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Long-term collaboration with strong friendship ties improves academic performance in remote and hybrid teaching modalities in high school physics

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Collaboration among students is fundamental for knowledge building and competency development. Nonetheless, the effectiveness of student collaboration depends on the extent that these interactions take place under conditions that favor commitment, trust, and decision making among those who interact. The worldwide pandemic due to COVID-19 and the transition to emergency remote teaching have added new challenges for collaboration, mainly because now students' interactions are wholly mediated by information and communication technologies. This study first explores the effectiveness of different collaborative relationships over performance in physics from a sample of secondary students from two schools located in rural and urban areas in southern Chile (exploratory study). We used social network analysis to map academic hierarchies as in the nominations for proficient peers in physics (i.e., physics prestige), collaboration, and friendship ties. We define a strong association if two students who collaborate shared a friendship tie. Using ordinary least squares multiple linear regression models on physics grades, we found positive effects of collaboration over grades, particularly among students working with friends (strong ties). To test whether the effects of collaboration found in the first study were stable throughout two semesters, the following year we designed a quasiexperiment in four classes from the same urban school in the exploratory study. Here, students attended hybrid school sessions where research participants were either in the classroom or participated remotely. The teacher collected the same social networks described in the first study at the end of semester 1, and two times during semester 2. In addition, we followed the same procedures to identify strong and weak collaboration from the network data on each wave of data collection. After fitting ordinary least squares multiple linear regression models, we found that collaborative variables negatively associated with grades on activity 1 (semester 1), yet at the end of the year (activity 3 in semester 2) having strong working ties became positively associated with physics grades. Interestingly, the relationship of academic hierarchies measured in physics prestige with grades transitions from positive on semester 1 to null by the end of the year. These results contribute to the literature of collaboration in physics education and its effectiveness, by taking into account social relationships and the needed time for developing beneficial collective processes among students in the classroom. We discuss these results and their implications for instructional design and guidelines for constructive group-level processes.

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I. INTRODUCTION

Student collaboration is increasingly gaining attention for its benefits on learning and overall human development [1–3]. Education scholars and policy makers have highlighted teamwork and social competencies as key abilities for life and work in the XXI century [4,5]. Using collaborative learning practices in education harnesses students' understanding of science and technology, analytical skills and openness to diversity [6]. This emphasis on social skills is necessary to equip individuals with skills for learning, adaptation, communication and creativity in the face of complex and multidisciplinary challenges [7]. The worldwide pandemic due to COVID-19, has without a doubt added external difficulties to the development of

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collaborative skills, as schools and universities were forced to move from face-to-face to remote instruction, and with the subsequent changes in students' roles and means for socialization and interaction.

Remote teaching implies that students' communication is mediated via information communication technologies (ICTs) [8–10], such as forums, chats, emails, or video conferences, in addition to informal channels of communication such as instant message applications and related technologies. Even though technologies are ubiquitous in today's society, the effectiveness of remote education strongly depends on students' access to technology, and on their readiness to navigate and deal with these autonomously and with self-regulation [11,12]. These conditions clearly affect how students engage in forums or chats, instances that become proxies of social engagement and collaboration [9,13,14], as individuals share or access information posted by their peers.

The effectiveness of social interactions for learning and academic performance are linked with having appropriate collaborative skills and finding the right partners to work with [15]. Identifying effective working ties implies assessing a myriad of variables related to the nature of the learning activity and its requirements [16], along with the trust and commitment embedded in one's working relationships [17]. Here, the use of social network analysis (SNA) affords relevant methodological and theoretical tools to capture the different types of social and collaborative relationships observed in the classroom, to later test whether these foster (or hinder) students' performance consistently throughout the year.

With the goal to extend our understanding of effective collaboration in physics classrooms in the midst of extraordinary academic years due to a worldwide pandemic, we explore the dynamic academic effects of having working ties with friends and/or students perceived by the class as high achieving in physics. In detail, on a first exploratory phase we tested the academic effects of different collaborative ties (i.e., strong, weak, and perceptions of academic prestige) at the end of the academic year during an online teaching modality in high school physics. Second, we conducted a quasiexperiment to test whether collaboration effects were stable throughout three group activities conducted during the academic year, in a hybrid teaching modality in high school physics. In both experiments, we used students' social networks to characterize different collaborative relationships depending on whether these occurred among friends (i.e., strong), in the absence of friendship (i.e., weak), and between peers perceived as proficient in physics (i.e., academic prestige). This work contributes first, with a novel method to categorize students' working relationships from SNA, and second, with empirical evidence that shows the academic gains of various collaborative ties under distinctive teaching conditions, as well as their timely evolution during a year.

II. THEORETICAL PERSPECTIVES

A. Student networks and performance

Using SNA in education research has enabled scholars in-depth analysis to understand the benefits of student collaboration from the logic of social capital, in the sense that the number and strategic social interactions enables access to various forms of resources and information, and the potential to adopt behaviors related to success [18,19]. Higher grades have been found to be associated with students' social networks in face to face [19–22] and remote courses [9,23,24], while covering a wide range of topics and strategies. Such findings align with the sociocultural view of cognitive and human development, as knowledge is constructed while learners work alongside others who could potentially expand the frontiers of their individual achievements, in what has been defined as the zone of proximal development (ZDP) [25].

The benefits of having multiple interactions with peers in the classroom, and becoming a central member of the network extends to other variables related to achievement, such as retention [26–28], and self-efficacy, or the belief in one's abilities to successfully meet the academic expectations [29]. Furthermore, programs grounded in the principles of collaborative learning have shown important results for developing social skills [30], and trust among team members, which increases the likelihood of group effectiveness [31].

Nonetheless, more recent evidence in SNA on university physics courses suggests that the academic gains from having multiple working ties depend on the nature of the learning task [21]. Accordingly, higher degree centrality is associated with a worse performance on well-defined physics problems (e.g., textbook problems), whereas open-ended and creative activities benefit from multiple social ties outside one's group (i.e., brokering knowledge [21,32]). Additional results in primary education found that the reciprocity of students' relationships becomes the necessary condition for higher achievement [33]. This evidence supports the claim that the academic gains afforded by social interactions are sensitive to both contextual and the personality of its constituents.

Furthermore, according to evidence in sociology and networks, the nature of the social relationship plays a key role in acquiring and developing knowledge depending on its complexity [34,35]. For instance, new tacit, factual or *knows what* type of information is easily accessible through weak social ties, that is, among individuals who do not share a sense of commitment nor are deeply embedded into the relationship [34]. The key consideration is that weak ties are observed between individuals who do not belong to one's cohesive group—governed by strong relationships—and are therefore preferable for accessing simple new ideas outside such networks. On the contrary, strong ties are better suited for learning complex and nontacit ideas, because developing this type of knowledge requires a social commitment and a common language to transfer the particularities of this new information [35]. Such learning considerations are frequently observed among individuals who share a strong relationship, like friendship. Plus, informal friendship ties are better at disseminating behaviors linked with high performance [36]. Yet, evidence on the challenges for effective collaboration have found that working with friends hinders individual responsibility and the seriousness in the construction of arguments [15], a finding that mirrors the negative effects of high network cohesion [37], which might lead to underestimating the complexity of the task through high team efficacy [38].

All of the above highlight the challenges of guiding students' collaboration in the classroom, taking into account the nature of the tasks and the information to be learned. These complexities are now relevant in this transition to remote teaching, where students' interactions are mediated by ICTs [9]. Studies on remote learning have conceptualized students' course participation using traditional methods, such as the number of posts on online forums [8,13], the time dedicated to reading comments [14,39], or via content analysis of the posts written [40]. Recently, researchers have used SNA to explore different forms of participation in online courses. For instance, Traxler *et al.* [9] conceptualized students' co-occurrence of posts on discussion forums, which were defined as the links on the participation network, and later used to identify students' centrality as a proxy in the access to the content-related ideas. Under this condition, higher access to information in forums, that is, high network centrality is positively correlated with academic success [9]. Through similar network methods, an additional study has found positive correlations between students' participation in online courses—centrality—with their sense of belonging [24]. Yet, the centrality in this participation network offers positive effects especially to high performance students, as content analysis has shown that their discussions circled around conceptual aspects of the course content, whereas the discussion networks formed by low performing students tend to focus on practical and superficial elements of the curriculum [41]. Although these experiences have sought to map underlying structures in the access to information through the co-occurrence of posts, for instance, in the studies we will describe later, we instead pay attention to students' declared social relationships. In the next section we dive into the interplay between teaching strategies and forms of collaboration found in relevant literature.

