, $p \le 0.009$; class: βs = 0.07–0.55, $p \le 0.01$; school: βs = 0.08–0.51, $p \le 0.01$]. The odds of being classified as susceptible to commencing smoking at follow-up were significantly increased with a 10% increase in the number of friends (OR = 1.14, $p < 0.001$), school class members (OR = 1.17, $p = 0.004$), or school year group members (OR = 1.31, $p < 0.001$), classified as susceptible to commencing smoking at follow-up.

Sensitivity analyses. After adjusting models for 'setting', influence effects from average friends' responses became non-significant ($p > 0.01$) for several outcomes, but these models could have been affected by multi-collinearity. Sensitivity analyses using ordered logistic regressions showed minimal change to the results (Supplementary Table S6). There was also minimal change to the results when restricting the analyses investigating peer influence effects from friends to reciprocated friends. Although the p-values increased slightly for some models, this is not surprising given the reduced power from the lower number of observations (Supplementary Tables S7–S9).

Objective 3: Cross-lagged panel models. The CLPMs showed that both the paths representing peer influence from friends ("cross1" in Fig. 1) and selection homophily ("cross2" in Fig. 1) were positive and significant ($p \le 0.01$) for the following outcomes: experimentally measured injunctive norms P2S2, P2S5, P2S7, P2S8, and the experimental injunctive norms scale (average of P2S2–P2S9); self-report injunctive norm IN6; self-report descriptive norms DN1.2, DN2.2, DN2.3, and the self-report descriptive norms scale 2 (average of DN2.1–DN2.3); self-report intentions, knowledge, perceived social risks, and perceived behavioral control (easy to quit; βs = 0.06–0.17 for peer influence, βs = 0.08–0.14 for selection homophily). Only the path representing peer influence from friends was positive and significant ($p \le 0.01$) for the following outcomes: experimentally measured injunctive norm P2S6; experimentally measured descriptive norm P3Q2, and the experimental descriptive norms scale (average of P3Q1–P3Q2); self-report injunctive norm IN7; self-report descriptive norms DN1.1, and DN2.1; self-report attitudes, self-efficacy opportunity subscale, perceived addiction risks; and objectively measured smoking behavior (βs = 0.07–0.30). However, in these models, the selection homophily path approached significance for the experimental descriptive norms scale, IN7, perceived addiction risks, and objectively measured smoking behavior ($p = 0.02$). Only the path representing selection homophily was positive and significant ($p \le 0.01$) for the following outcomes: self-report smoking behavior, self-efficacy friends subscale, perceived behavioral control (to avoid smoking), and smoking susceptibility (βs = 0.09–0.17). However, in these models, the peer influence path approached significance for self-report smoking behavior, and smoking susceptibility ($p = 0.02$; Supplementary Table S10).

Objective 4: SIENA models. The results of the meta-analyses for the main "peer selection homophily" and "peer influence" effect parameters for each of the smoking/vaping outcomes are reported in Table 6. Results are also reported for each subgroup of schools, along with tests for differences across subgroups. Meta-analyses results are reported and discussed in full for each smoking/vaping outcome in Supplementary Tables S11–S31. The results of the main meta-analyses showed that the peer selection homophily effect was positive and significant ($p \le 0.005$) for the model with smoking susceptibility as the behavioral dependent variable (unstandardized Snijders and Baerveldt coefficient [b] = 0.17, SE = 0.06, $p = 0.0017$). The peer influence effect was positive and significant ($p \le 0.005$) for the models with experimental injunctive norms ($b = 3.95$, SE = 1.03, $p < 0.0001$), donations to ASSIST/Dead Cool ($b = 4.13$, SE = 0.43, $p < 0.0001$), intentions ($b = 5.50$, SE = 3.72, $p = 0.0023$), and objectively measured smoking behavior ($b = 8.12$, SE = 1.48, $p < 0.0001$) as the behavioral dependent variable. The peer selection homophily effect was positive, and approached significance for models with self-report descriptive norms scale 2 ($b = 0.38$, SE = 0.16, $p = 0.0176$), self-report smoking behavior ($b = 0.30$, SE = 0.13, $p = 0.0074$), and self-efficacy opportunity subscale ($b = 0.48$, SE = 0.37, $p = 0.0111$) as the behavioral dependent variable. The peer influence effect was positive, and approached significance for models with experimental descriptive norms ($b = 1.57$, SE = 0.78, $p = 0.0056$), self-report descriptive norms scale 1 ($b = 3.63$, SE = 3.33, $p = 0.0115$), and knowledge ($b = 2.22$, SE = 0.64,

$p = 0.0051$) as the behavioral dependent variable. There were no significant differences across all schools included in the main meta-analyses for the peer selection homophily or peer influence effect estimates for any of the smoking/vaping outcomes ($p \geq 0.0249$).

There were significant differences across 'setting' subgroups for the peer selection homophily effect for the model with objectively measured smoking behavior as the behavioral dependent variable ($p < 0.0001$), which showed higher peer selection effects in Bogotá ($b = 0.59$) compared to NI ($b = -1.10$). There were significant differences across 'setting' subgroups for the peer influence effect for the models with self-report descriptive norms scale 1 ($p = 0.0030$), intentions ($p < 0.0001$), self-efficacy emotional subscale ($p = 0.0001$), and perceived benefits ($p < 0.0001$) as the behavioral dependent variable. Peer influence effects were higher for NI ($b = 5.87$ versus Bogotá $b = 0.10$), NI ($b = 13.56$ versus Bogotá $b = 0.80$), NI ($b = 2.74$ versus Bogotá $b = -3.43$), and NI ($b = -0.43$ versus Bogotá $b = -1.57$), respectively.

There were significant differences across 'intervention' subgroups for the peer selection homophily effect for the model with perceived physical risks as the behavioral dependent variable ($p = 0.0089$), which showed higher peer selection effects in Dead Cool schools ($b = 0.38$) compared to ASSIST schools ($b = -0.14$). There were significant differences across 'intervention' subgroups for the peer influence effect for the models with experimental descriptive norms ($p < 0.0001$), self-report smoking behavior ($p < 0.0001$), and perceived benefits ($p < 0.0001$) as the behavioral dependent variable. Peer influence effects were higher for ASSIST schools ($b = 3.25$ versus Dead Cool $b = -0.08$), Dead Cool schools ($b = 2.77$ versus ASSIST $b = 1.31$), and ASSIST schools ($b = 0.05$ versus Dead Cool $b = -1.70$), respectively.

For each of the smoking/vaping outcomes, the percentages of network autocorrelation attributable to peer selection, peer influence, undetermined (peer selection or peer influence), and control (or alternative explaining mechanisms) effects across all included schools are reported in Table 7. Results are also reported for each subgroup of schools. The violin plots of Moran's *I* distributions and stacked bar charts of Moran's *I* decompositions are shown in Figs. 4 and 5 for experimental injunctive norms for smoking/vaping. Violin plots and stacked bar charts for the rest of the smoking/vaping outcomes are shown in Supplementary Figs. S74–S115. The violin plots for experimental injunctive norms showed that the median Moran's *I* across the networks simulated from SIENA models specified including peer influence effects ("Full model" and "Excluding PS"), was approximately equal to the mean Moran's *I* across the observed networks in each school at follow-up (and greater than the mean Moran's *I* across the observed networks at baseline). For networks simulated from SIENA models specified excluding peer influence effects ("Excluding PI" and "Excluding PS and PI"), the median Moran's *I* lies substantially below the mean observed Moran's *I* at baseline and follow-up (Fig. 4). The relative contributions of peer selection, peer influence, undetermined peer selection or peer influence, and control effects to similarities between friends for experimental injunctive norms were 0.13%, 89.06%, 3.18%, and 7.63%, respectively (Fig. 5). This supports the meta-analysis results described in the previous paragraph since we found a significant peer influence effect for experimental injunctive norms, but no significant peer selection homophily effect. The Moran's *I* decompositions also support the other findings for significant peer selection homophily and peer influence effects from the meta-analysis, since we found the greatest proportion of the network autocorrelation was attributable to peer selection effects for smoking susceptibility (54.44%). For donations to ASSIST/Dead Cool, intentions, and objectively measured smoking behavior, the percentages of network autocorrelation attributable to peer influence were 83.46%, 59.21%, and 90.18%, respectively (Table 7, Supplementary Figs. S74–S115).

Across the 21 smoking/vaping outcomes examined in the SIENA models, the average relative contributions of peer selection, peer influence, undetermined peer selection or peer influence, and control effects to similarities between friends were 32.84%, 39.22%, 1.08%, and 26.86%, respectively. Broken down by subgroup, the percentages were: 23.55%, 44.34%, 2.86%, and 29.25% (NI); 36.52%, 33.87%, 1.91%, and 27.71% (Bogotá); 33.93%, 38.86%, 1.77%, and 25.43% (ASSIST), and; 21.38%, 30.02%, 2.44%, and 46.16% (Dead Cool).

Discussion

The MECHANISMS study was designed to investigate the mechanisms through which social norms for adolescent smoking and vaping behaviors are diffused through school friendship networks in NI and Bogotá (Hunter et al., 2020). If we conceptualize social norms in terms of shared understandings between individuals in social networks about rules and standards that guide social behavior (Cialdini and Trost, 1998; Hunter et al., 2020; Panter-Brick et al., 2006), the Krupka-Weber method of norms elicitation has advantages over other approaches (E. L. Krupka and Weber, 2013). The structure of the game provides incentives for participants to report their beliefs about others' beliefs on the social appropriateness of various actions to assess injunctive norms, or others' approval of various behaviors to assess descriptive norms. The existence of such shared 'second-order' beliefs (expectations about others' personal normative beliefs) is a theoretical precondition for the existence of a social norm (Bicchieri et al., 2018). Social norms and social influence are co-dependent (Cialdini and Trost, 1998). Therefore, it seems intuitive that we should observe peer influence effects on participants' responses to games designed to elicit shared perceptions about the beliefs of peers. We observed a high proportion of significant peer influence effects for these variables in our OLS regressions (objective 2), and our CLPMs showed the strongest evidence that selection homophily and peer influence from friends were operating together for the experimental norms outcomes, particularly for injunctive norms (objective 3). The SIENA models also showed positive peer influence effects that were significant for the experimental injunctive norms scale and donations to ASSIST/Dead Cool and approached significance for the experimental descriptive norms scale (objective 4). Notably, our mixed-effects logistic regressions showed that the individual experimental injunctive norms items enquiring about the social appropriateness of situations involving vaping and e-cigarettes were important sources of selection homophily (objective 1). This may reflect that tobacco usage patterns have shifted towards alternative products since the introduction of e-cigarettes into the market in the mid-2000s (National Center for Chronic Disease Prevention and Health Promotion (US) Office on Smoking and Health, 2016; Perikleous et al., 2018; Schneider and Diehl, 2016; Wang et al., 2014). Whilst many countries are adopting comprehensive tobacco-control policies in an effort to "de-normalize" and reduce smoking (including the UK and Colombia) (Action on Smoking and Health (ASH), 2017; Chapman and Freeman, 2008; Colombia Ombudsman Office, 2017; Dubray et al., 2015; Elias and Ling, 2018; Otálvaro-Ramírez et al., 2019), e-cigarettes are increasing in popularity amongst all age groups due to wide-scale marketing (East et al., 2019; Perikleous et al., 2018). E-cigarettes are gaining traction amongst adolescents who may perceive that they are healthier and safer than conventional cigarettes, and find the different product features attractive (e.g., flavors) (Perikleous et al., 2018). Recent research has also shown that perceived peer approval is higher for vaping compared to

Table 5 Results of ordinary least-squares linear regressions showing peer influence effects for focal participant responses to experimentally measured smoking and vaping norms, and other smoking outcomes, at follow-up.

