

Student interactions and experiences in online team-working activities in astrophysics and space science

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Motivated by the question of how the design of online team-working activities affects learning experiences, we present an analysis of three such activities studied by advanced undergraduate and postgraduate distance learning students in astrophysics and space sciences. The activities incorporate periods of team-working ranging from 1 to 9 weeks and have varied assessment strategies. Our study focuses on participation rates, the nature of student interactions, and the reported student experience and is informed by the content of asynchronous discussion forums and interviews with students. We find that variation in student participation differs between the three activities, and we suggest reasons for this related to activity design. We identify major themes of student interaction, these being related to learning and development, group building, and team self-organization. The incidence of communications in these thematic areas appears similar across all three activities. Our analysis framework includes subcategories of these themes, and interactions indicative of peer learning are found to be a major component of student communications. Such interactions are enhanced at the times at which teams are required to make major decisions to progress their joint work. Interviews with students reveal anxieties about participation in team-work and unequal contributions to group outputs. They also present a range of views about the different assessment models used. Overall, interviewees from all three activities report having positive experiences in their teams and that they see the activities as valuable for their individual learning as well as being useful preparation for future employment.

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I. INTRODUCTION

An expectation of university-level qualifications in physics is that they will help students in their development toward becoming practicing scientists. To this end, it is common to engage students in learning experiences that, to some extent, are authentic in the context of professional scientific practice. Such learning often requires collaborative work on open-ended problems and can be approached in a variety of ways, such as higher-level laboratory investigations [1,2] or projects within and supported by existing research groups [3]. The question of what constitutes a sufficiently authentic, yet appropriately supported, student activity is of particular interest in a distance learning setting where, by definition, students may never have the opportunity to meet face-to-face,

let alone carry out collaborative work in person. The online-only setting might appear in contrast to traditional laboratory classes held in dedicated spaces; however, online collaborative working increasingly reflects the reality of how scientific projects are often conducted. Because of the international collaborative nature of major projects in astrophysics and various branches of space science, it is common for researchers to work remotely from one another. It is of interest, then, to explore this approach as a teaching method, not only for distance learning students but also as a way for students in general to develop the skills needed for successful collaborative online team-working. This has particular importance given that one effect of the COVID-19 pandemic is an expected long-term increase in remote working [4]. Another effect of the pandemic was the necessity to invoke remote teaching of practical science for undergraduates, leading to a growing interest in the role of social interactions in learning in this area, such as in the context of remote physics laboratories [5].

The student activities that form the basis of this study are components of programs for advanced undergraduates in astrophysics and for graduate students in space science

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at The Open University in the United Kingdom (hereafter referred to as UKOU). These activities were designed and structured in a variety of ways (as described in Sec. II B) but have a core purpose to provide students with an opportunity to engage in meaningful team-work in pursuit of a scientific objective. Given this participation in a community of peers with a common purpose, it is useful to consider learning as taking place through a community of practice (CoP). This concept was originally proposed by Lave and Wenger [6] as a framework to discuss the type of learning (situated learning) that enables novices to become practitioners in a given field. Specifically, they introduced the idea that a novice or apprentice would follow a trajectory of participation within a community of experienced practitioners and, crucially, other apprentices. Such an approach builds on Vygotsky's ideas of social constructivism [7] that emphasize the effect that social interaction has on individual learning. In a CoP, individuals become enculturated to its norms and practices through a process of "legitimate peripheral participation." Over time, individuals may take on more central roles, resulting in them becoming experienced practitioners [6]. While these ideas originated from ethnographic studies of a wide range of career communities and other groups, the implications of applying a CoP viewpoint in formal education settings were immediately recognized as a matter of interest by Brown *et al.* with their idea of "situated cognition" [8]. This asserts that in order to be effective, academic learning should take place within the context and culture of that discipline. Teaching strategies that follow from this approach aim to engage students in activities that are authentic in the context of the discipline. This presents a particular challenge in distance learning environments. Consideration of how to support such learning in an online context led Herrington and Oliver [9] to recommend nine elements of the design of authentic learning environments that can be summarized as *authentic contexts; authentic activities; expert performances; multiple roles and perspectives; collaborative construction of knowledge; forming abstractions through reflection; articulation of tacit knowledge; coaching and scaffolding; and authentic assessment*. While having their origins in online learning, these elements have come to inform discussion about authentic learning more generally (see, e.g., Ref. [10]).

Over recent years, it has become increasingly recognized that communities of practice provide a useful framework in which to understand the transition from physics student to practicing physicist [1,2,11–13] and that they may also provide insights to inform curriculum design [14]. In this study, we are interested in the role of social interaction within authentic learning, and we use communities of practice as a lens with which to view student experiences within three different teaching activities. In taking this approach, it is important to appreciate that within educational settings such as these team activities, there are no

students who represent genuinely experienced practitioners as envisaged in Lave and Wenger's original study [6], and hence the importance of Herrington and Oliver's *expert performances* [9] for students to model their practice on. However, it is also the case that students come to these activities with different levels of individual specialist knowledge and experiences of team-working, and this may have an effect on their ability to take on central roles.

Since participation is a necessary condition for learning in a CoP, the first aim of the study is to examine quantitative measures of student participation in online learning communities. We might suppose that ideally, all members of a learning community should participate equally, although in reality, we anticipate a distribution of student participation that deviates from this ideal. We seek to measure and characterize this distribution for a range of teams and activities.

The second aim of the study is to gain insight into the nature of communications between students while engaged in team-working. From a CoP perspective, we anticipate communications in which students learn from one another, but there are also likely to be other themes of interaction. Understanding the whole picture of team interaction puts peer learning into context and may offer insights into the design of effective team activities.