B. Teaching strategies and students' collaboration

From the perspective of learning methodologies, active classrooms have shown higher levels of social interactions compared to traditional lecture-based instruction [21,42–45]. Student-centered classrooms favor autonomy over the learning process through peer interaction, because these tend to include activities designed to encourage decision making, content manipulation, and communication, thus allowing students to perceive learning as a construction mediated by collaboration [16,21]. The social and cognitive attributes of activities implemented in active learning methodologies are also recommended in virtual classrooms [46–49], because these encourage higher levels of academic achievement and digital competencies [50].

The work of Johnson *et al.* [51] on student collaboration adds fundamental conditions for group effectiveness: positive interdependence, or the belief that the success is a collective rather than individual effort; and personal responsibility for learning and engaging in one's tasks. According to social network research on education, the above conditions are modulated by the nature of the learning tasks. For instance, well-structured physics problems hinders positive independence, as students report addressing these activities by engaging in social interactions aimed at finding the right equation or variable to use [16]. On the contrary, real-world problems [52] such as generative activities [16], motivate collaborative strategies that align with the mentioned characteristics for effectiveness. Similar findings point to different levels of social engagements depending on students' perceived academic status. Here, in the face of creative activities, low achieving students tend to be more active in reaching out to their high performing peers [53]. The interplay of social ties and learning activities is also observed in lab practices, where students display limited social interactions between groups in traditional labs compared to reformed labs [54], which is associated with brokering knowledge and a key process for creative solutions [32].

The embedded attributes of the learning activity and the socially constructed norms in the classroom are some of the reasons why one could witness various forms of collaboration between different types of activities. First, well-structured and traditional learning activities in physics and other disciplines tend to be perceived as nonadditive tasks [55], given that when worked in groups these are likely solved by the most capable team member (i.e., academically prestigious students). These activities also relate to rather simplistic cognitive processes (e.g., application) according to a taxonomy of physics problems developed by Teodorescu and colleagues [56]. Conversely, unstructured tasks, such as generative problems [16] are intrinsically additive [55], because they require collective efforts for content manipulation and decision making, and thus demand high-level cognitive skills [56,57]. These demands require more complex forms of interactions than simply asking the most capable peer in the classroom. Second, students' collaborative ties are sensitive to socially constructed expectations for learning achievements and/or performance (e.g., higher grades) [58–60]. Here, instruction that emphasizes learning achievements fosters the adoption of study habits and constructive collaboration, whereas the collective pursuit of higher grades—not necessarily learning—goes along with competitive comparison and self-improvement [61]. Consequently, both the learning activity and the classroom climate play critical roles in encouraging either constructive or rather superficial forms of social interactions between friends and/or less known peers.

III. RESEARCH QUESTIONS

Considering the previous review, we are far from fully comprehending the complexity of students' interactions in the classroom, whether their effectiveness in terms of achievement is sensitive to teaching methodologies, organizational decisions in the classroom, and working time. Plus, the academic effects of different types of collaborative relationships has yet to be explored in physics education research (PER), particularly from a longitudinal perspective, and with the consideration of social and academic hierarchies. In sum, two studies were conducted to answer the following research questions:

1. (RQ1) Are there differences in the academic gains of collaborating with friends and those who enjoy academic prestige, during remote teaching in high school physics? (Exploratory experiment)
2. (RQ2) Are the academic gains of collaborating with friends and those who enjoy academic prestige stable in time during a hybrid teaching modality in high school physics? (Quasiexperiment)
3. (RQ3) Are there differences in the academic gains of different types of collaborative ties for student groups based on friendship or random assignment during hybrid teaching modality in high school physics? (Quasiexperiment)

IV. METHODS

A. Research context for exploratory analysis

The exploratory study was conducted to answer RQ1 during the second semester of 2020 on a sample of secondary students from parallel physics classes (A and B), and from two high schools in southern Chile (Sch-1 and Sch-2). Table I summarizes the schools' characteristics, showing information on the student population, number of research participants, location and education. We make explicit reference to location (Rural or Urban) and education (Scientific, Humanistic, and Technical), as it is important to clarify the possible social and cultural variables that mediate students' access to internet and ICTs, which in the context of remote teaching are the formal means through which individuals connect. Moreover, in Chile's educational system, technical schools dedicate a great percentage of the curriculum to develop technical skills, for instance, as an electrician or mechanic, and where students graduate as technicians. In contrast, scientific and humanistic schools guide students to pursue university degree programs in diverse disciplines, such as science, engineering, social science and humanities. Research participants in both schools gave consent via an online survey designed for this study, where we explain the analytical procedures along with privacy considerations. A total of 101 students agreed to be involved in the study, with 45% of female participants.

During 2020 and due to the COVID-19 pandemic, both schools adapted their teaching methodologies from face-to-face to online sessions introducing various ICTs. Initially in school 1, teachers began the academic year with asynchronous sessions using content videos shared via text messaging apps (e.g., WhatsApp). After two months, school 1 implemented synchronous 40 min sessions organized in MEET and CLASSROOM learning management systems (LMS). This scenario differed from school 2, where remote teaching began with 1–2 h synchronous course sessions a week after the school canceled face-to-face instruction. Similar to school 1, these sessions were organized on the same LMS.

In addition to the initial organizational differences, both schools organized and taught physics content following opposite learning methodologies. In school 1, the main methodology was lecture-based instruction, followed by problem-solving sessions where students faced well-structured activities (e.g., textbook problems), which were later assessed on their individual work. In school 2, however, physics taught via active learning methodologies, including generative activities [16], where students, for instance, worked in groups to design videos centered around physics content. Here, there was no particular mechanism for group formation, so it is assumed students teamed up with friends and/or individual affinities. The physics classes met once a week for 40 min and 1 h, respectively, for schools 1 and 2.

B. Data collection

Because this exploratory study aimed to determine the academic effects of different collaborative relationships in school physics, we collected final grades from the year prior to the study (2019), along with students' grades

TABLE I. School attributes and characteristics: Exploratory analysis.

School	Students	Participants	Location	Education
Sch1	650	55	Rural	Scientific, humanistic, and technical
Sch2	906	46	Urban	Scientific and humanistic

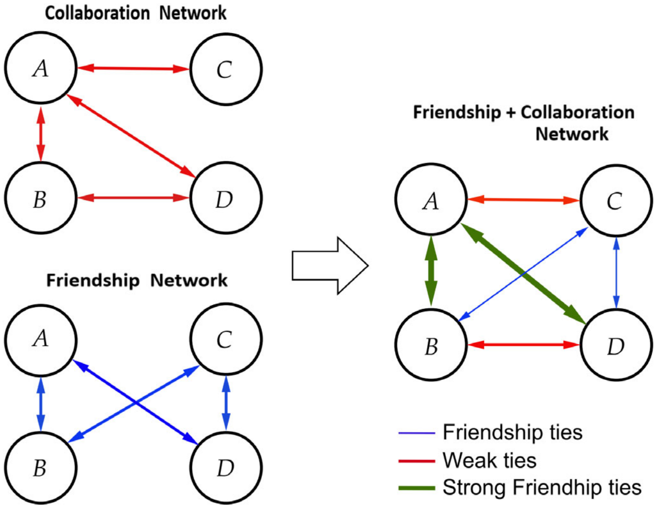

FIG. 1. Depiction of the methodology utilized to identify and construct collaborative variables number 2, 3, 4, and 5 described in Table III.

during the second semester of 2020. In 2020, students' performance in school 1 accounted for in-class activities (e.g., problem solving) and individual testing. Physics grades in school 2, however, consisted of the assessment of the generative activities (e.g., content videos and physics posters), which includes grading their structure and organization, language and theory, and a peer evaluation of the groups' performance.

Finally, to measure students' collaboration we use an online network survey at the end of semester 2, a reliable mechanism for network mapping [62]. This survey was designed to gather different social relationships: friendship ties; prestige in physics; and collaboration in physics. This instrument was constructed using the class's rosters, a technique utilized in previous studies to facilitate individuals' responses [21,42,63]. The institutional board in both schools approved the research protocol and instruments of data collection. In detail, the survey questions were

1. From the students in the classroom roster, indicate those who are your friends.
2. From the students in the classroom roster, indicate those who you consider are high achieving students in physics.
3. From the students in the classroom roster, indicate those you collaborated with during the classroom activities.