Outcomes	Time-point	Outcome variable: Focal participant responses to outcomes at follow-up														
		(1) $-i$ = Average of nominated friends[a]				(1) $-i$ = Average of nominated friends[b]			(2) $-i$ = Average of school class[a]				(3) $-i$ = Average of school year group[a]			
		n	Response$_{-i,\ t}$			Response$_{-i,\ t}$			n	Response$_{-i,\ t}$			n	Response$_{-i,\ t}$		
			b (SE)[c]	p-value	β[d]	b (SE)[c]	p-value	β[d]		b (SE)[c]	p-value	β[d]		b (SE)[c]	p-value	β[d]
Experiment Part 2: Injunctive norms for smoking/vaping (−1 = "extremely socially inappropriate" to +1 = "extremely socially appropriate").																
P2S2	t = base	1073	**0.34 (0.09)**	**<0.001**[h]	**0.1396**	**0.27 (0.09)**	**0.003**	**0.1096**	1087	**0.44 (0.12)**	**<0.001**[h]	**0.1176**	1087	**0.78 (0.18)**	**<0.001**[h]	**0.1510**
	t = fu	1018	0.15 (0.06)	0.02	0.0760	0.08 (0.06)	0.22	0.0399	1087	**0.31 (0.10)**	**0.003**	**0.0933**	1087	**0.57 (0.16)**	**<0.001**	**0.1199**
P2S3	t = base	1072	0.11 (0.07)	0.11	0.0489	0.12 (0.07)	0.09	0.0508	1086	0.17 (0.16)	0.28	0.0357	1086	0.01 (0.28)	0.96	0.0017
	t = fu	1017	0.12 (0.07)	0.09	0.0535	0.11 (0.07)	0.09	0.0534	1086	0.21 (0.14)	0.12	0.0523	1086	0.18 (0.25)	0.48	0.0213
P2S4	t = base	1070	0.13 (0.08)	0.09	0.0605	0.13 (0.08)	0.09	0.0601	1084	0.17 (0.12)	0.15	0.0424	1084	0.46 (0.32)	0.15	0.0582
	t = fu	1016	0.12 (0.07)	0.08	0.0568	0.09 (0.07)	0.19	0.0424	1084	**0.29 (0.11)**	**0.01**	**0.0780**	1084	0.44 (0.20)	0.03	0.0748
P2S5	t = base	1073	**0.19 (0.06)**	**0.002**	**0.0918**	**0.19 (0.06)**	**0.003**	**0.0897**	1087	**0.32 (0.10)**	**0.001**	**0.0981**	1087	**0.48 (0.15)**	**0.001**	**0.1028**
	t = fu	1018	**0.17 (0.06)**	**0.003**	**0.0902**	**0.17 (0.06)**	**0.005**	**0.0885**	1087	**0.45 (0.09)**	**<0.001**[h]	**0.1629**	1087	**0.45 (0.14)**	**0.001**	**0.1098**
P2S6	t = base	1070	0.16 (0.07)	0.02	0.0762	0.16 (0.07)	0.02	0.0753	1084	**0.36 (0.11)**	**0.001**	**0.1025**	1084	0.40 (0.19)	0.03	0.0774
	t = fu	1015	**0.16 (0.06)**	**0.007**	**0.0803**	**0.15 (0.06)**	**0.007**	**0.0797**	1084	**0.45 (0.10)**	**<0.001**[h]	**0.1417**	1084	**0.51 (0.15)**	**0.001**	**0.0977**
P2S7	t = base	1072	**0.16 (0.05)**	**0.003**	**0.0870**	**0.16 (0.05)**	**0.003**	**0.0861**	1086	**0.29 (0.09)**	**0.001**	**0.1006**	1086	0.28 (0.14)	0.04	0.0622
	t = fu	1018	**0.27 (0.06)**	**<0.001**[h]	**0.1474**	**0.27 (0.06)**	**<0.001**[i]	**0.1471**	1086	**0.41 (0.09)**	**<0.001**[h]	**0.1358**	1086	0.31 (0.17)	0.07	0.0630
P2S8	t = base	1073	**0.30 (0.05)**	**<0.001**[h]	**0.1578**	**0.30 (0.05)**	**<0.001**[i]	**0.1589**	1087	**0.31 (0.09)**	**<0.001**	**0.1037**	1087	**0.45 (0.14)**	**0.001**	**0.0940**
	t = fu	1018	**0.23 (0.05)**	**<0.001**[h]	**0.1235**	**0.23 (0.05)**	**<0.001**[i]	**0.1228**	1087	**0.47 (0.08)**	**<0.001**[h]	**0.1703**	1087	**0.48 (0.13)**	**<0.001**	**0.1083**
P2S9	t = base	1072	0.16 (0.07)	0.02	0.0711	0.15 (0.07)	0.02	0.0697	1086	**0.51 (0.12)**	**<0.001**[h]	**0.1230**	1086	**0.56 (0.21)**	**0.009**	**0.0767**
	t = fu	1017	**0.24 (0.07)**	**<0.001**	**0.1183**	**0.24 (0.07)**	**<0.001**	**0.1176**	1086	**0.41 (0.11)**	**<0.001**[h]	**0.1226**	1086	0.21 (0.20)	0.29	0.0330
Experimental injunctive norms scale (average P2S2–P2S9)	t = base	1064	**0.22 (0.06)**	**<0.001**[h]	**0.1098**	**0.23 (0.06)**	**<0.001**[i]	**0.1111**	1078	**0.35 (0.10)**	**<0.001**	**0.1054**	1078	**0.41 (0.15)**	**0.005**	**0.0766**
	t = fu	1011	**0.25 (0.05)**	**<0.001**[h]	**0.1341**	**0.25 (0.05)**	**<0.001**[i]	**0.1352**	1078	**0.47 (0.08)**	**<0.001**[h]	**0.1707**	1078	0.30 (0.14)	0.03	0.0620
Experiment Part 3: Descriptive norms for smoking/vaping (−1 = "none of my peers" to +1 = "all of my peers").																
P3Q1	t = base	1073	0.09 (0.06)	0.15	0.0451	0.10 (0.06)	0.11	0.0503	1087	0.24 (0.11)	0.03	0.0723	1087	0.15 (0.15)	0.33	0.0323
	t = fu	1018	0.09 (0.06)	0.14	0.0466	0.09 (0.06)	0.14	0.0462	1087	**0.30 (0.10)**	**0.004**	**0.0902**	1087	0.20 (0.17)	0.25	0.0354
P3Q2	t = base	1073	**0.19 (0.05)**	**<0.001**	**0.1017**	**0.20 (0.05)**	**<0.001**	**0.1033**	1087	**0.31 (0.08)**	**<0.001**[h]	**0.1187**	1087	**0.32 (0.11)**	**0.003**	**0.0927**
	t = fu	1018	**0.18 (0.06)**	**0.001**	**0.0942**	**0.18 (0.06)**	**0.002**	**0.0926**	1087	**0.30 (0.08)**	**<0.001**[h]	**0.1105**	1087	0.28 (0.12)	0.02	0.0695
Experimental descriptive norms scale (average P3Q1–P3Q2)	t = base	1073	**0.15 (0.06)**	**0.01**	**0.0764**	**0.16 (0.06)**	**0.007**	**0.0813**	1087	**0.26 (0.09)**	**0.003**	**0.0923**	1087	0.20 (0.11)	0.08	0.0544
	t = fu	1018	0.13 (0.06)	0.03	0.0642	0.13 (0.06)	0.03	0.0646	1087	**0.28 (0.09)**	**0.002**	**0.0938**	1087	0.17 (0.13)	0.19	0.0383
Experiment Part 4: Willingness to pay to support anti-smoking norms (Donations to ASSIST/Dead Cool; 0 = "0 tokens donated" to 10 = "10 tokens donated").																
Donation to ASSIST/ Dead Cool	t = base	1071	0.14 (0.06)	0.02	0.0740	0.12 (0.06)	0.03	0.0658	1085	0.15 (0.09)	0.12	0.0505	1085	0.26 (0.20)	0.20	0.0437
	t = fu	1016	**0.34 (0.06)**	**<0.001**[h]	**0.1877**	**0.32 (0.06)**	**<0.001**[i]	**0.1754**	1085	**0.48 (0.09)**	**<0.001**[h]	**0.1604**	1085	**0.66 (0.14)**	**<0.001**[h]	**0.1494**
Self-report injunctive smoking norms (−2 = "think(s) that I definitely should smoke" to +2 = "think(s) that I definitely should not smoke").																
IN1	t = base	1073	−0.04 (0.06)	0.51	−0.0173	−0.04 (0.07)	0.60	−0.0153	1082	0.05 (0.13)	0.72	0.0105	1082	0.36 (0.22)	0.09	0.0463
	t = fu	1070	0.07 (0.06)	0.27	0.0311	0.06 (0.06)	0.31	0.0288	1082	−0.17 (0.12)	0.16	−0.0378	1082	0.23 (0.23)	0.32	0.0326
IN2	t = base	1075	−0.02 (0.08)	0.80	−0.0061	−0.02 (0.08)	0.76	−0.0075	1084	0.20 (0.19)	0.28	0.0422	1084	0.23 (0.56)	0.68	0.0200
	t = fu	1072	0.14 (0.08)	0.07	0.0627	0.14 (0.08)	0.07	0.0602	1084	0.12 (0.11)	0.25	0.0308	1084	0.08 (0.27)	0.77	0.0095
IN3	t = base	1073	0.11 (0.07)	0.09	0.0513	0.11 (0.07)	0.11	0.0496	1082	0.18 (0.11)	0.13	0.0425	1082	0.26 (0.19)	0.16	0.0473
	t = fu	1070	0.08 (0.05)	0.13	0.0387	0.08 (0.05)	0.17	0.0358	1082	0.003 (0.10)	0.98	0.0007	1082	0.12 (0.20)	0.54	0.0184
IN4	t = base	1071	0.03 (0.06)	0.60	0.0134	0.03 (0.06)	0.55	0.0151	1081	−0.02 (0.13)	0.85	−0.0050	1081	0.69 (0.32)	0.03	0.0730
	t = fu	1069	0.06 (0.05)	0.28	0.0277	0.04 (0.05)	0.45	0.0194	1081	0.18 (0.12)	0.13	0.0396	1081	0.41 (0.22)	0.06	0.0567
IN5	t = base	1073	−0.01 (0.06)	0.83	−0.0055	0.005 (0.06)	0.93	0.0023	1082	−0.05 (0.11)	0.66	−0.0123	1082	−0.01 (0.23)	0.95	−0.0017
	t = fu	1070	0.03 (0.06)	0.58	0.0142	0.03 (0.06)	0.59	0.0140	1082	0.04 (0.11)	0.74	0.0088	1082	0.09 (0.20)	0.66	0.0120
IN6	t = base	1074	**0.21 (0.06)**	**<0.001**	**0.1013**	**0.19 (0.06)**	**0.001**	**0.0909**	1083	0.20 (0.10)	0.05	0.0570	1083	**0.44 (0.16)**	**0.007**	**0.0824**
	t = fu	1071	**0.25 (0.06)**	**<0.001**[h]	**0.1256**	**0.22 (0.06)**	**<0.001**[i]	**0.1129**	1083	**0.27 (0.09)**	**0.003**	**0.0794**	1083	**0.41 (0.16)**	**0.01**	**0.0801**

Table 5 (continued)