The final aim is to examine student perceptions of team-working based on their experiences. In terms of an authentic learning approach, the question of how students view the authenticity of their experiences is of particular interest. In addition, from the point of view of implementing online team activities as a teaching strategy, it is also useful to understand what barriers there may be to participation and whether students are consciously aware of peer learning that occurred through engagement with their team and the role that it may have in their own development.

These aims lead to the research questions for this study of online team-working activities:

RQ1: In what ways does student participation vary between teams and between activities?

RQ2: What is the nature of interaction during team-working?

RQ3: What do students report about their experiences of online team-working?

We address RQ1 and RQ2 through analysis of the asynchronous discussion forums used by students while conducting their work. RQ3 is addressed through interviews with a sample of students from each of the collaborative activities.

II. EDUCATIONAL CONTEXT

A. Institutional profile

The UKOU is a distance learning university that provides undergraduate and postgraduate qualifications

in a range of curriculum areas. Students at the UKOU have little or no opportunity to meet face-to-face, and in the subject areas under consideration here, all teaching is online. About 70% of students combine their studies with full- or part-time employment [15]. In order to be accessible to students with very diverse circumstances, the institution adopts a flexible self-study approach that minimizes the use of teaching sessions at set times (although in the activities considered here, varying degrees of synchronous participation are required). Consequently, the majority of student interactions are mediated through asynchronous online discussion forums.

Astrophysics is offered at the advanced undergraduate level, and space science is a postgraduate (master's-level) program. Modules in these areas attract about 120 and 50 students per annum, respectively.

A consequence of the UKOU's distance learning model is that experimental and observational facilities have to be accessed remotely. The UKOU has long used online methods in support of science teaching [16], including the provision of remote experiments to students (through an initiative called OpenSTEM Labs [17]). Two such facilities were used in team activities described here: a robotic telescope and a remotely operated rover in a Mars yard.

B. Team activities

The team activities studied here develop the practical skills required to conduct a scientific investigation and the communication skills needed to work effectively together. This study focuses on the three major team-working activities within the astrophysics and space science modules mentioned above. They are varied in terms of the nature of the investigations and involve students who are at an advanced stage of their studies and will shortly be in a position to seek employment (or continue to postgraduate research).

Considered in terms of Herrington and Oliver's [9] framework, the activities mirror professional practice and hence have an authentic context. The team-working approach facilitates the collaborative construction of knowledge, and as described below, the organization of teams necessitates contributions from multiple roles and perspectives.

The activity for astrophysics students takes the form of a choice between two team projects. One is based on the use of a remote telescope called Physics Innovations Robotic Telescope Explorer (PIRATE) [18,19] to acquire and analyze the light curve of a variable star. In the other project, students use an external research database, the Sloan Digital Sky Survey (SDSS) [20], to investigate the optical-UV spectra of quasars. In both cases, the team size is typically 6–11 students, and the activity runs over 9 study weeks, amounting to roughly 100 h of study. The team activity for space science students is a mission simulation rather than a project. Running over a single

week, teams of up to 16 students conduct a simulated exploration of a "Martian" landscape that includes realistic data and images to fulfill a set of mission goals.

All three team activities are further described below. There are however some common principles to their design and implementation, these being team decision-making, opportunities for individuals to take leading roles, and composition of teams. The requirement for team decisions was seen as an important prompt to encourage participation from all team members. The opportunities to demonstrate leadership were explicitly built-in so that individuals could evidence their contributions to the team. Team membership was preassigned and designed such that all teams included some members who had been notably active in other forum activities as well as some students who had performed well academically prior to the team-working activities. The inclusion of students who were active in other forums was seen as important in ensuring that every team contained at least some members who would be likely to engage in discussion about their assigned tasks. From a CoP viewpoint, such students could be interpreted as being those most likely to begin with high levels of central participation. Furthermore, the opportunity to take leading roles provides a mechanism for individuals to move toward more central participation in their team.

1. Robotic telescope project (PIRATE)

The PIRATE robotic telescope (mirror diameter 0.61 m) is located at the Observatorio del Teide (altitude 2390 m) in Tenerife, Spain (Fig. 1). The aim of the activity is to determine the physical characteristics of a star that shows periodic optical variability but is as yet unclassified or poorly studied. The candidate stars for this study are selected from a catalog [21] that matches stars with optical periodic variability (from the SuperWASP survey [22]) with x-ray sources. Each project group has up to four observing sessions spread over an interval of 5 weeks, facilitating photometry of a target star using a range of filters.

In the first 3 weeks of the project, the team selects a suitable target. This choice is vetted by an instructor prior to observing sessions being scheduled. During this phase of the project, students also conduct familiarization activities that prepare them for observing and reduction of CCD camera data.

During the observing phase (weeks 4–8), the telescope is controlled in real time by an observing team, a subgroup of up to four students. Observing sessions are organized as synchronous online meetings that start with a briefing from a member of the teaching staff with expertise in telescope operations. This staff member acts as a night duty astronomer and remains available for the duration of the session to provide assistance to the observing team if difficulties are encountered. The observing team is linked



FIG. 1. The robotic telescope facility at the Observatorio del Teide, Tenerife, Spain.

in an audio call while viewing a common software interface to the telescope. In this environment, they share the tasks of telescope operation, data quality monitoring, and session logging. Observing sessions commence at dusk in the United Kingdom (which is at a similar time to dusk in Tenerife) and continue for approximately 4 h until about midnight. After this time, the telescope is switched to a scheduler mode, allowing the team to acquire further data by specifying the parameters of observations to be made. As with any ground-based observatory, telescope operations are subject to the vagaries of the weather, and it is not unusual for observing sessions to be adversely affected.