C. Data analysis

From the network survey we identified key variables to characterize the groups in terms of their friendship relations, prestige and collaboration in both physics and mathematics courses. The survey yields indirect networks, that is, where ties are not necessarily reciprocal (e.g., A selects B as a friend, but B does not select A as a friend). Given that our analysis includes a combination of three networks and measures of degree centrality which do not include the direction of the relationship (see Fig. 1 and Table III), we decided to account for all participants who at least had a tie in one of the three networks. Table II summarizes the mean of key descriptive network variables for each of the social dimensions measured on the survey. The variables include the number of students per group, or nodes, the total number of ties observed, the average number of ties or average degree, and network density—percentage of observed ties considering 100% as if all nodes on the network were connected to each other [62,64].

We operationalized collaboration as degree centrality on the collaboration network, that is, their total number of ties. Degree centrality accounts for both incoming and outgoing ties, named indegree and outdegree centrality, respectively. The former indicates the number of ties headed from actors on the networks towards a focal node, whereas the latter accounts for relationships declared by the focal actor towards other nodes on the network. In addition to this definition of the variable *Collaboration* (see Table III), we combined friendship, prestige, and collaboration networks to identify different types of collaborative relationships among students. We turned to the strength of ties terminology used in the social network literature to differentiate between strong and weak collaborative ties [34,35], based on whether the observed collaborative ties occurred among students who are friends, and those who are not (i.e., strong and weak respectively). The process followed to construct these variables is depicted in Fig. 1, and shows how we combined two networks (e.g., collaboration and friendship) to define a third network of interactions but with weighted ties, given the added friendship attribute. In the diagram,

TABLE II. Descriptive statistics of directed networks: Friendship, physics prestige, and collaboration in physics.

		Friendship			Physics prestige			Collaboration in physics		
Group	Nodes	Ties	Degree[a]	Density	Ties	Degree[a]	Density	Ties	Degree[a]	Density
Sch1-A	29	132	4.55	0.16	54	1.86	0.07	43	1.48	0.05
Sch1-B	26	95	3.65	0.15	67	2.58	0.1	49	1.89	0.08
Sch2-A	23	194	8.44	0.38	126	5.48	0.25	52	2.26	0.1
Sch2-B	23	151	6.57	0.3	128	5.67	0.25	55	2.39	0.1

[a] Average number of incoming plus outgoing ties per student in the class.

TABLE III. Types of collaborative relationships and definition.

Type of collaboration	Definition
1. Collaboration	Degree centrality of the collaboration network, or the total number of collaborative ties.
2. Strong	Number of collaborative ties between students who are friends. Friendship is observed on the network when at least one of the actors on the dyad indicates the other as a friend (e.g., A → B).
3. Weak	Number of collaborative ties between students who do not declare themselves as friends.
4. Strong w/academic prestige	Number of collaborative ties between friends and who are perceived by the other as a high achieving student in the course. Friendship is observed in the network when at least one of the actors in the dyad indicates the other as a friend (e.g., A → B). Similarly, prestige comes from its respective network and when at least one of the actors in the dyad selects the other as s student with high academic prestige in the course (e.g., B → A, then B enjoys academic prestige).
5. Weak w/academic prestige	Number of collaborative ties between students who do not have neither incoming nor outgoing friendship ties, yet one of the actors in the dyad declares the other as a prestigious physics student.

these weights are depicted in arrows of different colors and width, and represent either collaboration between friends (green = strong ties), between students who are not friends (red = weak ties), or simple friendship ties (blue). Because our interest is placed on different types of collaboration, we counted the number—degree centrality—of these collaborative ties and saved them as individual attributes (e.g., node A has 4 strong and 2 weak ties, considering the incoming plus the outgoing ones). For the analysis of strong and weak ties we discarded simple friendship relationships. Table III describes the five collaboration variables constructed and used for the analysis.

We then used ordinary least squares multiple regressions models (OLS) to predict grades in both courses, while using collaboration variables as the main predictors (see Table III). In order to isolate the effects of collaboration on grades, we include control variables like performance in the year prior to the study, school to account for variability within institutions, and gender. We also tested interactions between schools and the key predictors, and found no significant difference between schools. Finally, as a robust check, we fitted hierarchical linear models to account for the class and schools' variance. Results here did not differ from the multiple regression models.

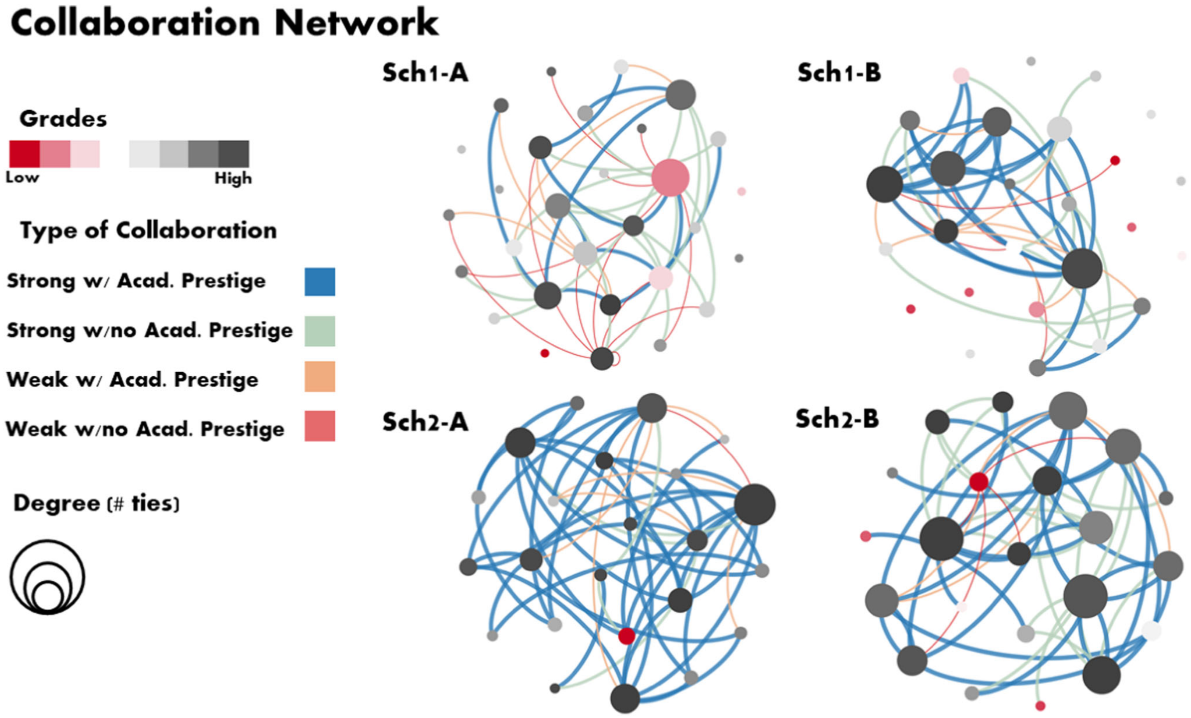

FIG. 2. Collaboration network for physics. Node color represents academic performance from low (red) to high grades (black), while its size indicates degree centrality—number of collaborative ties. Edge or link colors depict the type of collaborative relationship (e.g., blue ties are strong collaboration with high prestige students in physics). Note that by default isolates are set to the size of the lowest degree.

V. RESULTS: EXPLORATORY ANALYSIS

A. Collaboration and grades in physics

Figure 2 depicts the collaboration networks of all four classes from schools 1 and 2. The networks show four types of ties based on whether students display strong or weak relations with others, who at the same time enjoy academic prestige in physics, or with those who are not perceived as high achieving physics students. Furthermore, the network depiction illustrates grades in shades of green, as well as degree centrality as the nodes' size.

The network depictions allow a visual representation of the information contained in Table II, where classes Sch1-A and B have low network density, represented by the reduced number of ties compared to school 2. Plus, there are differences between groups in school 1, as in class A we observe an abundance of social relations of diverse nature spanning most of the students, whereas class B seems to be governed by strong ties with prestige (blue links) and with many isolated members. In this last group, connected students with high centrality appeared with the highest grades, differently from Sch1-A, where higher grades are not an exclusive attribute of central individuals. Finally, both networks in school 2 show an even distribution of higher grades, while their ties are mainly strong.

The multiple regression models fitted to predict physics grades are shown in Fig. 3. In model A we used degree centrality of the collaboration network as the main predictor, yielding a positive coefficient (0.2, $p < 0.05$) thus, suggesting that more working partners is associated with success in physics across schools. When differentiating the effects of types of collaboration, model B shows a null effect for weak ties, while having strong relationships indicates a positive predictive value over physics performance (0.22, $p < 0.05$). When adding academic prestige, model C shows the gains of working alongside others who are perceived as high achieving physics students, though this coefficient is not significant. Finally, it is worth highlighting the predictive value of prior grades on physics across all three models, and the mean difference between institutions in favor of school 2.