Outcomes	Time-point	Outcome variable: Focal participant responses to outcomes at follow-up														
		(1) $-i$ = Average of nominated friends[a]				(1) $-i$ = Average of nominated friends[b]			(2) $-i$ = Average of school class[a]				(3) $-i$ = Average of school year group[a]			
		n	$Response_{-i,\,t}$			$Response_{-i,\,t}$			n	$Response_{-i,\,t}$			n	$Response_{-i,\,t}$		
			b (SE)[c]	p-value	β[d]	b (SE)[c]	p-value	β[d]		b (SE)[c]	p-value	β[d]		b (SE)[c]	p-value	β[d]
IN7	t = base	1075	0.11 (0.06)	0.06	0.0537	0.09 (0.06)	0.14	0.0431	1084	0.21 (0.12)	0.07	0.0556	1084	**0.57 (0.18)**	**0.002**	**0.0996**
	t = fu	1072	**0.19 (0.06)**	**0.003**	**0.0944**	**0.17 (0.06)**	**0.007**	**0.0866**	1084	0.21 (0.11)	0.06	0.0572	1084	0.34 (0.18)	0.06	0.0644
Self-report injunctive	t = base	1068	0.07 (0.06)	0.23	0.0310	0.07 (0.06)	0.25	0.0288	1078	0.06 (0.12)	0.63	0.0145	1078	0.38 (0.18)	0.04	0.0634
norms scale (average IN1–IN7)	t = fu	1066	**0.19 (0.05)**	**<0.001**	**0.0936**	**0.19 (0.05)**	**<0.001**	**0.0923**	1078	0.20 (0.09)	0.03	0.0534	1078	0.24 (0.16)	0.13	0.0426
Self-report descriptive smoking norms (DN1: 1 = "smoke(s) very often" to 5 = "never smoke(s)"/"don't know"; DN2: 1 = "almost all of them smoke" to 5 = "almost none of them smoke"/"don't know").																
DN1.1	t = base	1075	**0.30 (0.10)**	**0.005**	**0.1340**	**0.28 (0.10)**	**0.008**	**0.1274**	1084	0.30 (0.14)	0.04	0.0842	1084	**1.06 (0.30)**	**0.001**	**0.1793**
	t = fu	1072	**0.33 (0.09)**	**<0.001**[h]	**0.1702**	**0.31 (0.09)**	**<0.001**	**0.1632**	1084	0.24 (0.13)	0.06	0.0703	1084	**0.62 (0.18)**	**0.001**	**0.1384**
DN1.2	t = base	1076	**0.13 (0.05)**	**0.007**	**0.0665**	**0.12 (0.05)**	**0.01**	**0.0636**	1085	0.08 (0.07)	0.24	0.0279	1085	0.16 (0.09)	0.06	0.0434
	t = fu	1073	−0.005 (0.04)	0.91	−0.0028	−0.02 (0.05)	0.71	−0.0092	1085	0.02 (0.08)	0.76	0.0073	1085	0.11 (0.09)	0.23	0.0266
DN1.3	t = base	1075	0.08 (0.04)	0.06	0.0399	0.08 (0.04)	0.07	0.0386	1084	0.06 (0.08)	0.45	0.0172	1084	0.13 (0.13)	0.30	0.0273
	t = fu	1072	0.02 (0.05)	0.64	0.0113	0.02 (0.05)	0.71	0.0089	1084	0.03 (0.08)	0.74	0.0072	1084	0.08 (0.14)	0.59	0.0142
DN1.4	t = base	1075	0.01 (0.04)	0.81	0.0047	0.01 (0.04)	0.79	0.0053	1084	0.07 (0.13)	0.59	0.0165	1084	0.11 (0.14)	0.43	0.0173
	t = fu	1072	−0.09 (0.04)	0.03	−0.0417	−0.09 (0.04)	0.04	−0.0414	1084	0.10 (0.15)	0.50	0.0253	1084	−0.10 (0.17)	0.56	−0.0134
DN1.5	t = base	1075	0.08 (0.05)	0.13	0.0300	0.07 (0.05)	0.15	0.0294	1084	0.16 (0.12)	0.16	0.0357	1084	0.29 (0.19)	0.13	0.0291
	t = fu	1072	−0.01 (0.05)	0.81	−0.0048	−0.01 (0.05)	0.81	−0.0049	1084	0.18 (0.11)	0.10	0.0453	1084	0.09 (0.16)	0.58	0.0116
Self-report descriptive	t = base	1073	0.09 (0.05)	0.06	0.0460	0.09 (0.05)	0.07	0.0438	1082	0.05 (0.07)	0.47	0.0181	1082	0.18 (0.10)	0.09	0.0474
norms scale 1 (average DN1.1–DN1.5)	t = fu	1070	0.04 (0.05)	0.41	0.0201	0.03 (0.05)	0.49	0.0168	1082	0.02 (0.07)	0.80	0.0062	1082	0.14 (0.10)	0.16	0.0380
DN2.1	t = base	1076	0.17 (0.07)	0.02	0.0774	0.16 (0.07)	0.03	0.0729	1085	0.17 (0.11)	0.11	0.0515	1085	0.21 (0.15)	0.14	0.0464
	t = fu	1073	**0.19 (0.07)**	**0.005**	**0.1012**	**0.18 (0.07)**	**0.007**	**0.0961**	1085	0.19 (0.11)	0.10	0.0584	1085	0.12 (0.16)	0.46	0.0246
DN2.2	t = base	1076	**0.17 (0.06)**	**0.006**	**0.0784**	0.14 (0.06)	0.03	0.0656	1085	**0.30 (0.10)**	**0.002**	**0.0955**	1085	**0.48 (0.16)**	**0.003**	**0.0994**
	t = fu	1073	0.11 (0.06)	0.07	0.0556	0.08 (0.06)	0.17	0.0431	1085	0.17 (0.09)	0.07	0.0526	1085	**0.38 (0.15)**	**0.01**	**0.0827**
DN2.3	t = base	1076	**0.26 (0.07)**	**<0.001**	**0.1278**	**0.25 (0.08)**	**0.001**	**0.1189**	1085	**0.57 (0.10)**	**<0.001**[h]	**0.1910**	1085	**0.65 (0.13)**	**<0.001**[h]	**0.1703**
	t = fu	1073	**0.18 (0.06)**	**0.002**	**0.1076**	**0.16 (0.06)**	**0.01**	**0.0930**	1085	**0.39 (0.09)**	**<0.001**[h]	**0.1525**	1085	**0.53 (0.11)**	**<0.001**[h]	**0.1633**
Self-report descriptive	t = base	1076	**0.22 (0.07)**	**0.001**	**0.1025**	**0.19 (0.07)**	**0.005**	**0.0903**	1085	**0.37 (0.10)**	**<0.001**[h]	**0.1250**	1085	**0.45 (0.13)**	**0.001**	**0.1151**
norms scale 2 (average DN2.1-DN2.3)	t = fu	1073	0.11 (0.06)	0.06	0.0624	0.08 (0.06)	0.18	0.0455	1085	**0.25 (0.08)**	**0.003**	**0.0936**	1085	**0.36 (0.12)**	**0.003**	**0.1014**
Survey questions about smoking behavior, intentions, knowledge, attitudes, and psycho-social antecedents, and objectively measured smoking behavior[e]																
Self-report smoking	t = base	1083	0.16 (0.07)	0.03	0.0726	0.16 (0.07)	0.03	0.0719	1093	0.22 (0.11)	0.04	0.0557	1093	**0.55 (0.16)**	**0.001**	**0.0920**
behavior (1–4)	t = fu	1081	**0.24 (0.06)**	**<0.001**[h]	**0.1342**	**0.24 (0.07)**	**<0.001**[i]	**0.1344**	1093	**0.22 (0.08)**	**0.01**	**0.0691**	1093	**0.38 (0.10)**	**<0.001**[h]	**0.0885**
Intentions (1–6)	t = base	1078	0.17 (0.08)	0.04	0.0630	0.15 (0.08)	0.07	0.0561	1087	**0.48 (0.14)**	**<0.001**	**0.1078**	1087	**0.96 (0.24)**	**<0.001**[h]	**0.1184**
	t = fu	1075	**0.21 (0.08)**	**0.005**	**0.1160**	**0.20 (0.08)**	**0.01**	**0.1095**	1087	0.11 (0.11)	0.32	0.0310	1087	**0.38 (0.14)**	**0.007**	**0.0811**
Knowledge (0–6)	t = base	1080	**0.20 (0.05)**	**<0.001**	**0.1001**	0.12 (0.06)	0.04	0.0621	1089	**0.41 (0.08)**	**<0.001**[h]	**0.1616**	1089	**0.45 (0.10)**	**<0.001**[h]	**0.1366**
	t = fu	1077	**0.29 (0.06)**	**<0.001**[h]	**0.1568**	**0.24 (0.06)**	**<0.001**[i]	**0.1329**	1089	**0.41 (0.08)**	**<0.001**[h]	**0.1773**	1089	**0.42 (0.11)**	**<0.001**[h]	**0.1362**
Attitudes (1–5)	t = base	1067	**0.16 (0.06)**	**0.007**	**0.0763**	**0.16 (0.06)**	**0.007**	**0.0763**	1076	−0.04 (0.11)	0.73	−0.0095	1076	0.34 (0.21)	0.10	0.0501
	t = fu	1064	**0.17 (0.06)**	**0.009**	**0.0844**	**0.17 (0.07)**	**0.009**	**0.0847**	1076	−0.10 (0.12)	0.41	−0.0246	1076	0.23 (0.17)	0.17	0.0417
Self-efficacy	t = base	1072	0.11 (0.07)	0.13	0.0484	0.10 (0.07)	0.19	0.0414	1081	**0.30 (0.12)**	**0.01**	**0.0735**	1081	**0.46 (0.17)**	**0.005**	**0.0797**
(Emotional; 1–6)	t = fu	1068	**0.29 (0.07)**	**<0.001**[h]	**0.1505**	**0.26 (0.07)**	**<0.001**	**0.1355**	1081	0.22 (0.09)	0.02	0.0629	1081	**0.42 (0.13)**	**0.001**	**0.0913**
Self-efficacy (Friends;	t = base	1078	0.06 (0.06)	0.33	0.0272	0.06 (0.06)	0.35	0.0256	1087	0.20 (0.11)	0.08	0.0495	1087	0.18 (0.17)	0.29	0.0294
1–6)	t = fu	1075	**0.20 (0.07)**	**0.003**	**0.0992**	**0.18 (0.07)**	**0.006**	**0.0919**	1087	0.11 (0.10)	0.27	0.0286	1087	0.27 (0.18)	0.13	0.0455
Self-efficacy	t = base	1079	0.13 (0.07)	0.07	0.0506	0.11 (0.07)	0.10	0.0441	1088	**0.38 (0.14)**	**0.006**	**0.0847**	1088	0.42 (0.20)	0.04	0.0646
(Opportunity; 1–6)	t = fu	1076	0.17 (0.07)	0.02	0.0846	0.14 (0.07)	0.04	0.0738	1088	0.21 (0.10)	0.04	0.0588	1088	0.29 (0.17)	0.08	0.0539
Perceived physical risks	t = base	1074	0.07 (0.05)	0.18	0.0387	0.07 (0.05)	0.21	0.0361	1082	0.15 (0.09)	0.09	0.0470	1082	0.07 (0.14)	0.61	0.0141
(0–100%)	t = fu	1070	0.12 (0.05)	0.03	0.0604	0.11 (0.05)	0.04	0.0571	1082	0.11 (0.11)	0.32	0.0312	1082	−0.15 (0.21)	0.48	−0.0238
Perceived social risks	t = base	1076	**0.15 (0.05)**	**0.003**	**0.0865**	0.08 (0.06)	0.18	0.0421	1085	**0.27 (0.07)**	**<0.001**[h]	**0.1070**	1085	**0.40 (0.09)**	**<0.001**[h]	**0.1248**
(0–100%)	t = fu	1073	0.13 (0.06)	0.02	0.0711	0.06 (0.06)	0.36	0.0318	1085	**0.24 (0.08)**	**0.005**	**0.0831**	1085	**0.40 (0.12)**	**0.001**	**0.1113**
Perceived addiction	t = base	1016	**0.23 (0.06)**	**<0.001**[h]	**0.1188**	0.05 (0.07)	0.45	0.0260	1025	**0.51 (0.09)**	**<0.001**[h]	**0.1870**	1025	**0.71 (0.10)**	**<0.001**[h]	**0.2253**
risks (0–100%)	t = fu	1009	**0.14 (0.05)**	**0.004**	**0.0833**	−0.06 (0.06)	0.33	−0.0328	1025	**0.39 (0.08)**	**<0.001**[h]	**0.1594**	1025	**0.58 (0.09)**	**<0.001**[h]	**0.2073**

Table 5 (continued)