In parallel to the observations, other students take on “office” work to support the project. As the project progresses, the focus of this work changes from data reduction to the more advanced analysis and literature review work needed for a group report. The group report itself is written in weeks 7–9 of the project.

In addition to the range of roles taken on during observing sessions, several roles within the wider project team were specified to help teams meet their goals. In weeks 2–6, there is a designated role of coordinator, with responsibility for organizing and summarizing the work of the group. In weeks 7–9, this role is replaced by two other coordinating roles of lead analyst and report editor. The team itself selects members to fill these roles on a weekly basis, such that all students have the opportunity to take on a leading role in their team.

The team communicates in various ways, with asynchronous discussion forums playing a core role. Such forums are also monitored by an instructor who provides support when needed. As noted above, synchronous audio communications are used during observing sessions.

Further synchronous meetings take place with an instructor to review progress. Teams are also encouraged to hold regular meetings (without an instructor) as a way of progressing their work, with many doing so on a weekly basis.

2. Quasar spectrum project (SDSS)

In this project, students are tasked with using data from the *SDSS* to create a composite quasar spectrum that extends from visible to UV wavelengths. The *SDSS* is an established research program of large-scale imaging and spectroscopic surveys conducted using a dedicated robotic optical telescope [20]. Data are made publicly available through staged data releases, and the survey and its database are clearly and comprehensively described through journal publications and a dedicated website. These features make it eminently suitable for advanced undergraduate use. A key aspect of the quasar spectrum project is the appropriate selection of data to create a composite spectrum. Hereafter, we refer to this activity as the “*SDSS* project” while noting that this educational activity has no formal connection with the Sloan Digital Sky Survey.

This project complements the robotic telescope project in various ways. From an educational perspective, it was designed to be accessible to students who, due to their circumstances, would be unable to participate in observing sessions at set times of day or are unable to commit to 9 continuous weeks of group work. Consequently, during the first 4 weeks, students individually complete a set of structured activities that develop their skills in retrieving, handling, and visualizing *SDSS* data. Many of these tasks are carried out using spreadsheets, although a bespoke

software tool is provided to facilitate the combination of multiple spectra with different redshifts. These activities also develop students' understanding of the spectra of quasars (and other classes of active galaxies). During this time, while there is no absolute requirement to work as a team, group discussion is prompted by the activities and strongly encouraged as a way to address any issues encountered. By the start of week 5, most students will have engaged in some way with their team, and individually, all students are expected to be able to work effectively with SDSS data. At this point, the team starts to work collaboratively to generate a high signal-to-noise ratio quasar spectrum. Teams work together to plan their approach to this problem. They then spend 2 weeks producing their composite spectrum and a further 2 weeks collaboratively writing a report to present their results. During the team-working phase, there are three synchronous meetings with an instructor: one to discuss plans for data selection and processing and two to discuss progress toward the final report.

As in the robotic telescope project, there are specified roles of project coordinator, lead analyst, and report editor, and students take on these roles for 1 week at a time. The methods of team communication are similar to those used on the robotic telescope project, albeit with a reduced frequency of synchronous meetings.

3. Mars rover mission simulation (ROVER)

The team activity for the postgraduate module in space science is a simulation of a Mars rover mission (hereafter referred to as the ROVER activity). It develops skills of working together online in a scenario that emulates real space mission operations. This activity has a much shorter duration than the astrophysics projects, lasting only 1 week and requiring about 16 h of study time. The activity uses a Mars yard facility at the UKOU campus and a robotic rover.

One of us (S. P. S) was the lead instructor for the development of this simulation, basing it on experience of

working with NASA's *Curiosity* rover (the MSL [23]). The simulation incorporates the following features: realistic timelines and deadlines, specialist roles for team members, evidence-based group decision-making, online discussions, and planning meetings. For reasons of practicality, the planning and operation cycle of the rover runs over 24-h rather than a true Martian solar day.

The mission scenario is that "a small scouting rover has been landed on Mars to assess whether its landing site is suitable for follow-up with a large rover that will search for evidence of past or present life." The goals of the mission are to document the landscape and its rock types, to seek evidence for water-bearing minerals, and to assess any evidence for past or present flowing or standing water. The team is expected to report daily on their findings. A key responsibility of the team is to ensure the continued safe operation of the rover, and the simulation includes hazards to navigation (such as sand dunes) that are a major concern in real rover operations.

The operating environment is an interior yard with approximate dimensions 6 m $\times$ 12 m. The floor area is covered in sand and contains a variety of rocks that are visual analogs to those found on Mars. This yard is surrounded by a blue screen so that Martian panoramas (from MSL) can be electronically added to images acquired by rover cameras. An example image, as relayed back to the student team, is shown in Fig. 2.

The rover is a small, six-wheel "all terrain" vehicle built using off-the-shelf components. It is equipped with three cameras for navigation and target inspection, one of which is a mast-mounted color camera (MastCam). There are no real science instruments on the rover; rather, there are two virtual instruments that return archival Mars data relevant to the target rocks. These virtual instruments are called LIBS—laser-induced breakdown spectrometer (similar to ChemCam on MSL, [24,25])—and the arm-mounted APXS—alpha proton x-ray spectrometer (as on the Mars Exploration Rovers [26]). LIBS provides spot chemical composition data at a distance, while APXS gives bulk



FIG. 2. An example image from the rover mast camera showing the simulated Martian environment (UKOU Mars yard in the foreground, Mars Science Laboratory (MSL) images in the background).