VI. METHODOLOGY: QUASIEXPERIMENTAL DESIGN

A. Research context

To test the stability of the findings presented in Fig. 3 (RQ2), we collected data on four courses from school 2 during the next academic year (2021). To test whether the collaborative gains are observed among student groups based on friendship or random assignment (RQ3), we devised a network intervention on two of the four classes from school 2 during two semesters in 2021 (SEM 1 and SEM 2). At the beginning of the academic year (March 2021), students in the experimental conditions ($N_{\mathrm{exp}} = 46, 50\%$ female students) were randomly assigned to working groups, while participants in the control condition ($N_{\mathrm{cont}} = 44, 56\%$ female students) (2 classes) had the liberty to decide their working teams. This organizational decision led to an initial average of 2 declared friends per group in the control condition, versus an average of 0.5 within-group friends in the experimental courses. The rationale for designing this intervention is grounded on the accessibility of strong and weak collaboration under both experimental conditions and its potential effects over grades. If the results from the exploratory study hold, one would expect the control group to perform better given that students are set to collaborate with their friends (i.e., strong ties), whereas students in the experimental

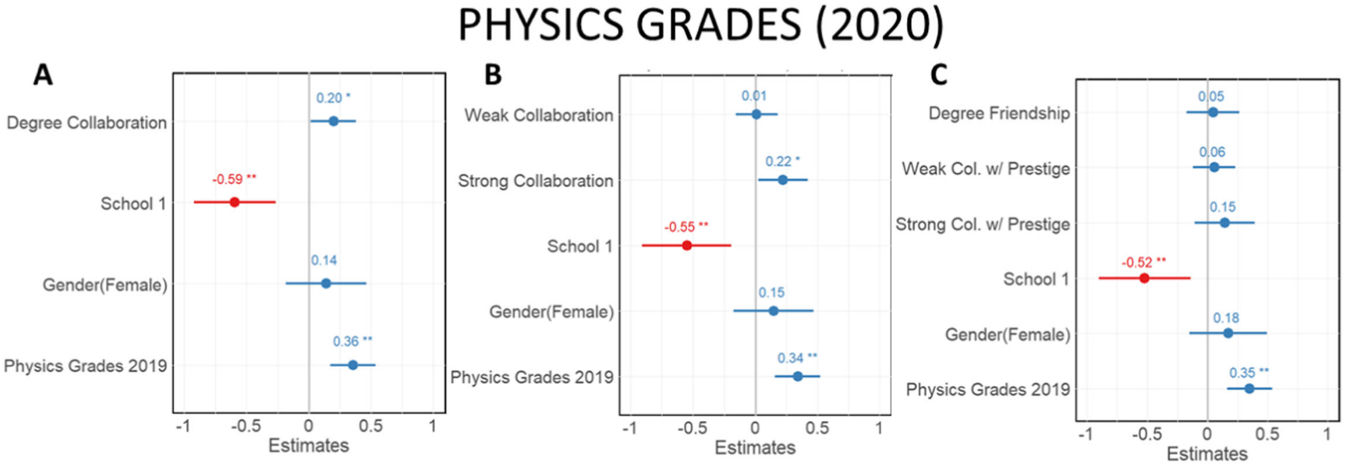

FIG. 3. Graphic depiction of OLS multiple linear regression models for physics grades regressed on collaborative variables: Degree collaboration, model A; weak and strong collaboration, model B, and weak and strong collaboration with high prestige in physics, model C. Models include confounding variables: School 1 (factor); female students (gender as a factor); physics grade in 2019 (previous academic year); and degree friendship. Positive coefficients are depicted in blue, while red coefficients indicate negative effects. Table VII in the Appendix reports statistics for models A, B and C. Note that. Note that $*p < 0.05$ y $**p < 0.01$.

TABLE IV. Quasiexperimental design and interventions: Longitudinal analysis.

		Grouping Mechanism		
Group	Subjects	(SEM[a] 1)	(SEM[a] 2)	Teaching Modality
Control	44	Affinity	Affinity	Active learning and hybrid
Experimental	46	Random	Affinity	Active learning and hybrid

[a] Semester.

conditions are weakly tied with their working peers. At the beginning of semester 2, students in both experimental and control conditions had the liberty to change their working teams, after which we observed that 31 (67.4%) and 13 (30%) participants decided to join new groups in the experimental and control condition, respectively. It is worth mentioning that this new group memberships was maintained for the entire semester 2.

Each of the four classes addressed active learning methodologies with group activities to cover the physics curriculum. Here, we refer to activity 1 as then one addressed during the second half of semester 1, while activities 2 and 3 took place during semester 2. These group activities were designed for students to actively engage with the content, for instance, to discuss and analyze conceptual errors in others' responses, generate posters and the design of practical experiments to show physics phenomena.

Additionally, during the year 2021, and due to a consistent decrease in COVID-19 cases along with a nation-wide immunization policy, schools offered students the possibility to slowly return to face-to-face classes. In this stage, a portion of students in school 2 had the opportunity to participate in face-to-face sessions, while the rest of the class assists online. We had no information on the average percentage of students per group that attended the school, nor the ones that participated remotely, yet, the teacher reported that by the end of the academic year, the vast majority of the students in each class attended the physics sessions in-person. In this hybrid teaching modality students voluntarily decide whether to attend in-person or online, with the chance to participate in the class in each of these modalities every other week. These contextual conditions are summarized in Table IV.

TABLE V. Descriptive statistics of directed networks in activities 1 at the end of semester 1, and activities 2 and 3 in semester 2: friendship ties, physics prestige nomination, and collaboration in physics.

Semester 1: Activity 1										
		Friendship			Physics prestige			Collaboration in physics		
Group	Nodes	Ties	Degree[a]	Density	Ties	Degree[a]	Density	Ties	Degree[a]	Density
1-A	24	117	4.88	0.21	147	6.13	0.27	134	5.58	0.24
1-B	24	175	7.29	0.32	127	5.29	0.23	113	4.71	0.21
2-A	22	125	5.68	0.27	108	4.91	0.23	71	3.22	0.15
2-B	20	117	5.85	0.31	101	5.05	0.27	57	2.85	0.15
Semester 2: Activity 2										
		Friendship			Physics prestige			Collaboration in physics		
Group	Nodes	Ties	Degree[a]	Density	Ties	Degree[a]	Density	Ties	Degree[a]	Density
1-A	24	220	9.17	0.4	144	6	0.26	131	5.46	0.24
1-B	24	193	8.04	0.35	165	6.88	0.299	89	3.71	0.16
2-A	22	188	8.55	0.41	134	6.09	0.29	64	2.91	0.14
2-B	20	188	9.4	0.5	109	5.45	0.29	82	4.1	0.22
Semester 2: Activity 3										
		Friendship			Physics prestige			Collaboration in physics		
Group	Nodes	Ties	Degree[a]	Density	Ties	Degree[a]	Density	Ties	Degree[a]	Density
1-A	24	198	8.25	0.34	181	7.54	0.328	113	4.71	0.21
1-B	24	196	8.52	0.39	160	6.67	0.29	101	4.21	0.18
2-A	22	196	8.91	0.42	119	5.41	0.258	72	3.27	0.16
2-B	20	151	7.55	0.4	112	5.6	0.3	74	3.7	0.2

[a] Average number of incoming plus outgoing ties per student in the class.

B. Data collection and analysis

Similar to our experience in the exploratory phase of this study, we collected data on students' collaborative ties, friendship, and perceptions of academic proficiency in the course at the end of semester 1 (end of activity 1), and two times during semester 2 (end of Activities 2 and 3). The online surveys displayed the same network questions designed for the exploratory phase of the study, and were administered by the physics teacher in each wave of data collection. Later, by following the method depicted in Fig. 1, we constructed the same variables described in III for the exploratory phase of the study. Similarly, collected data yielded three directed and binary networks: Friendship network; physics prestige nominations; and collaboration network. Table V summarizes whole network measures (i.e., nodes, ties, average degree, and density). Along with this, we gathered information on students' gender and performance in each of the activities, which came from assessing the structure, organization, language, and theory presented on students' group work.