Outcomes	Time-point	Outcome variable: Focal participant responses to outcomes at follow-up														
		(1) $-i$ = Average of nominated friends[a]				(1) $-i$ = Average of nominated friends[b]			(2) $-i$ = Average of school class[a]				(3) $-i$ = Average of school year group[a]			
		n	Response$_{-i,\ t}$			Response$_{-i,\ t}$			*n*	Response$_{-i,\ t}$			*n*	Response$_{-i,\ t}$		
			b (SE)[c]	*p*-value	β^d	*b* (SE)[c]	*p*-value	β^d		*b* (SE)[c]	*p*-value	β^d		*b* (SE)[c]	*p*-value	β^d
Perceived benefits	t = base	1029	−0.04 (0.06)	0.46	−0.0208	−0.04 (0.06)	0.47	−0.0207	1038	0.08 (0.12)	0.48	0.0198	1038	0.34 (0.20)	0.10	0.0474
(0–100%)	t = fu	1025	0.03 (0.06)	0.62	0.0137	0.03 (0.06)	0.62	0.0137	1038	−0.08 (0.12)	0.50	−0.0192	1038	−0.15 (0.25)	0.55	−0.0175
PBC (easy to quit; 1–5)	t = base	1076	**0.27 (0.06)**	**<0.001**[h]	**0.1457**	0.03 (0.07)	0.63	0.0185	1085	**0.50 (0.08)**	**<0.001**[h]	**0.1987**	1085	**0.68 (0.09)**	**<0.001**[h]	**0.2347**
	t = fu	1073	**0.17 (0.06)**	**0.003**	**0.0970**	−0.10 (0.07)	0.14	−0.0580	1085	**0.50 (0.08)**	**<0.001**[h]	**0.2046**	1085	**0.60 (0.09)**	**<0.001**[h]	**0.2177**
PBC (to avoid smoking;	t = base	1080	0.06 (0.07)	0.37	0.0283	0.01 (0.07)	0.92	0.0034	1089	**0.36 (0.13)**	**0.008**	**0.0875**	1089	**0.77 (0.22)**	**<0.001**	**0.1259**
1-5)	t = fu	1077	0.09 (0.07)	0.20	0.0426	0.01 (0.07)	0.84	0.0071	1089	0.12 (0.13)	0.39	0.0304	1089	**0.53 (0.18)**	**0.003**	**0.1036**
Objectively measured	t = base	1041	**0.37 (0.05)**	**<0.001**[h]	**0.2707**	0.07 (0.07)[f]	0.32	0.0484	1048	**0.38 (0.05)**	**<0.001**[h]	**0.2634**	1048	**0.59 (0.06)**	**<0.001**[h]	**0.3702**
smoking behavior	t = fu	1022	**0.48 (0.09)**	**<0.001**[h]	**0.3852**	**0.39 (0.09)**	**<0.001**[i]	**0.3103**	1048	**0.84 (0.06)**	**<0.001**[h]	**0.5470**	1048	**0.87 (0.06)**	**<0.001**[h]	**0.5078**
(0–30)																
Smoking susceptibility		n	OR (SE)	p-value	OR (SE)	p-value	n	OR (SE)		p-value		n	OR (SE)		p-value	
(binary)[g]	t = base	1078	**1.14 (0.04)**	**<0.001**[h]	**1.12 (0.04)**	**<0.001**	1087	1.10 (0.07)		0.12		1087	1.21 (0.12)		0.05	
	t = fu	1075	**1.14 (0.03)**	**<0.001**[h]	**1.11 (0.03)**	**0.001**	1087	**1.17 (0.06)**		**0.004**		1087	**1.31 (0.10)**		**<0.001**	

[a]In each model the outcome variable is the focal participant's (i) response to the relevant item at follow-up. The predictor variable is the average of the relevant peer group's ($-i$) responses to the equivalent item at baseline (t = base) or follow-up (t = fu), where $-i$ = (1) focal participant's nominated friends; (2) focal participant's school class; (3) focal participant's school year group. All models include robust (Huber–White) standard errors specified using Stata's 'vce(robust)' option. The following baseline variables are included as covariates in all models: Gender (0 = boy; 1 = girl/prefer not to say), Age (1 = 12 years or less; 2 = 13 years; 3 = 14 years or more), Intervention (1 = ASSIST; 2 = Dead Cool), Ethnicity (0 = no ethnic minority; 1 = ethnic minority), Socio-economic status (NI: 1 = NIMDM2017 ≤ 296.6; 2 = 296.6 < NIMDM2017 ≤ 593.2; 3 = NIMDM2017 > 593.2; Bogotá: 1 = Informal settlement/Lowest/Low; 2 = Middle-Low/Middle; 3 = Middle-High/High), and baseline values of the outcome variable.

[b]Results of models adjusted for Setting (0 = Northern Ireland; 1 = Bogotá). Baseline variables included as covariates in all models are: Gender, Age, Intervention, Ethnicity, Socio-economic status, baseline values of the outcome variable, and Setting. Results are reported for $-i$ = (1) focal participant's nominated friends.

[c]Unstandardized regression coefficients representing the average change in i's response category to the relevant question at follow-up for a one-unit increase in the average of $-i$'s responses to the equivalent item at baseline (t = base) or follow-up (t = fu), holding other variables constant.

[d]Standardized regression coefficients representing the standard deviation change in the outcome variable, for a one standard deviation increase in the predictor variable.

[e]Higher numerical values represent higher self-report anti-smoking outcomes, apart from objectively measured smoking behavior (higher numerical values represent higher levels of smoking behavior).

[f]For the model including focal participants' carbon monoxide readings at follow-up as the outcome variable, and average carbon monoxide readings for nominated friends at baseline as the predictor variable, variance inflation factors were 3.00 for Setting and 3.02 for the predictor variable when the model was adjusted for Setting.

[g]Logistic regressions were run for models including focal participants' smoking susceptibility as the outcome variable, with robust (Huber White) standard errors specified using Stata's 'vce(robust)' option. Results are odds ratios, standard errors, and p-values. Odds ratios represent the multiplicative change in odds of being susceptible to commencing smoking for a 10% increase in the number of nominated friends/pupils in the same school class/pupils in the same school year group classified as being susceptible to commencing smoking (1 out of 10 nominated friends/pupils in the same school class/pupils in the same school year group).

[h]Retained statistical significance at the 5% level after using the Holm–Bonferroni procedure to correct the p-values for multiple testing ($p \leq 0.05$; based on all tests reported in Table 5, excluding results of models which were repeated to adjust for Setting).

[i]Indicates where the p-value in models examining peer influence effects from the average responses of nominated friends still met the Holm–Bonferroni threshold when the model was additionally adjusted for Setting ($p \leq 0.05$).

Bold values show the results meeting the significance level of $p \leq 0.01$.

Table 6 Results of meta-analyses of SIENA model results for each school modeling the co-evolution of friendship ties and smoking/vaping outcomes (results reported for peer selection homophily and peer influence effects).

Outcome[a]	Effect[b]	All schools ($N = 12$)[a]						Subgroup analysis: Setting (NI: $N = 6$; Bogotá: $N = 6$)[a]							Subgroup analysis: Intervention (ASSIST: $N = 6$; DC: $N = 6$)[a]						
		Snijders and Baerveldt, (2003)[c]		Fisher's combination tests one-sided[d]		Heterogeneity (across schools)[e]		Subgroup	Snijders and Baerveldt, (2003)[c]		Fisher's combination tests one-sided[d]		Heterogeneity (across subgroups)[f]		Subgroup	Snijders and Baerveldt, (2003)[c]		Fisher's combination tests one-sided[d]		Heterogeneity (across subgroups)[f]	
		b	SE	*p*-value	df	Q-statistic	*p*-value		*b*	SE	*p*-value	df	Q-statistic	*p*-value		*b*	SE	*p*-value	df	Q-statistic	*p*-value
Experimental injunctive norms	PS	−0.20	0.15	0.2882	24	7.38	0.7672	NI	−0.40	0.23	0.0883	12	1.77	0.1828	ASSIST	−0.25	0.20	0.3214	12	0.11	0.7348
								Bogotá	−0.005	0.19	0.7576	12			DC	−0.13	0.26	0.3221	12		
	PI	**3.95**	**1.03**	**<0.0001**[g]	24	14.07	0.2292	NI	4.41	2.28	0.0053	12	0.04	0.8380	ASSIST	**5.06**	**1.52**	**0.0005**[g]	12	0.70	0.4023
								Bogotá	**3.93**	**1.21**	**0.0002**[g]	12			DC	**3.38**	**1.42**	**0.0019**	12		
Experimental descriptive norms	PS	0.10	0.22	0.2327	20	11.84	0.2223	NI	0.09	0.37	0.2907	8	<0.01	0.9609	ASSIST	0.17	0.27	0.1360	12	0.24	0.6255
								Bogotá	0.09	0.31	0.2654	12			DC	−0.08	0.43	0.3183	8		
	PI	1.57	0.78	0.0056	24	17.88	0.0844	NI	2.43	0.77	0.0371	12	1.24	0.2659	ASSIST	**3.25**	**0.26**	**0.0012**[g]	12	**42.79**	**<0.0001**[h]
								Bogotá	1.60	1.46	0.0267	12			DC	−0.08	1.32	0.4090	12		
Experimental donation to ASSIST/Dead Cool	PS	0.18	0.14	0.2494	24	9.33	0.5913	NI	0.22	0.24	0.1670	12	0.18	0.6699	ASSIST	0.37	0.19	0.0589	12	2.60	0.1068
								Bogotá	0.11	0.17	0.4703	12			DC	−0.04	0.18	0.3784	12		
	PI	**4.13**	**0.43**	**<0.0001**[g]	24	4.69	0.9451	NI	**4.41**	**0.33**	**<0.0001**[g]	12	0.93	0.3355	ASSIST	**4.03**	**0.69**	**<0.0001**[g]	12	0.07	0.7953
								Bogotá	**3.69**	**0.92**	**0.0006**[g]	12			DC	**4.26**	**0.59**	**0.0001**[g]	12		
Self-report injunctive norms	PS	−0.002	0.13	0.4608	24	7.04	0.7957	NI	0.15	0.21	0.3924	12	2.13	0.1442	ASSIST	0.09	0.18	0.6340	12	0.90	0.3437
								Bogotá	−0.21	0.17	0.2454	12			DC	−0.18	0.22	0.3896	12		
	PI	2.30	1.51	0.0757	20	9.21	0.4179	NI	3.16	0.82	0.1306	8	1.14	0.2848	ASSIST	3.62	2.05	0.0345	10	0.87	0.3508
								Bogotá	1.60	2.83	0.1438	12			DC	0.74	2.31	0.4267	10		
Self-report descriptive norms 1	PS	0.25	0.21	0.0261	24	16.85	0.1123	NI	0.32	0.10	0.0901	12	0.47	0.4943	ASSIST	0.32	0.23	0.1040	12	0.12	0.7240
								Bogotá	0.19	0.58	0.0626	12			DC	0.31	0.39	0.0537	12		
	PI	3.63	3.33	0.0115	12	11.65	0.0399	NI	**5.87**	**6.71**	**0.0019**	6	**8.82**	**0.0030**	ASSIST	**5.88**	**6.90**	**0.0023**	6	5.05	0.0247
								Bogotá	0.10	1.20	0.5646	6			DC	0.49	1.41	0.5072	6		
Self-report descriptive norms 2	PS	0.38	0.16	0.0176	24	8.50	0.6679	NI	0.42	0.28	0.0314	12	0.02	0.8799	ASSIST	0.57	0.25	0.0363	12	0.91	0.3401
								Bogotá	0.40	0.22	0.1102	12			DC	0.26	0.22	0.0968	12		
	PI	3.83	0.74	0.0294	22	2.72	0.9873	NI	4.48	1.25	0.0323	10	0.58	0.4452	ASSIST	3.77	1.34	0.0756	12	0.01	0.9126
								Bogotá	3.27	0.99	0.1720	12			DC	3.91	0.79	0.0848	10		
Self-report smoking behavior	PS	0.30	0.13	0.0074	20	8.63	0.4720	NI	0.32	0.17	0.1116	8	0.11	0.7361	ASSIST	0.36	0.14	0.0069	12	0.28	0.5941
								Bogotá	0.37	0.23	0.0121	12			DC	0.20	0.32	0.1859	8		
	PI	2.07	0.91	0.3684	12	1.12	0.9527	NI	2.18	2.18	0.3108	4	0.01	0.9401	ASSIST	1.31	1.64	0.5369	8	**24.31**	**<0.0001**[h]
								Bogotá	2.00	1.24	0.4113	8			DC	2.77	0.14	0.1984	4		
Intentions	PS	0.06	0.18	0.3878	14	4.77	0.5739	NI	0.17	0.20	0.3698	6	0.32	0.5689	ASSIST	0.001	0.20	0.5441	8	3.17	0.0748
								Bogotá	−0.02	0.34	0.5418	8			DC	0.74	0.38	0.2434	6		
	PI	**5.50**	**3.72**	**0.0023**	12	12.84	0.0249	NI	**13.56**	**4.92**	**0.0002**[g]	6	**21.75**	**<0.0001**[h]	ASSIST	8.64	9.33	0.0066	4	0.21	0.6452
								Bogotá	0.80	1.08	0.5650	6			DC	4.15	4.30	0.0378	8		
Knowledge	PS	−0.03	0.12	0.4398	24	6.20	0.8594	NI	−0.01	0.24	0.3261	12	0.09	0.7677	ASSIST	0.14	0.13	0.5077	12	2.72	0.0991
								Bogotá	−0.06	0.09	0.5486	12			DC	−0.21	0.18	0.1751	12		
	PI	2.22	0.64	0.0051	24	8.81	0.6395	NI	**2.92**	**0.68**	**0.0045**	12	1.73	0.1887	ASSIST	2.02	1.24	0.0176	12	0.08	0.7786
								Bogotá	1.25	1.19	0.1524	12			DC	2.07	0.65	0.0496	12		
Attitudes	PS	0.14	0.26	0.3080	14	6.07	0.4149	NI	0.08	0.44	0.4659	6	0.02	0.8866	ASSIST	0.23	0.46	0.2926	4	0.07	0.7960
								Bogotá	0.17	0.37	0.2343	8			DC	0.08	0.35	0.3467	10		
	PI	1.49	0.93	0.0532	24	12.39	0.3354	NI	1.51	1.68	0.0974	12	0.36	0.5482	ASSIST	1.83	1.55	0.0507	12	0.05	0.8233
								Bogotá	2.13	1.07	0.1319	12			DC	1.50	1.34	0.2324	12		
Self-efficacy (Emotional)	PS	0.30	0.17	0.0945	22	9.83	0.4554	NI	0.01	0.40	0.5766	10	0.61	0.4338	ASSIST	0.47	0.15	0.0254	12	2.40	0.1210
								Bogotá	0.37	0.22	0.0319	12			DC	−0.09	0.37	0.2938	10		
	PI	−2.64	0.89	0.1714	16	2.17	0.9496	NI	2.74	1.63	0.3242	4	**14.93**	**0.0001**[h]	ASSIST	−2.46	0.99	0.2380	8	0.05	0.8151
								Bogotá	−3.43	0.39	0.0745	12			DC	−2.91	1.84	0.2140	8		
Self-efficacy (Friends)	PS	0.22	0.21	0.1493	24	13.25	0.2775	NI	0.15	0.22	0.6242	12	0.16	0.6886	ASSIST	0.49	0.23	0.0530	12	2.28	0.1307
								Bogotá	0.31	0.39	0.0468	12			DC	−0.10	0.33	0.2806	12		
	PI	−0.52	1.44	0.3998	18	6.79	0.5599	NI	3.28	4.52	0.2524	6	0.83	0.3611	ASSIST	0.28	2.05	0.5206	8	0.33	0.5667
								Bogotá	−1.05	1.49	0.2292	12			DC	−1.54	2.43	0.3014	10		
Self-efficacy (Opportunity)	PS	0.48	0.37	0.0111	16	12.36	0.0893	NI	0.24	0.53	0.1477	4	0.27	0.6043	ASSIST	0.75	0.37	0.0055	8	0.77	0.3802
								Bogotá	0.62	0.53	0.0154	12			DC	0.10	0.77	0.2679	8		
	PI	1.96	2.01	0.1275	14	6.76	0.3437	NI	5.57	4.40	0.0302	6	2.01	0.1560	ASSIST	1.33	0.75	0.4310	8	0.72	0.3978
								Bogotá	0.39	1.36	0.6321	8			DC	2.49	5.21	0.0607	6		