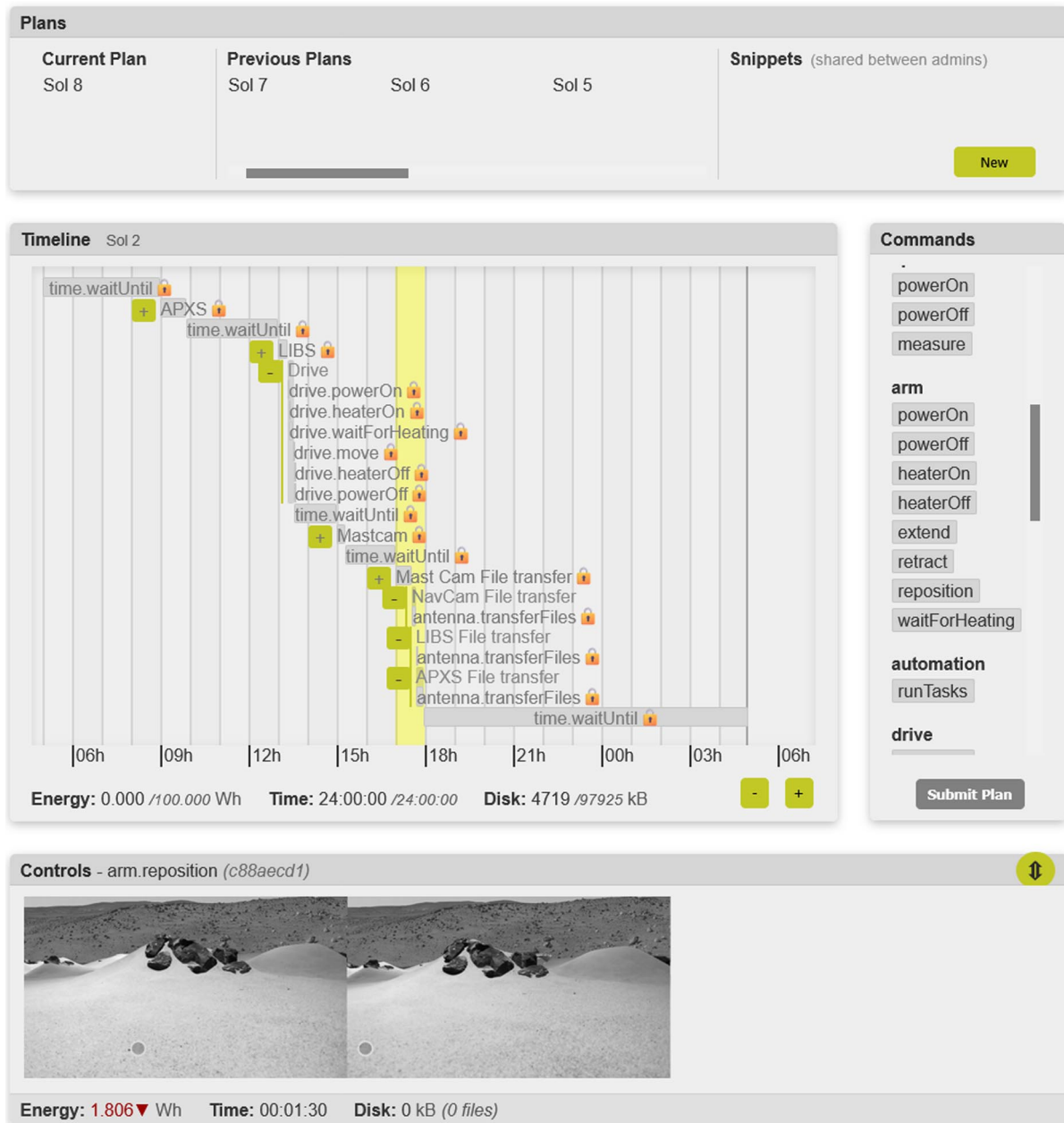


FIG. 3. An example view of the interface used to define daily rover operational plans in the Mars mission simulation. The center panel shows scheduled actions on a timeline (each action has further detail that is not shown in this view). The lower panel shows images from the Rover's navigation camera at the end of the previous day's operations. (Note that the term "Sol" on the upper panel refers to a Martian day.)

compositional data. Crucially, the simulation also incorporates a realistic software model for the energy budget and data constraints of the rover. Rover operations are planned through a software interface that integrates these physical, virtual, and modeled components (Fig. 3).

The mission team is split into subteams with given responsibilities. These subteams are Mission Lead, Mission Scientist, Rover Driver, and instrument teams (MastCam, LIBS, and APXS). Typically, about 16 students participate in each simulation run, with 2 or 3 students

allocated to each subteam. Rover operations are carried out over 5 days, with a daily set of activities that includes planning, rover task upload, data download, and analysis that feeds into the following cycle. There are daily online synchronous meetings to report on rover status, discuss results, and plan the next day's activity. The planning process involves the whole team agreeing on the subsequent target based on scientific goals and analysis of returned data and images of the environment around the rover. Subteams then express their part of the plan through

the shared software interface as instructions for the rover and its instruments to execute. Initially, this usually results in a plan that is not viable, e.g., because the rover's energy budget has been exceeded, prompting further analysis and negotiation about how the plan should be revised. Once the team has agreed to their final sequence of rover commands, it is uploaded with no further possibility of modification. Data (including images) that are acquired become available the following day. Asynchronous forums are used by team members to discuss such data, allowing them to prepare for the next (synchronous) daily meeting. The simulation is supported by a lead instructor who provides the initial briefing and attends the online meetings to provide guidance to the team and a support instructor to help individual students. The mission ends with a debriefing session in which the results are summarized by the team and instructor feedback is given as to how the team performed.

C. Assessment

The PIRATE and SDSS projects follow a common assessment model. The assessment has two components—a group report that is created by the team and a set of individual progress reports produced by each student. The group report requires an account of the project work modeled along the lines of a scientific paper. It is presented as a wiki document of about 5000 words in length. The other component, the set of individual progress reports, is a compilation of reflective logs, written on a weekly basis to record the contribution to the project work. These two components are equally weighted in contributing to the overall student score.