To find evidence in light of RQs 2 and 3 (are the academic gains of collaborating with friends and those who enjoy academic prestige stable in time throughout an academic year in high school physics? and are these changes similar for student groups based on friendship or random assignment? and are there differences in the academic gains of different types of collaborative ties for student groups based on friendship or random assignment in high school physics?), we fitted OLS multiple linear regression models for each wave of data collection. Here, we regressed physics grades upon collaboration variables (see Table III) as the main predictors. With this, we sought to compare the regression coefficients across activities (models) as evidence of change in the collaborative effect over physics grades. We further checked the robustness of our findings, addressing some concerns related to time-invariant unobserved confounders, by following a *difference-and-difference* [65] procedure and tested whether the observed differences in the collaborative effects hold (see Table VIII in the Appendix). The difference in difference (DID) procedure [66] is a quasiexperimental design that requires longitudinal data (at least two periods) from both treated and control groups to obtain a counterfactual to estimate the causal effect. We use this identification strategy to analyze the impact of cooperation on academic performance. DID relies on the condition of parallel trends for a causal interpretation of results. In other words, the difference in difference method requires that in the absence of treatment, the difference between the "treatment" and "control" group is constant over time. Even though is impossible to test this assumption statistically, we can argue in favor of its plausibility and thus assume that most of these unobserved variables are time invariant within our study period. Finally, we found no contradicting evidence from the difference in difference analysis.

VII. RESULTS: QUASIEXPERIMENTAL DESIGN

First, Figs. 4, 5, and 6 depict students' collaboration networks on activities 1 (end of SEM1) and 3 (end of SEM2), for each of the four classes. Figure 4 shows the network of collaboration ties (degree), while Figs. 5 and 6

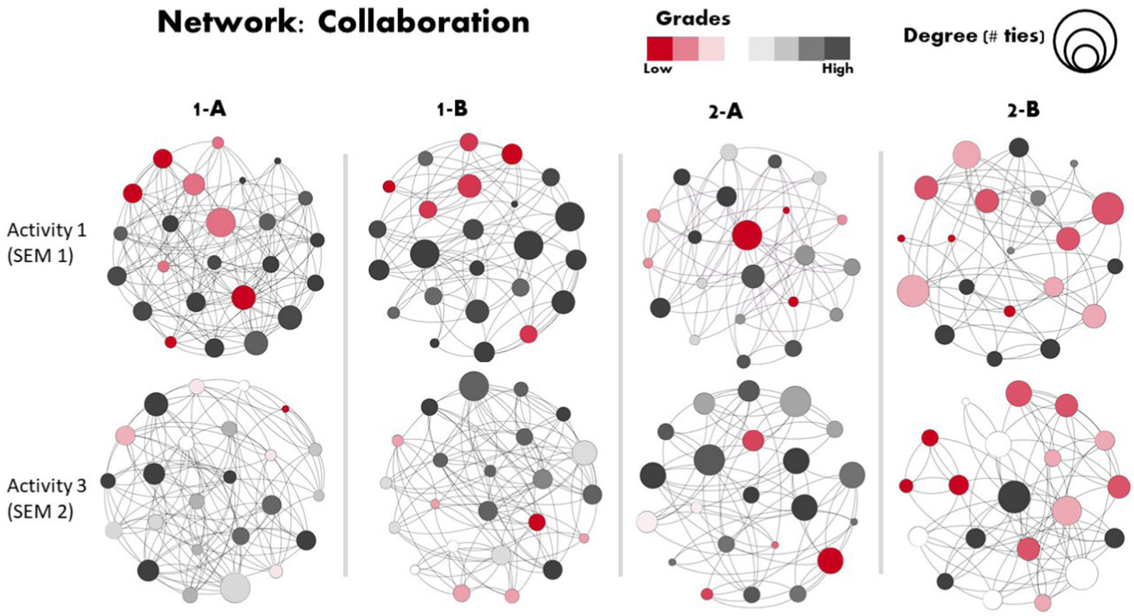

FIG. 4. Collaboration network on activities 1 (end of semester 1) and 3 (end of semester 2) for each class. Node color represents academic performance from low (red) to high grades (black); size of nodes indicates degree centrality—number of collaborative ties.

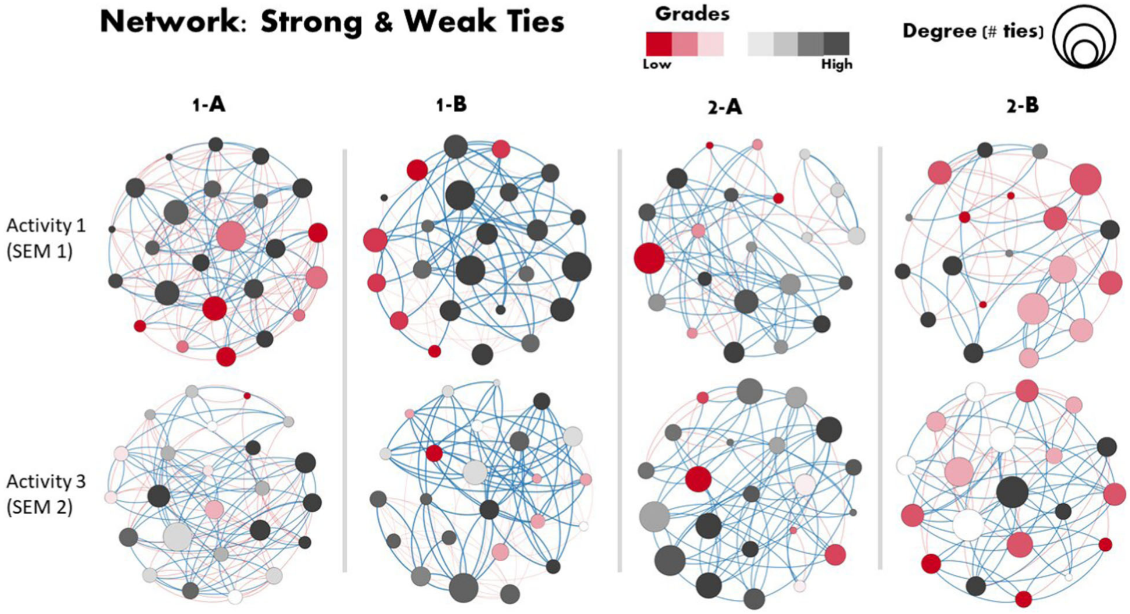

FIG. 5. Strong and weak collaboration network on activities 1 (end of semester 1) and 3 (end of semester 1) for each class. Node color represents academic performance from low (red) to high grades (black); size of nodes indicates degree centrality—number of collaborative ties; edges' colors indicate strong ties (blue) and weak ties (red).

depict, respectively, the network of strong and weak collaboration ties, and strong and weak collaboration ties among academically prestigious peers in physics. In all the figures, the size of the nodes represents degree centrality, while darker green indicates higher grades. From a first look into the networks it is noticeable how the network density—number of ties—progressively diminishes on Figs. 4, 5, and 6—thus reflecting the restrictions imposed onto strong and weak ties, plus the added dimension of prestige. Further, the location of dark green (i.e., higher grades) and larger nodes (i.e., higher degree centrality) changes from activity 1 to activity 2, thus suggesting

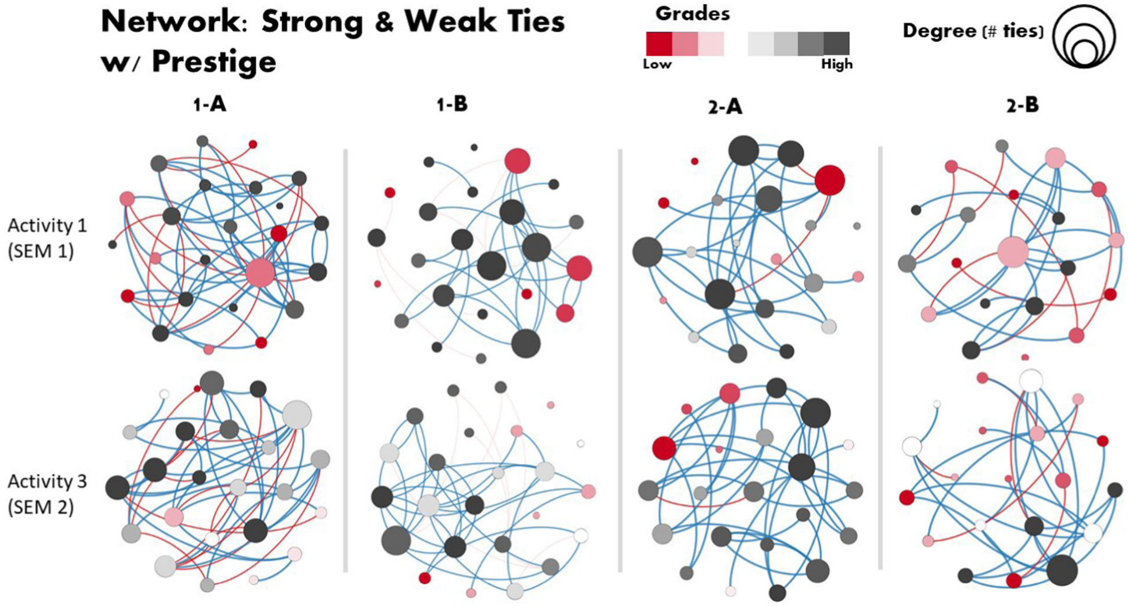

FIG. 6. Strong and weak collaboration network with academic prestige on activities 1 (end of semester 1) and 3 (end of semester 1) for each class. Node color represents academic performance from low (red) to high grades (black); size of nodes indicates degree centrality—number of collaborative ties; edges' colors indicate strong ties (blue) and weak ties (red) with proficient students. Note that by default isolates are set to the size of the lowest degree.