Table 6 (continued)

Outcome[a]	Effect[b]	All schools ($N = 12$)[a]						Subgroup analysis: Setting (NI: $N = 6$; Bogotá: $N = 6$)[a]							Subgroup analysis: Intervention (ASSIST: $N = 6$; DC: $N = 6$)[a]						
		Snijders and Baerveldt, (2003)[c]		Fisher's combination tests one-sided[d]		Heterogeneity (across schools)[e]		Subgroup	Snijders and Baerveldt, (2003)[c]		Fisher's combination tests one-sided[d]		Heterogeneity (across subgroups)[f]		Subgroup	Snijders and Baerveldt, (2003)[c]		Fisher's combination tests one-sided[d]		Heterogeneity (across subgroups)[f]	
		b	SE	*p*-value	df	Q-statistic	*p*-value		*b*	SE	*p*-value	df	Q-statistic	*p*-value		*b*	SE	*p*-value	df	Q-statistic	*p*-value
Perceived physical risks	PS	0.13	0.13	0.2701	24	9.27	0.5969	NI	−0.03	0.12	0.6400	12	2.12	0.1457	ASSIST	−0.14	0.21	0.3412	12	**6.84**	**0.0089**
								Bogotá	0.24	0.25	0.0828	12			DC	0.38	0.11	0.1083	12		
	PI	1.11	0.54	0.2190	24	6.15	0.8630	NI	1.55	1.00	0.2607	12	0.27	0.6037	ASSIST	1.24	0.71	0.2132	12	0.09	0.7702
								Bogotá	0.92	0.68	0.2776	12			DC	0.89	0.94	0.3345	12		
Perceived social risks	PS	−0.11	0.11	0.3890	24	5.36	0.9126	NI	−0.42	0.21	0.2104	12	2.60	0.1069	ASSIST	−0.17	0.21	0.4411	12	0.18	0.6679
								Bogotá	−0.04	0.13	0.6410	12			DC	−0.06	0.14	0.3508	12		
	PI	−0.12	0.55	0.3805	24	8.17	0.6980	NI	−1.04	1.32	0.2356	12	0.56	0.4561	ASSIST	−0.25	1.11	0.2415	12	0.01	0.9129
								Bogotá	0.05	0.62	0.5397	12			DC	−0.12	0.80	0.5745	12		
Perceived addiction risks	PS	0.08	0.15	0.2726	24	8.96	0.6260	NI	0.34	0.13	0.2040	12	4.13	0.0422	ASSIST	0.17	0.23	0.1319	12	0.34	0.5582
								Bogotá	−0.05	0.26	0.4298	12			DC	−0.002	0.19	0.6427	12		
	PI	0.70	0.80	0.5471	24	10.68	0.4707	NI	1.12	0.87	0.3315	12	0.87	0.3502	ASSIST	0.36	0.87	0.6009	12	0.35	0.5569
								Bogotá	−0.80	1.88	0.1642	12			DC	−0.16	1.95	0.2575	12		
Perceived benefits	PS	0.46	0.25	0.0356	20	10.33	0.3248	NI	0.34	0.33	0.1850	12	0.23	0.6332	ASSIST	0.12	0.33	0.4457	8	1.33	0.2496
								Bogotá	0.60	0.44	0.0340	8			DC	0.65	0.36	0.0153	12		
	PI	−0.78	0.69	0.3437	12	1.60	0.9010	NI	−0.43	1.03	0.3797	8	**83.05**	**<0.0001**[h]	ASSIST	0.05	1.33	0.7014	6	**47.20**	**<0.0001**[h]
								Bogotá	−1.57	0.09	0.3102	4			DC	−1.70	0.13	0.2752	6		
PBC (easy to quit)	PS	0.23	0.14	0.1722	24	10.11	0.5204	NI	0.35	0.20	0.1210	12	0.95	0.3292	ASSIST	0.24	0.13	0.2072	12	0.16	0.6861
								Bogotá	0.06	0.23	0.4017	12			DC	0.09	0.35	0.2567	12		
	PI	0.32	0.40	0.6762	24	5.93	0.8780	NI	0.38	0.69	0.5914	12	0.02	0.8825	ASSIST	0.65	0.56	0.4226	12	0.72	0.3950
								Bogotá	0.26	0.51	0.6090	12			DC	−0.06	0.62	0.4323	12		
PBC (to avoid smoking)	PS	0.12	0.29	0.2729	20	9.20	0.4192	NI	−0.20	0.31	0.5539	8	1.20	0.2732	ASSIST	0.19	0.42	0.2516	12	0.14	0.7132
								Bogotá	0.27	0.40	0.1147	12			DC	−0.02	0.43	0.6734	8		
	PI	0.68	0.58	0.4756	22	6.17	0.8004	NI	1.71	0.74	0.1760	10	3.24	0.0718	ASSIST	1.01	0.67	0.4064	12	0.48	0.4863
								Bogotá	−0.20	0.77	0.4163	12			DC	0.13	1.12	0.5096	10		
Objectively measured smoking behavior	PS	0.39	0.36	0.4672	14	3.63	0.7260	NI	−1.10	0.36	0.2462	4	**17.14**	**<0.0001**[h]	ASSIST	−0.16	0.23	0.5476	6	5.57	0.0183
								Bogotá	0.59	0.35	0.2521	10			DC	0.51	0.61	0.2537	8		
	PI	**8.12**	**1.48**	**<0.0001**[g]	20	15.79	0.0713	NI	**10.83**	**2.68**	**<0.0001**[g]	10	2.99	0.0839	ASSIST	**8.98**	**2.57**	**<0.0001**[g]	12	0.25	0.6175
								Bogotá	**6.34**	**1.27**	**<0.0001**[g]	10			DC	**7.58**	**1.46**	**<0.0001**[g]	8		
Smoking susceptibility	PS	**0.17**	**0.06**	**0.0017**	22	11.35	0.3308	NI	0.19	0.09	0.0101	12	0.05	0.8281	ASSIST	0.11	0.08	0.0388	12	3.58	0.0586
								Bogotá	0.16	0.10	0.0264	10			DC	0.32	0.09	0.0062	10		
	PI	0.77	0.49	0.2351	22	5.66	0.8433	NI	0.57	0.61	0.4990	12	0.14	0.7083	ASSIST	0.85	0.74	0.1615	12	0.05	0.8179
								Bogotá	0.94	0.90	0.1305	10			DC	0.62	0.74	0.4671	10		

SIENA simulation investigation for empirical network analysis, *NI* Northern Ireland, *ASSIST* A Stop Smoking in Schools Trial, *DC* dead dool, *b* unstandardized coefficient, *SE* standard error, *df* degrees of freedom, *PS* peer selection, *PI* peer influence, *PBC* perceived behavioral control.

[a]For some of the meta-analyses, individual schools are excluded due to non-convergence of the SIENA models. Various parameters are also constrained for some SIENA models due to non-convergence or multi-collinearity issues. Score tests for fixed parameters were all non-significant ($p > 0.05$) indicating the goodness-of-fit of the models was not decreased. The results of the meta-analyses for each of the smoking/vaping outcomes are reported and discussed in full in Supplementary Tables S11–S31. See the footnotes of Tables S11–S31 for details of excluded schools and constrained parameters for each of the smoking/vaping outcomes.

[b]PS: Smoking/vaping outcome similarity (peer selection homophily) effect. PI: Smoking/vaping outcome friends (peer influence) effect. See Table 2 for definitions of effects included in all SIENA models. Table 6 reports the results of peer selection homophily and peer influence effects for the meta-analysis for each outcome. The results of the meta-analyses for each of the smoking/vaping outcomes are reported and discussed in full in Supplementary Tables S11–S31.

[c]Unstandardized coefficients according to the meta-analytic method of Snijders and Baerveldt (2003).

[d]*p*-values are calculated using Fisher's combination of one-sided tests procedure (Fisher, 1925; Hedges and Olkin, 1985). The test statistic follows a chi-squared distribution with ($2N$) degrees of freedom (N = number of combined estimates for each parameter). Only one-sided *p*-values in the direction of the sign of the Snijders and Baerveldt coefficients are reported. One-sided *p*-values in the other direction were all non-significant. Bold values indicate significant results ($p \leq 0.005$).

[e]Heterogeneity (across schools): Tests the null hypothesis that the effect parameters are constant across schools using the methods of Cochran (1954), adapted for social network analysis by Snijders and Baerveldt (Cochran, 1954; Snijders and Baerveldt, 2003). The *Q*-statistic follows a chi-squared distribution with ($N-1$) degrees of freedom (N = number of combined estimates for each parameter). Bold values indicate significant differences across schools ($p \leq 0.01$).