The ROVER project is assessed using a self-reflection exercise. Students provide an account of their role and reflect on aspects of their performance. They identify three aspects of their engagement with the team that had gone well and two where performance was not as good as they would have liked. They then suggest how to further improve their performance in one of the areas that had gone well.

III. STUDENT INTERACTION

Our investigation of student interactions in the team-working activities is based on the records of asynchronous forum communications (the forums are within a customized version of the Moodle virtual learning environment). The frequency of forum postings provides quantitative information about student participation within a team and hence can inform RQ1. Analysis of forum content sheds light on the nature and timing of the interactions taking place in a team and is used to address RQ2. Below, we describe the methods applied for these two approaches before reporting the results.

A. Methods

1. Frequency analysis of forum postings

We make the assumption that the number of posts made by a student in a team forum provides some measure of that individual's participation. Clearly, there are caveats to adopting this measure. First, the three activities in this study also used synchronous meetings (e.g., daily planning meetings for the ROVER activity and team observing sessions for the PIRATE project) but to different degrees. Counting of forum posts may under-represent the activity of students who make more use of synchronous communication. Also, some students may make many short posts, while other (similarly active) students may make fewer but longer posts. Finally, viewed through a CoP lens, passive engagement (i.e., reading but not writing posts) is considered legitimate peripheral participation [6]. We assume that every student within a group engages, at least in a passive sense, with every other student, and we do not study the detailed interconnections between students (as would be provided by social network analysis). Despite these potential shortcomings, we believe that the count of forum posts can be a useful proxy measure for individual contribution.

Within a given team, the contribution of individual members is assumed to be represented by the number of posts (P). To characterize the team, we place individuals in order of decreasing P to obtain a rank R (the most prolific contributor has $R = 1$, etc.). As will be justified below (Sec. III B 1), we adopt an exponential model to describe the team posting behavior:

$$P = P_0 \exp(-mR), \quad (1)$$

where P_0 (the number of posts at a hypothetical rank zero) and m (a decay rate) are determined from the data. The latter parameter (m) provides a measure of the distribution of individual contributions for a given team. It is informative to describe the typical relative decrease in P from any one student in a group to the next in rank, and this is given by:

$$\Delta_P = 1 - \exp(-m). \quad (2)$$

The results of determining this quantity for the different team activities in this study are presented in Sec. III B 1.

2. Content analysis of forum postings

Our approach to the analysis of the content of forums is exploratory and aims to identify themes of student interaction. We therefore adopted a grounded theory approach [27] rather than seeking to analyze in terms of any particular theoretical framework. The analysis framework was developed as follows. We conducted a preliminary analysis of a single SDSS forum (from 2017, the year

before the cohorts considered in this study). This revealed a diversity of message types that could be grouped under a small number of overarching themes. These included interaction with teaching staff, the communication needed to organize and manage a team task, and peer discussion about scientific knowledge and interpretation of data. In addition, this analysis also identified communications that were primarily social in nature and not explicitly related to progressing any aspect of the team's activities. There were also a (small) number of contributions in which students expressed their feelings about some aspect of the activity. This led to a framework in which the purpose of forum content is categorized into the following five broad areas:

- learning and skills development through peer interaction (learning and development)
- organization and management of the project work (project management)
- group building and social interaction (group building and social)
- expression of own emotional state (feelings)
- interaction with teaching staff (teaching support).

Hereafter we refer to these categories using the abbreviated terms given in parentheses above.

Since our aim is to examine the distribution of forum content between these categories, we adopted a quantitative measure of that content. Although it is appealing to work in terms of individual postings, these often serve more than one purpose. Consequently, we took the approach of coding every part of a forum posting (what we term a “contribution”) that could be attributed to a distinct category or subcategory. These contributions then constitute our adopted measure of an individual's engagement.

In order to examine the detail within the broad categories described above, we developed a hierarchical classification scheme in which subcategories were defined, again, by inspection of the data. So, for example, “feelings” was subdivided into further subcategories: anxiety, confusion, excitement and enthusiasm, frustration and anger, and satisfaction and pride.

This scheme was then reviewed and refined by applying it to a second SDSS forum (again from 2017) that was jointly coded by two of the authors (J. H. C and M. H. J). Following this process, some subcategories were consolidated or removed to reach a final two-level hierarchical coding scheme used for forum content as shown in Table II. Note that not every contribution could be subclassified, and there are some that are only classified at the top level.

For the purposes of examining some of the content in greater detail, a third level of subcategory was invoked where needed. In the analysis presented here, this is only used within the subcategory of “peer learning” (within “learning and development”): this was broken down into “asking for help or information,” “providing help or

information,” or “discussion.” This coding is used to examine the time variation of interactions (see Sec. III B 3).

The development of the coding scheme was also used to assess interrater reliability for the two individuals involved in coding. Reliability was estimated on the basis of agreement at the top level of the coding scheme. The forum that was jointly analyzed had 606 contributions and yielded a value of Cohen's $\kappa = 0.79$. There was an expectation that this would improve when applied to the data in this study, since the raters had discussed the implementation of the scheme. The interrater reliability was tested again when applied to the datasets presented in this study (see Sec. III B 2).

B. Results

This study is based on team activities carried out in 2018 by 162 students in 17 separate teams (6 PIRATE, 8 SDSS, and 3 ROVER). All teams were subject to the frequency analysis of forum postings, whereas forum content analysis was conducted using a sample of three teams for each type of project. All three ROVER teams were analyzed. For the PIRATE and SDSS projects, three teams were chosen for each so as to cover a range of forum activity (as measured by the total number of posts) between the minimum and the mean (for that activity). Although this approach is biased by excluding highly active teams, given that all chosen teams did successfully complete their tasks, it is assumed that they are a representative sample of their respective activities. A summary of the teams and the analysis applied is given in Table I.