TABLE VI. OLS multiple regression models of physics grades regressed on collaboration predictors and controlling for confounding variables.

	Dependent variable:								
	Physics grades 2021								
	(1. Act.1)	(2. Act. 2)	(3. Act. 3)	(4. Act. 1)	(5. Act. 2)	(6. Act. 3)	(7. Act. 1)	(8. Act. 2)	(9. Act. 3)
Collaboration (degree)	−0.300**	−0.123	0.067						
	(0.102)	(0.121)	(0.105)						
Weak collaboration				−0.294*	−0.213	−0.160			
				(0.120)	(0.115)	(0.122)			
Strong collaboration				−0.256	−0.056	0.393*			
				(0.131)	(0.166)	(0.157)			
Weak col. w/ prestige							−0.092	0.157	0.071
							(0.112)	(0.111)	(0.112)
Strong col. w/ prestige							−0.215	0.190	0.464**
							(0.145)	(0.145)	(0.128)
Control group	−0.129	−0.145	−0.046	−0.264	−0.193	−0.168	−0.186	0.163	−0.114
	(0.203)	(0.243)	(0.202)	(0.228)	(0.242)	(0.201)	(0.224)	(0.236)	(0.202)
Gender (female students)	0.457	−0.750**	−0.613**	0.472	−0.783**	−0.518*	0.540*	−0.658**	−0.470*
	(0.236)	(0.229)	(0.222)	(0.238)	(0.229)	(0.214)	(0.244)	(0.227)	(0.212)
Scores (prior)	0.009	−0.009	0.205	0.033	−0.039	0.193	0.068	−0.031	0.076
	(0.124)	(0.120)	(0.116)	(0.124)	(0.121)	(0.110)	(0.129)	(0.120)	(0.115)
Physics prestige	0.294*	0.168	−0.063	0.307*	0.165	−0.057	0.396*	0.057	−0.132
	(0.132)	(0.129)	(0.111)	(0.138)	(0.129)	(0.103)	(0.159)	(0.138)	(0.104)
Friendship (degree)	0.044	0.029	0.051	0.032	−0.048	−0.328**	0.029	−0.010	−0.180
	(0.119)	(0.114)	(0.109)	(0.132)	(0.158)	(0.154)	(0.127)	(0.131)	(0.135)
Constant	−0.148	0.424*	0.310	−0.085	0.464*	0.327	−0.157	0.223	0.278
	(0.185)	(0.187)	(0.178)	(0.197)	(0.186)	(0.174)	(0.196)	(0.183)	(0.174)
Observations	90	90	90	90	90	90	90	90	90
R^2	0.193	0.203	0.216	0.194	0.225	0.315	0.137	0.230	0.330
Adjusted R^2	0.134	0.145	0.159	0.125	0.159	0.256	0.063	0.164	0.273
Residual standard error	0.930 (df = 83)	0.925 (df = 83)	0.917 (df = 83)	0.936 (df = 82)	0.917 (df = 82)	0.862 (df = 82)	0.968 (df = 82)	0.914 (df = 82)	0.852 (df = 82)
F statistic	3.300**	3.514**	3.814**	2.811*	3.407**	5.384**	1.861	3.491**	5.781**
	(df = 6; 83)	(df = 6; 83)	(df = 6; 83)	(df = 7; 82)	(df = 7; 82)	(df = 7; 82)	(df = 7; 82)	(df = 7; 82)	(df = 7; 82)

$^{*}p < 0.05$
$^{**}p < 0.01$

a dynamic and complex pattern of relationships in each class.

OLS multiple regression models for predicting physics grades in each activity are shown in Table VI. Models 1, 2, and 3 contain degree centrality in the collaboration network as the main predictor. Models 4, 5, and 6 use the number of strong and weak collaborative ties as the main predictor, whereas for models 7, 8, and 9, strong and weak ties with prestigious others as the key independent variable. The first three models show that at the beginning of the academic year the number of collaborative ties yields a negative effect over grades, but by activity 3 such effect got closer to zero. The effects of strong collaboration (i.e., working ties with friends), however, transition from negative at the end of SEM1 to positive by the end of the year (models 4, 5, and 6). We observe basically no change for working with acquainted peers on models 4, 5, and 6. Finally, the inclusion of physics prestige aligns with the previous results, as working with either friends or acquaintances increases over time. This effect is stronger for those who work with friends that enjoy academic prestige.

Figure 7 depicts the comparison between the regression coefficients shown in Table VI. Here, it is possible to observe the different effects of collaboration variables in performance across activities 1 (light blue), activity 2 (orange), and activity 3 (light green). The squared coefficients on Fig. 7 evidence the evolving effect of classroom collaboration towards effectiveness throughout two academic semesters. Note that from activity 1 towards activity 2 a percentage of students under both experimental and control

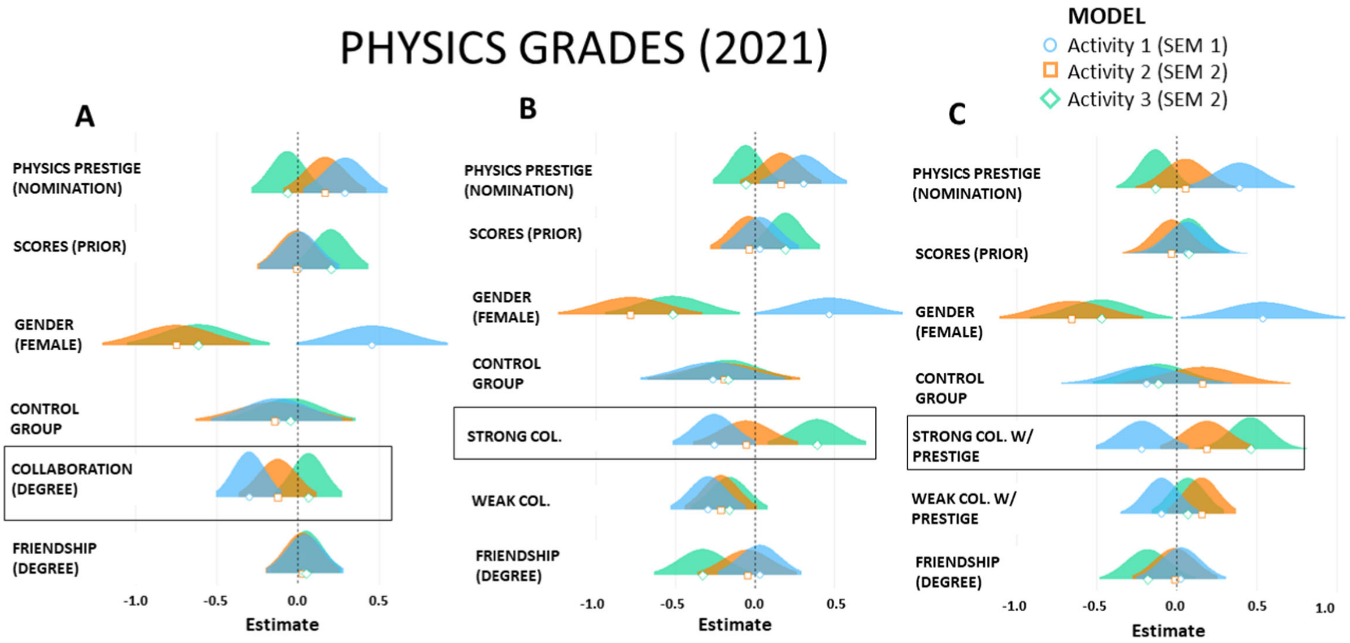

FIG. 7. Graphic depiction of OLS multiple linear regression coefficient comparison between activity 1 at the end of semester 1 (light blue); activity 2 at the beginning of semester 2 (orange); and activity 3 at the end of semester 2 (light blue). Coefficient distributions at the left from the dashed line indicate negative effects, and positive coefficients are located at the right. Key predictors are enclosed in black boxes: collaboration (degree), model A; strong collaboration, model B; and strong collaboration with high prestige students in physics, model C.

conditions decided to pair with their friends, thus increasing their chances to higher scores through consistently working with friends (i.e., strong ties). Interestingly, physics prestige loses power in predicting grades across activities, thus suggesting that achieving high performance (e.g., grades) is no longer an exclusive benefit for those who are deemed as proficient in high school physics, that is, those who enjoy high academic prestige. Here, we noticed that the correlation between students with high physics prestige and physics grades on activity 1 (semester 1) is low but positive [$r(88) = 0.21$, $p < 0.05$], whereas at the end of semester 2 (activity 3) the correlation is not statistically different from zero [$r(88) = -0.15$, $p =$ n.s.].