[f]Heterogeneity (across subgroups): Tests the null hypothesis that the effect parameters are constant across subgroups (NI versus Bogotá for 'Setting', ASSIST versus Dead Cool for 'Intervention') using methods for testing differences across subgroups from the Cochrane Handbook (Higgins and Thomas, 2022). The *Q*-statistic follows a chi-squared distribution with (N-1) degrees of freedom (N = number of subgroups, i.e., $N = 2$). Bold values indicate significant differences across subgroups ($p \leq 0.01$).

[g]Indicates where the *p*-value from the Fisher's combination of one-sided tests procedure retained statistical significance at the 5% level after using the Holm–Bonferroni procedure to correct the *p*-values for multiple testing ($p \leq 0.025$; each *p*-value is adjusted for 21 tests, i.e., the number of smoking/vaping outcomes).

[h]Indicates where the *p*-value from the heterogeneity test (across schools or across subgroups) retained statistical significance at the 5% level after using the Holm–Bonferroni procedure to correct the *p*-values for multiple testing ($p \leq 0.05$; each *p*-value is adjusted for 21 tests, i.e., the number of smoking/vaping outcomes).

Bold values show the results meeting the significance level of $p \leq 0.005$ for Fisher's combination tests (one-sided), and $p \leq 0.01$ for heterogeneity tests (across schools or subgroups).

smoking amongst adolescents (East et al., 2019), and that the number of adolescents who have never smoked but have tried vaping is increasing (McNeill et al., 2019).

By contrast, many of the self-report injunctive and descriptive smoking norms outcomes showed no significant peer influence effects in our OLS regressions (objective 2). However, most of these items inquire about perceived approval for smoking or engagement in smoking behaviors of specific groups (e.g., mothers, fathers, siblings). Peer influence effects were observed for self-report norms items enquiring about approval for smoking or engagement in smoking behavior from more generic groups (e.g., "most of the people who are important to me", "friends", "best friends", "other family members", or "classmates"). Our CLPM results complemented these findings by generally showing that peer influence and selection homophily operated simultaneously for these individual items (objective 3). In the SIENA models, the peer influence effect approached significance for self-report descriptive norms scale 1 (enquiring about how often important others engage in smoking), whilst the peer selection homophily effect approached significance for self-report descriptive norms scale 2 (enquiring about the proportion of groups of important others who are smokers; objective 4). Our mixed-effects logistic regressions suggested that the self-report norms were more important for selection homophily processes, particularly for friend nominations at baseline (objective 1). Since the self-report norm measures are more subject to social desirability biases, our participants could have been exhibiting a desire to conform to behaviors and attitudes of friends when responding to the self-report norm items (Murray et al., 2020).

Self-report smoking behavior, intentions, other self-report smoking-related outcomes, and objectively measured smoking behavior were subject to both selection homophily and peer influence. The largest effect sizes in the regression analyses were observed for objectively measured smoking behavior for selection homophily processes (objective 1) and peer influence (objective 2). Similar to Hoffman et al., our CLPM results showed some evidence that peer influence and selection homophily were simultaneously operating between baseline and follow-up for self-report smoking behavior (the selection homophily path was statistically significant, the peer influence path approached statistical significance) (Hoffman et al., 2007). Our CLPMs also showed similar results for smoking intentions, susceptibility, and objectively measured smoking behavior (objective 3). In the SIENA models, the peer selection homophily effect was significant for smoking susceptibility and approached significance for self-report smoking behavior. The peer influence effect was significant for intentions and objectively measured smoking behavior and approached significance for knowledge of smoking (objective 4). Previous studies have also found evidence of selection homophily and/or peer influence effects for adolescent smoking behavior and susceptibility (Go et al., 2012; Hoffman et al., 2007; Mercken et al., 2012; Robalino and Macy, 2018).

While there may be a temporal lag between when peer influence occurs and when it exerts its effects on outcomes (E. Krupka et al., 2016), an individual's current social context may also enhance or diminish that influence. In our OLS regressions, we examined lagged peer influence effects (from nominated friends, school classes, and school year groups at baseline), and contemporaneous peer influence effects (from nominated friends, school classes, and school year groups at follow-up; objective 2) for smoking/vaping outcomes at follow-up. Of the observed significant peer influence effects, 48.4% were from baseline and 51.6% were from follow-up. For most outcomes, the significant peer influence effects were dispersed fairly evenly between baseline and follow-up. For the experimental outcome capturing participants' willingness to pay to support anti-smoking norms (donations to ASSIST/Dead Cool), the contemporaneous social context at follow-up was more important (e.g., peer influence effects were observed from follow-up scores of friends, school classes, and school year groups, but no peer influence effects were observed from baseline scores). By contrast, Krupka et al., found evidence of peer influence for an incentivized measure of patience that pertained to both lagged and contemporaneous behavior in the network (E. Krupka et al., 2016). However, peer influence effects for donations to ASSIST/Dead Cool were positive and significant in the SIENA models (objective 4), and approached significance in the CLPMs (objective 3). The SIENA models and CLPMs both account for changes in smoking/vaping outcomes between baseline and follow-up (for both the focal participants and their nominated friends). Selection homophily processes were also examined in terms of the association between adding or dropping friends, with absolute differences between focal participants' and potential friends' outcomes at both baseline and follow-up (objective 1). Again, the social context at baseline and the contemporaneous social context at follow-up were both important in determining network movements between baseline and follow-up.

In our OLS regressions, similar proportions of significant influence effects were observed from friends, school classes, and school year groups, and the magnitude of the standardized regression coefficients was similar for peer influence effects from the three groups (objective 2). Previous research has also investigated the roles of proximal (close friends in the immediate social circle) versus distal (e.g., the peer group one interacts with as part of a larger community within their school year group) peers in developing adolescents' health-related attitudes and behavior (Paek and Gunther, 2007; Salvy et al., 2014). Peer proximity has been shown to moderate the indirect effect of media messages on adolescent smoking intentions and attitudes via changes in perceived peer norms, with changes in perceived norms of more proximal peers having a greater impact (Paek and Gunther, 2007). Theoretically, peer influence may operate at both the proximal and distal levels, however, the influence mechanisms may be different (Paek and Gunther, 2007). Whilst peer pressure may explain proximal peer influence, distal peer influence may operate more subtly by diffusion of a normative climate of standards and values (Bearman et al., 1999; Paek and Gunther, 2007). The influence of perceived norms from distal peers on behavior may be more removed from everyday experiences. Perceived norms may form due to direct observations of individuals' behavior, which are perpetuated and inflated through social conversations (Salvy et al., 2014). Proximal peer influence (e.g., having close friends who smoke) is more likely to have a direct impact on behavior since young people in close relationships spend more time together, observe each other's behavior, and share environments and opportunities where behaviors are engaged in (Salvy et al., 2014). Our results suggest both mechanisms may be important sources of peer influence on adolescent smoking.

Our approach of comparing estimates of selection homophily and peer influence effects from conventional regression methods with SIENA models is advantageous in this respect. Whilst it has been argued that results from regression methods may overestimate selection homophily and peer influence effects, compared to SIENA models which explicitly control for network dynamics and structures (Ragan et al., 2019), the SIENA models do not allow us to unearth peer influence effects from distal peers throughout the whole school year group (i.e., the social network in MECHANISMS schools) as well as proximal peers (i.e., nominated friends). There are also slight differences in how peer influence is defined between the regression-based (objectives 1–3) and SIENA (objective 4) methods. Whilst the regressions use

Table 7 The relative contributions of peer selection effects, peer influence effects, and control or alternative explaining mechanisms to similarities between friends for each of the smoking/vaping outcomes.

Outcome	All schools ($N = 12$)[a]				Subgroup analysis: Setting (NI: $N = 6$; Bogotá: $N = 6$)[a]					Subgroup analysis: Intervention (ASSIST: $N = 6$; DC: $N = 6$)[a]				
	% network autocorrelation attributed to each parameter block[b]				Subgroup	% network autocorrelation attributed to each parameter block[b]				Subgroup	% network autocorrelation attributed to each parameter block[b]			
	PS	PI	Undetermined	Control		PS	PI	Undetermined	Control		PS	PI	Undetermined	Control
Experimental injunctive norms	0.13	89.06	3.18	7.63	NI	0.00	86.84	0.00	13.16	ASSIST	5.50	79.70	1.16	13.64
					Bogotá	15.15	74.80	6.49	3.57	DC	0.00	100.00	0.00	0.00
Experimental descriptive norms	0.00	81.59	0.00	18.41	NI	0.00	83.26	0.00	16.74	ASSIST	26.08	64.01	1.05	8.87
					Bogotá	31.30	53.64	1.76	13.30	DC	0.00	35.23	0.00	64.77
Donation	3.90	83.46	0.59	12.05	NI	4.78	78.19	1.48	15.55	ASSIST	18.10	66.90	3.31	11.69
					Bogotá	1.66	91.05	0.84	6.45	DC	0.00	89.73	0.00	10.27
Self-report injunctive norms	0.00	100.00	0.00	0.00	NI	20.50	52.84	26.66	0.00	ASSIST	0.00	100.00	0.00	0.00
					Bogotá	0.00	100.00	0.00	0.00	DC	0.00	0.00	0.00	100.00
Self-report descriptive norms 1	38.48	45.24	2.07	14.22	NI	34.67	45.17	0.76	19.40	ASSIST	35.73	59.91	3.35	1.01
					Bogotá	42.38	44.34	5.71	7.57	DC	42.61	23.15	0.15	34.09
Self-report descriptive norms 2	50.30	42.85	3.83	3.02	NI	46.83	45.24	7.93	0.00	ASSIST	51.17	42.77	1.94	4.13
					Bogotá	48.83	35.51	4.66	11.00	DC	49.23	42.96	6.14	1.67
Self-report smoking behavior	50.13	15.37	5.44	29.06	NI	37.22	27.19	7.85	27.73	ASSIST	55.16	8.04	8.07	28.73
					Bogotá	57.88	8.27	3.99	29.86	DC	38.08	31.52	0.59	29.81
Intentions	11.70	59.21	2.44	26.65	NI	9.72	59.51	1.78	28.99	ASSIST	2.51	60.04	7.29	30.16
					Bogotá	0.00	0.00	0.00	100.00	DC	21.81	51.62	6.14	20.44
Knowledge	0.00	88.99	0.00	11.01	NI	0.00	91.31	0.00	8.69	ASSIST	0.00	93.40	0.00	6.60
					Bogotá	0.00	84.72	0.00	15.28	DC	0.00	85.55	0.00	14.45
Attitudes	0.00	71.46	0.00	28.54	NI	0.00	80.99	0.00	19.01	ASSIST	0.00	82.01	0.00	17.99
					Bogotá	0.00	54.82	0.00	45.18	DC	9.19	41.80	7.29	41.72
Self-efficacy (Emotional)	38.85	0.00	0.00	61.15	NI	0.00	0.00	0.00	100.00	ASSIST	51.70	0.00	0.00	48.30
					Bogotá	55.87	0.00	0.00	44.13	DC	0.00	0.00	0.00	100.00
Self-efficacy (Friends)	27.21	0.00	0.00	72.79	NI	0.00	0.00	0.00	100.00	ASSIST	39.14	0.00	0.00	60.86
					Bogotá	43.00	0.00	0.00	57.00	DC	0.00	0.00	0.00	100.00
Self-efficacy (Opportunity)	75.81	0.00	2.39	21.79	NI	40.34	56.06	3.60	0.00	ASSIST	87.86	0.00	0.00	12.14
					Bogotá	74.29	0.00	0.00	25.71	DC	0.00	11.32	17.79	70.90
Perceived physical risks	28.03	0.81	0.13	41.03	NI	0.00	29.85	0.00	70.15	ASSIST	0.00	33.76	2.52	63.72
					Bogotá	43.79	29.93	0.59	25.69	DC	57.21	24.72	2.74	15.33
Perceived social risks	0.00	0.00	0.00	100.00	NI	0.00	0.00	0.00	100.00	ASSIST	45.35	0.00	0.00	54.65
					Bogotá	39.77	16.50	5.09	38.64	DC	0.00	0.00	0.00	100.00
Perceived addiction risks[a]	92.57	0.00	0.00	7.43	NI	99.14	0.00	0.00	0.86	ASSIST	78.73	0.00	0.00	21.27
					Bogotá	86.50	0.00	0.00	13.50	DC	0.00	0.00	0.00	100.00
Perceived benefits	47.16	0.00	0.00	52.84	NI	60.61	0.00	0.00	39.39	ASSIST	0.00	0.00	0.00	100.00
					Bogotá	18.67	0.00	0.00	81.33	DC	75.10	0.00	0.00	24.90
PBC (easy to quit)	63.09	0.00	0.00	36.91	NI	77.57	0.00	0.00	22.43	ASSIST	66.11	0.00	0.00	33.89
					Bogotá	50.99	0.00	0.00	49.01	DC	0.00	0.00	0.00	100.00
PBC (to avoid smoking)	99.35	0.00	0.00	0.65	NI	0.00	92.02	0.00	7.98	ASSIST	100.00	0.00	0.00	0.00
					Bogotá	100.00	0.00	0.00	0.00	DC	81.51	0.00	0.00	18.49
Objectively measured smoking behavior	8.41	90.18	1.41	0.00	NI	1.31	89.00	9.69	0.00	ASSIST	3.06	89.39	7.55%	0.00%
					Bogotá	8.34	82.70	8.96	0.00	DC	8.47	82.43	9.10%	0.00%
Smoking susceptibility	54.44	25.45	1.18	18.92	NI	61.85	13.65	0.26	24.23	ASSIST	46.44	36.06	1.04%	16.46%
					Bogotá	48.49	34.93	1.92	14.66	DC	65.86	10.31	1.39%	22.44%

NI Northern Ireland, *ASSIST* A Stop Smoking in Schools Trial, *DC* Dead Cool, *PS* peer selection, *PI* peer influence, *PBC* perceived behavioral control.