1. Frequency analysis of forum postings

The rank-postings data (R - P) for all teams in the study are displayed in Fig. 4. It can be seen that team posting behavior can be reasonably well described as an exponential decay in P with R (i.e., the model described in Sec. III A 1 above). This is especially the case for the SDSS and ROVER activities (see, for example, SDSS-E and ROVER-A in Fig. 4). The approximation is improved if we require that P has to exceed a threshold for participation; we adopt $P \geq 10$ as being appropriate for indication of active involvement in a team. For each group, the value of m was found by least-squares fitting to the data (subject to $P \geq 10$). The corresponding values of Δ_P (Eq. 2) are reported in Table I. This measure of the difference in active participation between group members is useful because the ideal situation (i.e., that all students participate to approximately the same degree) should result in low values of Δ_P .

For each of the three activities, we calculated values of $\Delta_P = 1 - \exp(-\langle m \rangle)$, where the mean is taken over all groups undertaking that activity. Lines (in black) corresponding to these mean behaviors are shown on Fig. 4. The values of Δ_P (and ranges) were found to be

TABLE I. A summary of the student teams in this study and the analysis applied. Individual teams are identified by activity type (SDSS, PIRATE, or ROVER) and a single letter suffix. N_s is the number of students in each group. “Y” indicates that the corresponding analysis was carried out. The number of interviews conducted is also shown. The table also reports the quantitative measure of forum interactivity (Δ_p) found from frequency analysis (see Sec. III B 1).

Project team	N_s	Forum frequency analysis	Forum content analysis	Interviews	Δ_p
SDSS-A	9	Y	Y		28%
SDSS-B	10	Y	Y	1	18%
SDSS-C	7	Y	Y	1	21%
SDSS-D	11	Y		1	32%
SDSS-E	11	Y		2	19%
SDSS-F	11	Y			26%
SDSS-G	11	Y			22%
SDSS-H	9	Y			24%
PIRATE-A	6	Y	Y	1	44%
PIRATE-B	7	Y	Y	2	28%
PIRATE-C	7	Y	Y		37%
PIRATE-D	8	Y			30%
PIRATE-E	8	Y			24%
PIRATE-F	7	Y			26%
ROVER-A	11	Y	Y	2	16%
ROVER-B	16	Y	Y	1	13%
ROVER-C	13	Y	Y	3	18%

SDSS: 24% (18%–32%), PIRATE: 32% (24%–44%), and ROVER: 15% (13%–18%). There is considerable variation between types of activity, as well as a large spread within particular types of activity. The interpretation of these values is discussed further in Sec. V.

2. Distribution of contributions by theme

Content analysis was carried out on the nine datasets indicated in Table I using the hierarchical coding scheme described above. To monitor whether the coding scheme was appropriate and sufficient to capture the content of these forums, all possible exceptions to the original scheme were recorded. The number of total contributions coded was 6089 (from 4187 individual postings), with 308 contributions flagged as possible exceptions. On review, all exceptions could be included within the coding scheme without it being amended. Interrater reliability was reestimated for the final datasets presented here. This was done at two levels: for the five top-level categories and for the first-level subcategories, yielding values of Cohen’s κ of 0.89 and 0.81, respectively. These estimates were based on a sample of 5% (i.e., 300) of the contributions that were independently coded twice. This is somewhat lower than the sample size of 10%–25% that is commonly adopted [28] but is justified on the basis that a sample of 606 contributions (i.e., about 10% of the size of the analyzed

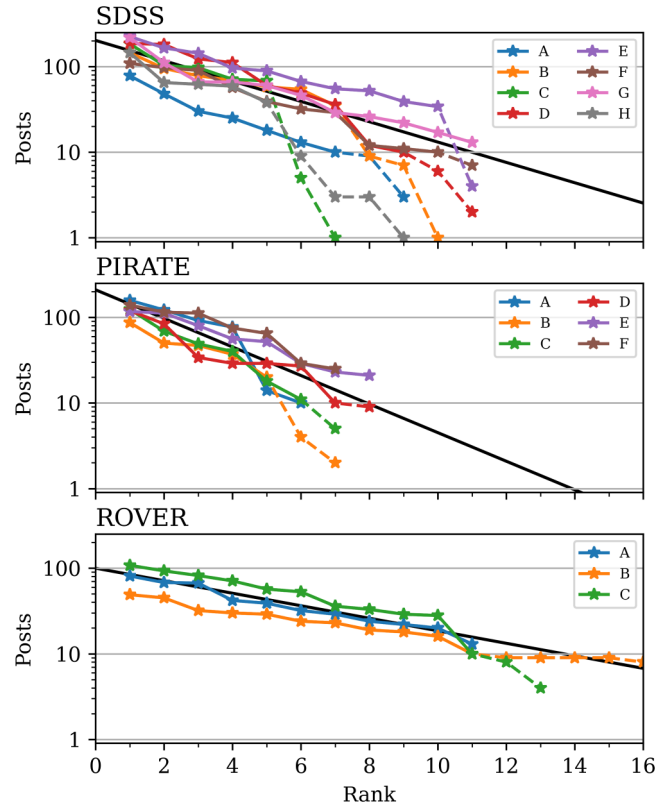


FIG. 4. The number of posts (P) by each student plotted against rank (R) for all teams. Within a team, participating ($P \geq 10$) and insufficiently participating ($P < 10$) students are connected by solid and dashed lines, respectively. Black solid lines show the exponential model representing the characteristic behavior of active students in all groups for a given activity.

dataset) was used to develop and test the coding scheme (as described in Sec. III A 2).