From Table VI both types of group configurations (random and friendship-based) afford similar levels of academic achievement. Moreover, on average, female students got better grades than males on activity 1, but performed worse during the second semester (activities 2 and 3).

VIII. DISCUSSION

A. Exploratory study

The multiple regression models fitted for the exploratory study show the expected results of having multiple working peers in the classroom, which align with the benefits of social integration on education [67]. The observed learning gains are also consistent with sociocultural theory [25] and the principles of social capital [68], in the sense that social relationships enable access to information and ease collective learning, in this context, pertaining to physics. Nonetheless, when examining the academic effects of different collaborative relationships, strong friendship ties showed an advantage compared to weak ties observed among those who do not declare friendship ties, which is evidence to answer RQ1. One could attribute this effect to the type of information needed to successfully address activities in each school, following the evidence from Hansen [35] and Granovetter [34], with complex ideas being better disseminated and learned through strong ties, because individuals on strongly connected networks are proxies of collective trust and commitment, with shared common forms of communication.

Alternatively, if the information-based approach fails to explain the effect of strong ties on physics grades, we could appeal to the contrasting nature of the learning activities administered in school 1 and 2. Here, the effectiveness of strong relationships implies the adoption of strategic behaviors from working with friends to overcome the academic challenges embedded in each task. Plus, it is possible that remote teaching accentuates existing students' social networks due to the costs of expanding one's ties via ICT's mediated communication. In simple terms, collaboration with friends implies a lesser effort than embarking on new working ties through remote activities, compared with face-to-face interactions, where verbal and nonverbal cues, along with physical proximity reduce the costs and uncertainties of working with less known peers.

Results show clear differences in the density of collaboration and friendship ties between both schools. This contrasting scenario might be attributable to the socioeconomic and cultural characteristics found in both student populations. Even though we do not account for information about students' social or economic capital, schools' geographical locations in rural and urban areas allow us to imply certain comparative advantages relative to the access to internet and communication technologies, which might have facilitated, or otherwise hindered students' interactions for miscellaneous purposes. The COVID-19 pandemic brought public attention to the internet and technological gap between students in urban and rural areas throughout the country, and its related disadvantages during the emergency transition to remote teaching. Accordingly, students in rural areas faced hardship in their connectivity and more limited use of laptops, tablets, or smartphones in families with more than one student, or with parents working remotely who shared their technological devices. The fact that students in the rural school answered the online survey at a high rate indicates access to internet, yet not whether they enjoyed it at the same level as those students in the urban and private school. Based on the literature on online education and ICTs, success depends highly on students' accessibility and their readiness to use digital tools [11,12]. Consequently, one could think that students from school 1 (rural) experienced higher limitations on accessing internet and interacting with ICTs, yielding to less ICTs' mediated communication and interactions compared to school 2, and thus resulting in lower network density in both friendship and prestige networks. Higher exposure to others' comments, behaviors, and grades due to easier ICT accessibility becomes a form of social information that is reflected in the higher average of ties observed in the friendship and prestige networks in school 2. Adding to this plausible explanation is the nature of the teaching methodologies enacted in each school, with with active learning and group activities observed in the urban school, whereas a traditional learning setting could have hindered social dynamism in the rural school.

In addition to the difference in the number of working ties on schools 1 and 2, we found no significant interactions between the schools and the collaborative variables to support the claim that context and teaching methodologies might have led to diverse academic gains. The lack of differences across schools might be attributed to distinctive social processes enacted in the face of the teaching strategies observed in each learning context. As both schools put in place traditional (school 1) and active (school 2) physics classrooms, it is reasonable to think that the ways in which students worked together to meet their academic goals differed between both teaching methodologies. Even though students in school 1 might have addressed the task in online groups, traditional well-structured problems are not characterized by requiring high levels of interdependence and effective collective coordination [16,51,55], and, consequently, partnerships with one or two closest friends would be enough to access and develop appropriate knowledge to solve the activities. Conversely, the open-ended nature of the activities observed in school 2 should have encouraged student groups' higher levels of coordination and communication with their two or three group members. We resort to this interpretation given the lack of insight knowledge on the collective processes these activities encouraged. Because in all four courses the vast majority of the collaborative ties are observed between friends, it is clear that students were able to identify effective working partners to meet the academic goals in each learning scenario.

B. Quasiexperimental design

As shown, the effects of collaboration over physics grades evolve along with external social reconfigurations. Throughout the academic year, collaboration becomes more effective in fostering higher performance in high school physics, particularly for those who form partnerships with friends and those perceived as high achieving physics students, and the response to RQ2. The dynamic effects of the different collaborative ties captured throughout the three activities could be a consequence of both structural conditions and personal processes. Schools and classroom organization, as in the hybrid modality with half the students attending the classroom while the other half remained online during the first semester, presumably slowed down groups' coordination and communication, and with negative consequences over their physics grades. In the control groups, for instance, it is likely that students found themselves at the beginning of the year teaming up with friends who were attending the sessions remotely, with the alternative configuration (i.e., most friends connected online) a likely scenario as well. In either case, developing group-level strategies between face-to-face and remote communication is nontrivial due to the difficulties for online members to catch up with face-to-face conversation, and vice versa. Conversely, students in the experimental group faced an additional challenge to coordinate their groups' work in semester 1, either in-person and/or remotely with less known classmates. Even though this added complexity, the experimental and control groups performed at the same level during first and second semesters.

Based on our results, there are no performance differences between both experimental conditions (RQ3). The lack of performance differences between student groups from control and experimental conditions during the first semester might also be caused by the negative symptoms of working with close friends within a highly cohesive network. From an effort perspective, a working environment constructed among friends could hinder responsibility and individual accountability [15], or alternatively, high cohesion could lead to overestimating the individual and collective capabilities to perform a particular task [37,38]. Conversely, and accounting for all the challenges associated with coordination and building working ties, groups in the experimental condition could have overcome such initial limitations by assembling effort in response to this new working scenario. It is possible that students hold a strong belief regarding their role as learners in a traditional physics classroom, where the attention goes to individual performance via well-structured activities, rather than collective performance. Such performance-driven identity might also be caused by the learning environment experienced in other disciplines. Therefore, facing open-ended and group activities could have required a level of adaptation that teachers must include in their daily practices.

Further into the year, and after having the chance to reconfigure their groups, collaboration became increasingly more effective in affording better grades, particularly for those who declare working ties with friends and high achieving students. A larger number of new groups were formed in the experimental course, presumably due to participants seeking out to form teams with close friends and other proficient classmates. On top of that, at the end of the second semester, a vast majority of students were present in the classroom. Consequently, the combination of face-to-face collaboration with friends in a learning environment already known for requiring nontraditional group tasks, could have eased the development of adequate group-level processes, thus boosting teams' effectiveness in the classroom. Moreover, because of the managerial decision and liberties experienced during the second semester, it is also likely that students, in general, optimized their working relationships by the end of the year. This implies either that participants strengthen their effective social ties, or rather discarded unfruitful ones to work alongside more academically oriented peers, which constitutes an opportunity to develop critical collaborative abilities. This is observed in the effects of strong and weak ties with prestigious peers in physics, because even in the case of weak relationships, there was a value added at the end of the year for interacting with high achieving students outside the personal network of friends.

Interestingly, students who are perceived as proficient in physics classrooms scored significantly better only on activity 1. During activity 1 it is possible that group members reproduced the group-level strategies enacted on traditional physics problems, resulting in more frequent attention to prestigious members within each group and across working teams [21]. On activities held during the second semester however, the effect of such academic hierarchies is reduced to zero and even becomes negative. The contrasting academic effects for physics prestige and collaboration with students with high achieving peers is evidence that higher results are associated with collaboration with individuals with various levels of academic prestige, rather than the isolated knowledge and skills of those perceived as proficient in physics. This supports our prior interpretations that groups built up better collective processes as they became accustomed to the nature and requirements of additive tasks in semester 2, and with performance opportunities that extend to all members who engage in collaboration, and beyond the socially constructed hierarchies defined by perceptions of physics proficiency. In addition, future research could explore in more detail the variables that drive students to nominate others as proficient in physics and other disciplines, and their time stability. One could presume that information onto others' grades could be enough to assess one's academic status in the classroom. Yet, our results suggest a more complex interplay of variables in this regard, as students might have included for this assessment various group-level skills (e.g., communication, leadership), creative and critical thinking, among many other competencies and behaviors not typically observed in traditional physics classrooms governed by textbook problems.