[a]For some of the meta-analyses, individual schools are excluded due to non-convergence of the original SIENA models, and exclusion from the meta-analysis. In addition, for perceived addiction risks of tobacco use, Schools 5 and 7 are excluded due to non-convergence of the SIENA models when excluding peer selection effects. See details alongside Supplementary Figs. S74–S115.

[b]Calculations are based on the decomposition of the mean Moran's *I* statistic from networks simulated under different model specifications (1. including both peer selection and peer influence effects; 2. excluding peer selection effects; 3. excluding peer influence effects; 4. excluding peer selection and peer influence effects). For each model specification, 500 networks were simulated from the SIENA model results on the observed networks in each school (24,000 simulated networks in total for outcomes with all 12 schools included). Decompositions (calculated by comparing the mean Moran's I across the simulated networks under each model specification in each school) are presented for all schools, and by subgroups of schools (Northern Ireland schools, Bogotá schools, ASSIST schools, and Dead Cool schools).

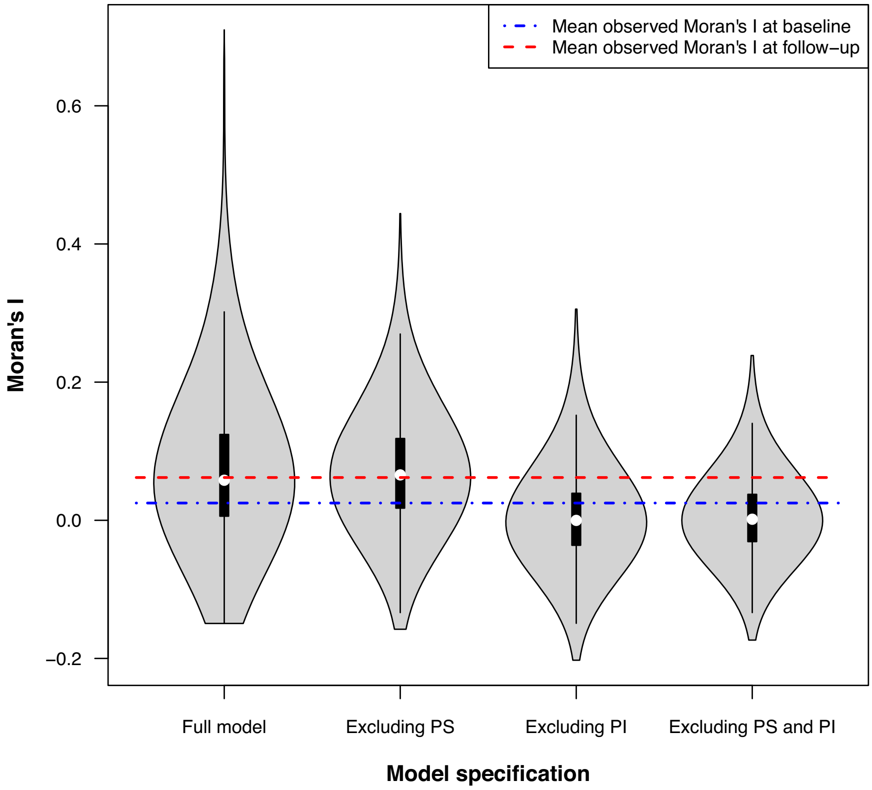

Fig. 4 Violin plot showing the distribution of Moran's *I* statistic for experimental injunctive norms for smoking/vaping across networks simulated under different model specifications. The distribution of the Moran's *I* statistic is shown for networks simulated under the following model specifications: (1) including both peer selection and peer influence effects ("Full"); (2) excluding peer selection effects ("Excluding PS"); (3) excluding peer influence effects ("Excluding PI"); and (4) excluding peer selection and peer influence effects ("Excluding PS and PI").

peer-group averages on the outcome variables, the SIENA models use the average of centered similarity scores describing each participant's similarity to his/her nominated friends on the outcome variables (Ripley et al., 2022). This may have affected our assessment of peer influence for the following smoking/vaping outcomes, which showed significant peer influence effects from both proximal peers (nominated friends) and distal peers (school classes and school year groups) in the OLS regressions and CLPMs (objectives 2 and 3) but non-significant peer influence effects in the SIENA models (objective 4): self-report descriptive norms scale 2, self-report smoking behavior, perceived social and addiction risks, perceived behavioral control (easy to quit smoking), and smoking susceptibility.

On the other hand, our results may indeed reflect a tendency for regression methods to produce larger estimates of selection homophily and peer influence effects compared to SIENA models. Whilst our CLPMs showed selection homophily and peer influence generally operated simultaneously between baseline and follow-up for our smoking/vaping outcomes (objective 3), we did not find evidence for both effects operating together in any of the SIENA models (objective 4). However, when Ragan et al., previously investigated this issue empirically they found no evidence that regression methods were biased towards overestimating peer influence compared to SIENA (Ragan et al., 2019). On the contrary, the authors found that their SIENA models produced larger estimates of peer influence compared to the regressions. They concluded that regression methods with adequate statistical controls may even have the potential to produce more conservative peer influence estimates, although they assume independence among actors and generally do not account for endogenous network processes (Ragan et al., 2019). Furthermore, our decomposition of the mean Moran's I across networks simulated under different model specifications, indicated that comparable percentages of network autocorrelation (i.e., the similarity between friends across the 21 smoking/vaping outcomes examined in the SIENA models) were attributable to selection homophily (32.8%) and peer influence (39.2%; objective 4). These proportions are also similar to (or even greater than) those reported in previous studies finding evidence for the importance of selection homophily and/or peer influence processes in determining adolescents' smoking outcomes (Mercken et al., 2009, 2012).

When we broke these proportions down by intervention group, we found that a higher proportion of similarity between friends on the smoking/vaping outcomes was attributable to selection homophily and/or peer influence for ASSIST schools (74.6%) compared to Dead Cool schools (53.8%; objective 4). This finding accords with the theoretical underpinnings of the programs, and our study hypotheses (Hunter et al., 2020). Specifically, we expect to observe more network-mediated change in outcomes in ASSIST schools compared to Dead Cool, since the ASSIST program is specifically designed to leverage peer influences whilst the Dead Cool program is based on more conventional classroom pedagogy (Campbell et al., 2008; Thurston et al., 2019). Previous evaluations of social network processes for smoking outcomes in the original ASSIST and Dead Cool trials support this finding. For example, whilst Mercken et al., found evidence for peer influence and selection homophily in the original ASSIST trial (although selection homophily was the more salient predictor of smoking behavior) (Mercken et al., 2012), Badham et al., found no evidence for the diffusion of smoking-related attitudes through school friendship networks in Dead Cool (Badham et al., 2019).

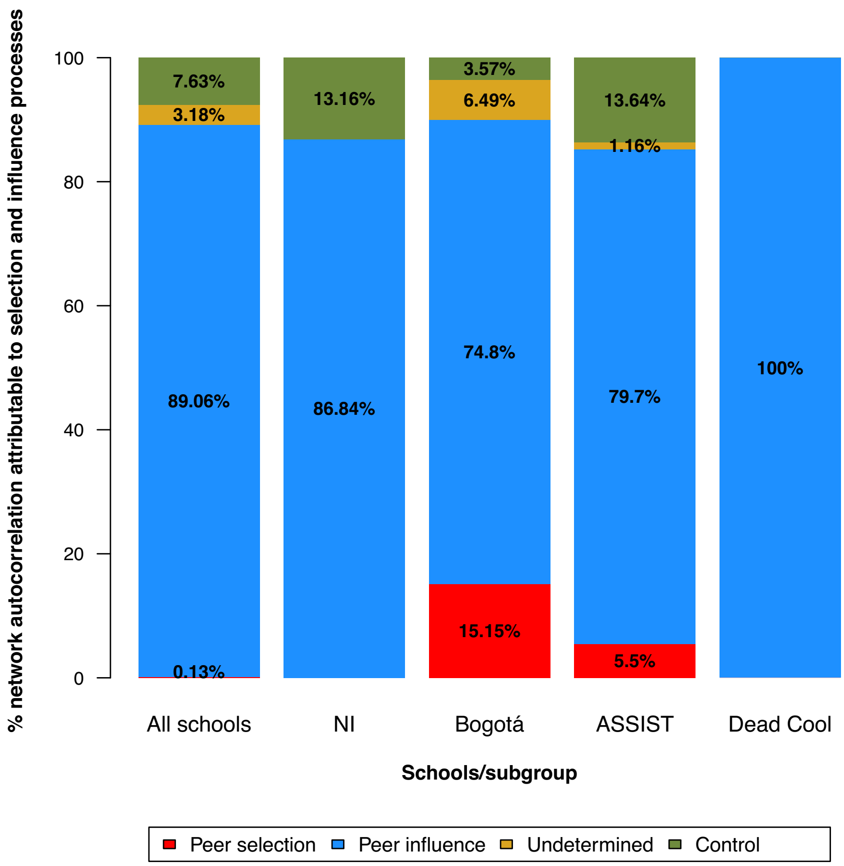

Fig. 5 Bar plot showing the decomposition of Moran's I statistic into parameter blocks for experimental injunctive norms for smoking/vaping. The bars show the relative contribution of peer selection effects, peer influence effects, and control/alternative explaining mechanisms to similarities between friends for experimental injunctive norms for smoking/vaping. Calculations are based on the decomposition of the mean Moran's *I* statistic from networks simulated under different model specifications (1. including both peer selection and peer influence effects; 2. excluding peer selection effects; 3. excluding peer influence effects; 4. excluding peer selection and peer influence effects). For each model specification, 500 networks were simulated from the SIENA model results on the observed networks in each school ($N = 12$; 24,000 simulated networks in total). Decompositions (calculated by comparing the mean Moran's I across the simulated networks under each model specification in each school) are displayed for all schools, and by subgroups of schools (Northern Ireland schools, Bogotá schools, ASSIST schools, and Dead Cool schools).

Our subgroup analyses also showed that peer selection homophily effects were stronger in Bogotá compared to NI (for objectively measured smoking behavior), whilst peer influence effects were stronger in NI compared to Bogotá (for self-report descriptive norms scale 1, intentions, the self-efficacy emotional subscale, and perceived benefits). Furthermore, the percentage of similarity between friends across the 21 smoking/vaping outcomes examined in the SIENA models that were due to peer selection homophily was >10% higher in Bogotá compared to NI (the percentage of similarity between friends due to peer influence was >10% higher in NI compared to Bogotá). Thus, whilst we did not find evidence that similarity between friends on the smoking/vaping outcomes differed between the settings overall, we did find evidence that for at least some smoking/vaping outcomes, the mechanisms producing smoking/vaping-based homogeneity in the networks (selection homophily versus peer influence) differed between the settings.