The distribution of forum contributions by our coding scheme for each project is given in Table II and shown graphically in Fig. 5. At the top level of the coding scheme, the three projects show similar distributions, but with some differences. Discussion relating to project management constitutes 40.1% for the PIRATE project but is less for the SDSS and ROVER projects (34.7% and 33.9%, respectively). This likely reflects the complexity of the PIRATE project, requiring, as it does, the operation of a remote telescope and subsequent data reduction. Every observing session has an associated forum thread that is used to support prior planning and for organizing the handling of acquired data. These threads form a substantial contribution to the overall forum content. The contributions coded as learning and development show the reverse trend, with PIRATE being the lowest at 33.9% and SDSS and ROVER at 42.7% and 39.0%, respectively. While this indicates that PIRATE has a lower proportion of peer-learning forum content, there are student interactions in synchronous observing sessions during which such learning does occur. It is likely that these sessions set a precedent for peer

TABLE II. The two-level coding categories used in the analysis of forum content and their percentage frequencies by activity. The top-level coding categories and their frequencies are indicated in bold. Summary statistics of the analyzed content are also given. The combined frequencies are the means of the percentage frequencies for each activity.

		SDSS	PIRATE	ROVER	Combined	
		Forum posts	1416	1214	1557	4187
		Contributions	2229	1920	1940	6089
Hierarchical coding classification		Percentage frequency				
Top level	Second level					
Feelings		1.97	3.28	2.06	2.44	
	Anxiety	0.40	0.68	0.15	0.41	
	Confusion	0.27	0.31	0.15	0.25	
	Excitement and enthusiasm	0.76	0.99	0.46	0.74	
	Frustration and anger	0.36	0.99	0.41	0.59	
	Satisfaction and pride	0.13	0.05	0.93	0.37	
Group building and social		16.22	13.65	16.25	15.37	
	Acknowledging others' contribution	9.05	6.35	7.20	7.53	
	Acknowledging team achievement	0.54	0.10	1.95	0.87	
	Dealing with nonparticipants	0.22	0.42	0.00	0.21	
	Disruptive or negative contribution	0.00	0.00	0.00	0.00	
	Encouragement or support	2.33	2.60	1.59	2.18	
	Humor	0.94	0.16	3.75	1.62	
	Own lack of contribution or participation	1.52	0.57	1.03	1.04	
	Reference to topics not related to the team task	0.99	1.72	0.21	0.97	
	Stating or implying that others should contribute more	0.00	0.05	0.00	0.02	
Learning and development		42.70	33.85	39.02	38.52	
	Acknowledgement of mistakes	0.49	0.68	0.62	0.60	
	Mention of existing skills, strengths, or weaknesses	0.04	0.31	0.21	0.19	
	Peer learning	37.90	25.89	37.63	33.81	
	Reflection on learning	0.13	0.00	0.26	0.13	
	Writing process	4.17	6.98	0.00	3.72	
Project management		34.72	40.05	33.93	36.24	
	Asking or directing others to carry out a task	3.81	2.81	1.18	2.60	
	Clarifying who should carry out specific tasks	0.31	0.78	1.59	0.90	
	Recommendation of software for specific tasks.	0.13	0.05	0.36	0.18	
	Reference to instructions or guidance	2.06	1.15	2.62	1.94	
	Reference to synchronous meeting	6.81	13.23	5.19	8.41	
	Reflection on group progress	0.72	0.68	0.00	0.46	
	Reporting on actions	13.31	11.46	12.70	12.49	
	Role selection	1.21	3.39	0.00	1.53	
	Stating availability to carry out tasks	2.46	2.14	3.14	2.58	
	Technical problems	1.79	4.17	2.98	2.98	
Teaching support		4.39	9.17	8.74	7.43	
	Module team communication	1.12	5.89	8.43	5.15	
	Tutor input	3.27	3.28	0.31	2.29	

learning that then continues through further synchronous meetings.

Interestingly, all three projects show a similar level (~15%) of group building and social contributions despite having varied reliance on synchronous meetings and different durations. This suggests that a certain level of such forum interaction is a characteristic of a functional team regardless of other considerations. In all types of

projects, the largest fraction of these contributions are those acknowledging work carried out by other members of the team. For the SDSS and PIRATE projects, the next most frequent type of contribution (at 2.3% and 2.6%, respectively) is messages of support or encouragement for team members facing difficulties in engaging with the work. The 9-week duration of these projects may be important here: many students experience a perception that