Finally, the collaboration networks measured throughout the year for the quasiexperiment are notably more dense than their similar networks mapped during the remote teaching modality. As mentioned, this is not surprising as face-to-face interactions seem to afford higher chances for connecting classmates compared to digitally mediated communications, under the assumption that students indeed utilize formal means to relate with each other (e.g., chats and forums). Additionally, the motivation to attend face-to-face sessions at the school increased students' social engagement considerably from the first to the second semester, and by the end of the year teachers witnessed a vast majority of students were in the classroom participating in the group activities.

C. Teaching implications, future questions, and limitations

The similar performance observed in both control and experimental groups, especially on activity 1, is an encouraging sign for using random groups in physics classrooms. Even though the collaborative effects during the first semester were not what we would have expected, it is possible that consistency brings the desired academic gains. Accordingly, future research should explore in detail whether continues work in randomly assigned groups in physics education fosters appropriate coordination for learning and high performance. Plus, interesting processes such as intergroup collaboration, or more complex mechanisms like brokerage are future avenues for research, particularly given the creative orientation in today's education [7,17]. Accordingly, managerial decisions such as forming random or friend-based groups could have encouraged students to reach other groups based on the likelihood of having their friends outside their groups. In randomly assigned groups, having friendship ties with other team members could foster first, more frequent between-group interactions and the possibility for students to bridge structural holes [17], a relevant process for creativity in physics classrooms [21] and other fields [32]. Plus, experiencing the need to develop working ties with less known team members becomes an opportunity to extend and fortify one's social network, because effective working ties might evolve into friendship, whereas it becomes also possible to discard ineffective collaborative relationships [69,70].

Friend-based groups seemed to ease collective coordination and the consequent advantage of social relationships. This is a positive sign in the pursuit of social competencies in the classroom, which has been found limited in some student populations [15]. Additionally, it is important to include collaborative guidelines for effective performance, especially in students who are not accustomed to learning processes associated with positive interdependence, individual accountability, coordination, and decision making [16,51]. This becomes critical in traditional learning contexts where the nature of the scientific knowledge is grounded in well structured and close-ended problems, and thus fortifies a certain way of performing in physics classrooms that differs from real-world scientific and professional endeavors.

Finally, both documented research experiences lack information on internet connectivity; accessibility and teacher and student training in ICTs, given the major role these play in remote education; and in-depth characterization of interactions between the participants physically present in the classroom and those attending remotely in year 2021. We recognize that the conducted study does not account for students' personal experience during the transition from face-to-face to online instruction, nor the difficulties experienced by teachers on such transitions. For instance, data on teachers' behaviors and strategies to guide the social processes on both remote and hybrid teaching modalities could clarify underlying difficulties or effective group-level mechanisms in the classroom. Here, qualitative information and analytical tools might have provided valuable information to either support or reject the interpretations described in the paragraphs above. Furthermore, the study pretends to encourage the research and teaching community to reflect and pursue new studies and interventions on the interplay between students' networks, teaching methods, and learning. This avenue of research is promising, particularly since social and collaborative skills are nowadays necessary for human development and to face the complex challenges of the XXI century [4,7].

IX. CONCLUSIONS

We found evidence to answer the three research questions that motivate this study. First, friendship-based working ties, or what we have defined as strong ties, are more effective in fostering grades than working with less known peers in the classroom during fully remote teaching modalities. These results hold in both traditional and group-based active learning methodologies. Even though the learning conditions changed from one year to the next giving students flexibility to attend schools, we found that the effectiveness of strong ties gain strength with continuity and persistence, with end of the year activities benefiting more from friendship-based working ties. These gains presumably come along with better group-level processes and familiarity with unstructured activities. Finally, we found no statistical differences between randomly assigned and friendship-based groups in terms of performance, which is an encouraging sign, meaning that such pedagogical decisions are not necessarily detrimental for students' grades.

ACKNOWLEDGMENTS

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APPENDIX

This appendix contains first, in Table VII the OLS multiple regression models fitted for the exploratory analysis, which are earlier depicted in Fig. 3 in models A, B and C respectively. Secondly, Table VIII reports the results of the difference in difference procedure conducted as a robustness check in the quasi experimental phase of the study, particularly regarding time-invariant unobserved confounders for the longitudinal analysis.

TABLE VII. OLS multiple linear regression models for physics grades regressed on collaborative variables, controlling for confounding variables.

	Dependent variable:		
	Physics grades 2020		
	(1)	(2)	(3)
Degree collaboration	0.199*		
	(0.092)		
Weak collaboration		0.012	
		(0.085)	
Strong collaboration		0.224*	
		(0.100)	
Degree friendship			0.048
			(0.109)
Weak Col. w/prestige			0.059
			(0.088)
Strong Col. w/prestige			0.145
			(0.125)
School 1	−0.595**	−0.550**	−0.520**
	(0.166)	(0.180)	(0.192)
Gender (female students)	0.138	0.148	0.177
	(0.163)	(0.162)	(0.162)
Physics grades 2019	0.357**	0.343**	0.352**
	(0.091)	(0.092)	(0.094)
Constant	0.247	0.216	0.190
	(0.142)	(0.148)	(0.151)
Observations	99	99	99
R^2	0.447	0.453	0.446
Adjusted R^2	0.423	0.424	0.410
Residual Std. error	0.767 (df = 94)	0.767 (df = 93)	0.776 (df = 92)
F statistic	18.990** (df = 4; 94)	15.399v (df = 5; 93)	12.335** (df = 6; 92)

$^{*}p < 0.05$
$^{**}p < 0.01$

TABLE VIII. Difference and difference procedure.

	Dependent variable:					
	Physics grades 2021					
	(1)	(2)	(3)	(4)	(5)	(6)
Gender (female students)	−0.032	0.046	−0.032	0.071	0.008	−0.029
	(0.154)	(0.148)	(0.148)	(0.148)	(0.155)	(0.145)
Experimental group	0.212	0.147	0.335*	0.141	0.139	0.349*
	(0.149)	(0.149)	(0.154)	(0.148)	(0.156)	(0.153)
Activity 3	0.317*	0.353*	0.282	0.350*	0.305*	0.297*
	(0.150)	(0.150)	(0.148)	(0.148)	(0.152)	(0.146)
Degree collaboration	−0.257**					
	(0.095)					
Weak col.			−0.409**			−0.438**
			(0.118)			(0.118)
Weak col. w/prestige					−0.049	
					(0.108)	
Degree friendship	0.132		0.017		0.144	
	(0.083)		(0.087)		(0.081)	

(Table continued)

TABLE VIII. *(Continued)*

	Dependent variable:					
	Physics grades 2021					
	(1)	(2)	(3)	(4)	(5)	(6)
Physics prestige	0.056					
	(0.078)					
Act.3*D. collaboration	0.277					
	(0.152)					
Strong col.		0.020				−0.049
		(0.101)				(0.082)
Act.3*strong col.		0.099				
		(0.152)				
Act.3*Weak col.			0.297*			0.291*
			(0.146)			(0.146)
Strong col. w/prestige				0.074		
				(0.101)		
Act.3*strong col. w/prestige				0.106		
				(0.149)		
Act.3*weak col. w/prestige					0.166	
					(0.150)	
Constant	−0.258	−0.279	−0.265	−0.283	−0.225	−0.281
	(0.149)	(0.148)	(0.148)	(0.147)	(0.151)	(0.143)
Observations	180	180	180	180	180	180
R^2	0.095	0.048	0.117	0.059	0.063	0.118
Adjusted R^2	0.058	0.021	0.086	0.032	0.030	0.088
Residual Std. Error	0.970 (df = 172)	0.990 (df = 174)	0.956 (df = 173)	0.984 (df = 174)	0.985 (df = 173)	0.955 (df = 173)
F Statistic	2.586*	1.751	3.813**	2.188	1.924	3.874**
	(df = 7; 172)	(df = 5; 174)	(df = 6; 173)	(df = 5; 174)	(df = 6; 173)	(df = 6; 173)

$^{*}p < 0.05$
$^{**}p < 0.01$

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