Strengths and limitations. Strengths of this paper include the large sample size, and inclusion of data collected in two settings with varying norms, cultural traits, regulatory contexts, and health behavior patterns. Prior to implementation in Bogotá, all study materials were culturally adapted (Sánchez-Franco et al., 2021). We have investigated selection homophily and peer influence effects for self-report and objective measures of smoking behavior and for smoking norms assessed by self-report and experimental methods. This is the first study to apply experimental methods to elicit norms for adolescent smoking and vaping behaviors (Hunter et al., 2020). Experimental methods of eliciting social norms mitigate social desirability bias and provide richer insights to better explain behavioral heterogeneity and potentially deepen our understanding of the mechanisms of norms-based public health interventions (Murray et al., 2020). Since temporal precedence is one of the necessary conditions for making causal inferences (i.e., a cause should temporally precede an effect) (Kenny, 1979), our longitudinal study design directly lends itself to inferring which mechanism (selection homophily or peer influence) is pre-dominant in the regression models examining lagged effects under objectives 1 and 2, and in the CLPMs examining reciprocal relationships between focal participant and friends' variables under objective 3. Since an individual's current social context may be the most prominent influence, these models were repeated to examine contemporaneous selection homophily and peer influence effects at follow-up (objectives 1 and 2). The lack of temporality in this latter set of models is a potential limitation. That is, the outcome variable (focal participants' smoking/vaping outcomes), and the predictor variable (average peer group responses to the smoking/vaping outcomes) were both measured at follow-up and so the predictor variable does not temporally precede the outcome variable.

Disentangling selection homophily and peer influence have been recognized as challenging (Ragan et al., 2019; Shalizi and Thomas, 2010), and we believe that our comparison of results from different statistical approaches (regressions, CLPMs, and SIENA) is a strength of this paper. It has been argued that results from regression methods may overestimate selection homophily and peer influence effects, compared to SIENA models which explicitly control for network dynamics and structures (Ragan et al., 2019). However, a previous study conducted by Ragan et al. investigated this issue empirically and found no evidence that regression methods were biased towards overestimating peer influence compared to SIENA (Ragan et al., 2019). Furthermore, distal peer influence is not accounted for in the SIENA models. By contrast, our regression analyses specifically examine peer influence from both proximal (i.e., nominated friends) and distal peers (i.e., school classes and school year groups; objective 2). This is particularly important for the experimental norms outcomes, which ask participants to infer norms in the entire school year group (friends and non-friends). Since selection homophily is a process that involves selecting your friends based on observable or known characteristics, the experimental norms cannot really be susceptible to selection homophily in the same way, because they are unobserved. We believe that the absence of material differences between the ORs for experimental and self-report variables in our regression-based assessment of selection homophily (objective 1) strengthens our conclusions about peer influence. Our regression-based analyses (objectives 1 and 2) also offered the opportunity to take a closer look at the temporality of the peer selection and peer influence processes.

This paper has several other limitations. The MECHANISMS study included a relatively small sample of schools. We endeavored to recruit schools with a range of deprivation levels and mixed gender. Our results should be interpreted with caution due to multiple testing. We accounted for multiple testing by discussing our results with reference to a more stringent significance criterion ($p \leq 0.01$). The issue of adjusting for multiple testing within a study is widely debated. There are no established rules or guidance, and several prominent academics have made a strong case for why it is not always desirable, or even correct, to adjust for multiple testing (Feise, 2002; Perneger, 1998; Rothman, 1990). Whilst adjusting p-values for multiple testing reduces type one error rates (the rate of falsely declaring a significant result), they also increase type two error rates (declaring a null result in error), meaning that important findings can be missed. Our paper also set out to test theoretically justifiable hypotheses (i.e., that, for peer influence, we would observe correlated smoking-related outcomes for pupils and their friends, and that pupils would be more likely to nominate friends who are similar to themselves on smoking-related outcomes, for selection homophily). Therefore, we adopted the approach of discussing all results meeting the $p \leq 0.01$ criterion. Throughout our results tables, we have also highlighted which results would have attained significance at the $p \leq 0.05$ level after using the Holm–Bonferroni procedure to adjust the p-values for multiple testing (Holm, 1979). Our results are based on complete case analyses, so nominated friends with missing attribute data were excluded. However, we had a high participation rate across the schools (93.1%), and rates of completion for the experiments (93.1–94.6%) and survey (90.0–94.8%) were high at both timepoints.

Implications for future research. Peer influence is an important determinant of adolescent smoking and vaping norms, smoking behavior, and other smoking-related outcomes. This is true for influence from proximal and distal peers and for lagged and contemporaneous peer influence effects. Thus, our findings support using the social norms approach as an intervention strategy to change health behaviors (altering perceived peer norms in such a way as to convince individuals that their peers approve of, or engage in, the desired behavior) (Dempsey et al., 2018). In line with one of our study's main hypotheses, our results provide some evidence that there was more network-mediated change in smoking/vaping outcomes in ASSIST schools compared to Dead Cool schools (with a higher percentage of similarity between friends attributable to selection homophily and/or peer influence for ASSIST schools compared to Dead Cool). This is expected since the ASSIST program is specifically designed to leverage peer influences (Campbell et al., 2008). We also found some indication that whilst smoking/vaping-based similarity between friends was similar across the settings, the mechanisms producing smoking/vaping-based homogeneity within the networks (i.e., selection homophily versus peer influence mechanisms) differed in NI compared to Bogotá, for at least some of the outcomes. In future research, we intend to use moderator analysis to investigate whether the peer influence effects examined in our OLS regressions (objective 2) differ according to setting (NI versus Bogotá), intervention (ASSIST versus Dead Cool), personality characteristics, or social network positions. For example, previous research suggests that social influences may have a stronger impact on the behavior of individuals with characteristics (e.g., personality, cultural, and environmental traits) that make them susceptible to social influences (Stacy et al., 1992). Our results suggest that peer influence on adolescent smoking and vaping outcomes operates from both proximal and distal peers within schools. However, there may be heterogeneity in school-level influence across different schools (e.g., the SIENA model results showed evidence for school-level heterogeneity for some of the social network structural effects; Supplementary Tables S11–S31). Therefore, investigating moderation of the peer influence effects according to different social network characteristics and parameters is an important area for our future research.

It is also interesting to note recent novel conceptualizations of attitude formation which take account of network theories that are being invoked to reconcile the "connectedness" of related psychological substrates at the individual level and the connectedness of individuals sharing similar attitudes. For example, Dalege et al., have conceived of attitudes as "systems of causally interacting evaluative psychological reactions that strive for a coherent representation of the attitude object" (Dalege et al., 2016). Based on this basic idea, they have developed the "Causal Attitude Network" (CAN) model that links research on attitudes to network theory. Important tenets of the model are that: (1) networks of variables affecting attitudes (elicited for example in large population surveys) show a high degree of clustering, with similar evaluative reactions exerting stronger influence on each other than dissimilar evaluative reactions, and; (2) that strong attitudes correspond to highly connected attitude networks. It is claimed that CAN models may to some degree reflect biological substrates (with respect to the interconnections between brain regions) (Telzer et al., 2021). Telzer et al., claim that some measures of network connectivity may better predict behavior than the raw psychological constructs themselves when incorporated into traditional regression-based models (Telzer et al., 2021). In a recent Nature paper, Galesic et al., (including Dalege) called for a number of enhancements of existing CAN models, including the need to account for the dependency of people's beliefs (what they refer to as social sensing, a notion resonating closely with the action of social norms), and a drive to improve their informational value through machine learning approaches (Galesic et al., 2021). We aim to incorporate a CAN perspective in future sensitivity analyses of our examination of selection homophily and peer influence for our MECHANISMS school friendship networks.

Another avenue for future research revolves around the elaboration of alternative functional forms of the norms' susceptibility concept (e.g., the Kimbrough–Vostroknutov model used in the MECHANISMS study), and their incorporation in studies of selection homophily and social influence and their behavioral determinants (Kimbrough and Vostroknutov, 2016, 2018; Krupka and Weber, 2013). One possible choice was illustrated in the CASCADE study on alcohol consumption, and the authors claim that the use of a machine learning approach in a generative social science endeavor may lead to more efficient representations of this mechanism in the future (Probst et al., 2020).

Future research should also investigate whether these results apply in different settings. Our results support the recommendation that adolescent smoking prevention research should consider both selection homophily and social influence processes, as comparable proportions of similarity between friends on the smoking/vaping outcomes were due to selection homophily and peer influence across all schools (Mercken et al., 2009, 2012).

Conclusions

This paper investigates selection homophily and peer influence effects for adolescent smoking and vaping-related outcomes collected as part of the MECHANISMS study using regression-based methods, structural equation modeling (CLPMs), and SIENA models. Lagged and contemporaneous peer influence effects were shown to be an important determinant of adolescent smoking and vaping norms, and other smoking-related outcomes, from both proximal peers in friendship networks and distal peers throughout whole school year groups. Selection homophily in peer selection was determined, at least partly, by similarities and dissimilarities with potential friends on smoking and vaping outcomes. Overall, we found comparable proportions of similarity between friends on the smoking/vaping outcomes were due to selection homophily and peer influence. We also found evidence that a higher percentage of similarity between friends was attributable to selection homophily and/or peer influence for ASSIST schools compared to Dead Cool. Whilst smoking/vaping-based similarity between friends was similar across the settings, the mechanisms producing smoking/vaping-based homogeneity within the networks seem to differ in NI compared to Bogotá, for at least some of the outcomes (selection homophily was more important in Bogotá whilst peer influence was more important in NI). These findings support using social norms strategies in adolescent smoking prevention interventions. Future adolescent smoking prevention research should investigate both selection homophily and social influence processes, examine potential moderators of these peer influence effects, and investigate whether these findings translate to other settings with varying cultural and normative traits.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available as participants were informed that no-one outside of the research team would have access to the research data when they signed their consent forms. Detailed break-downs of the syntax used to generate the results for the study have been provided in the Supplementary Methods. For further information about the study datasets, please contact the corresponding authors (Emails: Jennifer.Murray@qub.ac.uk; ruth.hunter@qub.ac.uk).

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Author contributions

JMM was a Research Fellow working on the study in NI, led the statistical analysis and drafted the manuscript. SCS was a Research Fellow working on the study in Bogotá, led the cultural adaptation, and assisted with the interpretation of the results in Bogotá. OLS, FK, and RFH were study Principal Investigators and helped draft the manuscript. EOK, RK, AR, and ELK were study co-Investigators and designed the experiments. CT was a PhD student working on the study, and helped with data collection and delivery of the intervention programs in NI. SCM was a post-doctoral researcher working on the study, and helped with data collection and delivery of the intervention programs in NI. LD was a study co-Investigator, and led the school recruitment in NI. FM and HZ were study co-Investigators and advised on analyzing the social network data. LM and LB were study co-Investigators with expertise in tobacco research who helped design the study and contributed to the manuscript. BL is a tobacco control expert who contributed to the cultural adaptation in Bogotá. All authors reviewed and approved the final manuscript, and contributed to the study design.

Competing interests

The authors declare no competing interests.

Ethical approval

The study was approved by the School of Medicine, Dentistry and Biomedical Sciences Ethics Committee at Queen's University Belfast on September 21, 2018 (ref. 18:43) and by the Research Ethics Committee at the University of Los Andes on July 30, 2018 (ref. 937/2018). This study complies with all relevant ethical regulations. All study procedures were carried out in accordance with institutional guidelines for research involving human participants and with the Declaration of Helsinki.

Informed consent

Written, informed consent was obtained for all participants. Prior to the baseline assessment, each school was provided with Teacher information sheets, Pupil information sheets, Parent/guardian information sheets, Pupil consent forms, and Parent/guardian opt-out forms. All pupils were required to complete written consent forms indicating whether they agreed or declined to participate. Parents/guardians who did not wish their child to take part were asked to return completed opt-out forms. The experimental protocol, and all data collection procedures, were carried out in accordance with institutional guidelines for research involving human participants and with the Declaration of Helsinki.

Additional information

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