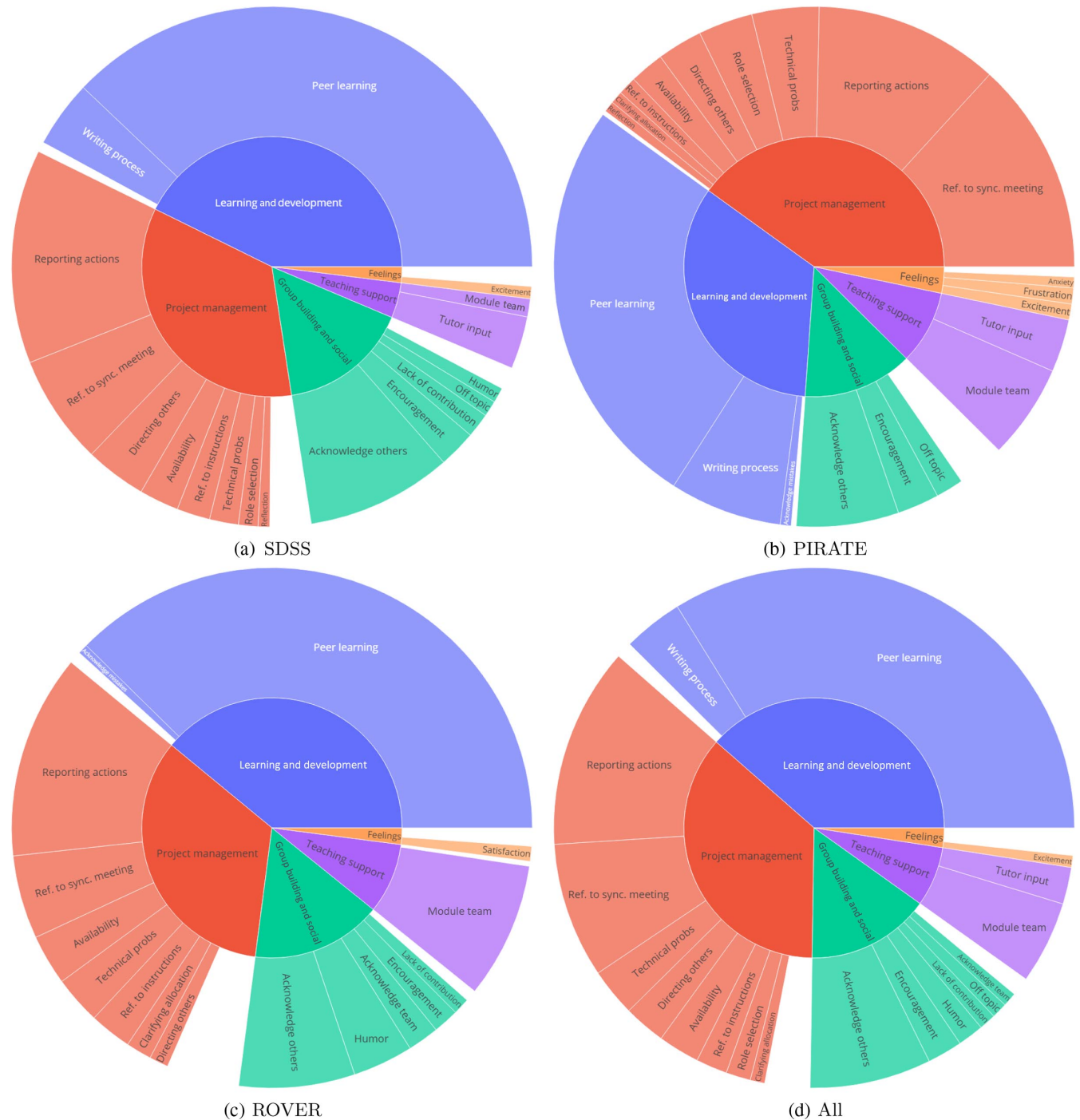


FIG. 5. The distribution of contributions to forum discussions by category and subcategory (as reported in Table II). Note that for clarity of presentation, contributions that comprise less than 0.6% of the total are excluded. (a) SDSS, (b) PIRATE, and (c) ROVER. (d) Shows the mean of the fractional distributions of forum contributions from the three activities.

they are falling behind, but other group members intervene to provide mutual support and encouragement. For the much shorter (1-week) ROVER activity, the frequency of such contributions is lower (1.6%). Another notable difference in group building and social contributions is the incidence of humorous content. Such content appears most frequently in the ROVER project (3.75%) and is less

prominent in SDSS (0.94%) and PIRATE (0.16%). The high incidence in the ROVER project is unlikely to be due solely to the high number of synchronous meetings (since PIRATE students engage in a similar number of meetings). It is possible that the high frequency (i.e., daily) of ROVER activity meetings helps set a culture in which students feel comfortable in exchanging such messages, or that humor is

a way in which students react to the pressure of dealing with the daily planning deadlines.

The contributions coded as teaching support comprise student discussions with teaching staff. These were broken down into two subcategories, “module team communications” and “tutor input” that reflect instructors working with a central team and those with responsibility for supporting particular groups of students, respectively. We do not distinguish between these subcategories in the analysis presented here. The lowest incidence of teaching support interaction occurs on the SDSS project (4.4%), while the PIRATE and ROVER projects show approximately double this (at 9.2% and 8.7%, respectively). The difference between the SDSS and PIRATE projects likely has its origins in the fact that the former is structured such that the first 4 weeks of engagement were designed to be conducted in a self-study manner. While teaching staff are available to answer student queries during this time, communication with the team about their task starts in week 5. The PIRATE project requires team interaction from the start, and teaching staff are more visibly present on forums throughout. The high level of teaching support interactions on the ROVER week is likely due to the very specific role played by the lead instructor, and we discuss this further in Sec. V.

There are only a small fraction (2.0%–3.3%) of contributions in which students express their emotional state (feelings). It is useful to summarize these in terms of positive (excitement and enthusiasm and satisfaction and pride) and negative (anxiety, confusion, and frustration and anger) emotional states. The positive:negative distributions for each project vary. The ROVER project shows the most positive expression of emotion at (1.39:0.72). The SDSS project has slightly more negative than positive contributions (0.90:1.03), while the PIRATE project has more again (1.04:1.98). The design of these projects provides possible explanations for these distributions of sentiment. Both the PIRATE and SDSS projects are long-term activities with multiple stages, so there is more scope for issues to arise that may affect their completion. Such issues may then lead to anxieties and expression of negative sentiment.

Finally, it should be noted that there are some subcategories with very low incidence in this analysis. Anecdotally, it was known from previous years that some teams may experience difficulties in working together, so our scheme included a subcategory (“disruptive or negative contribution”) to record such issues. There were no instances of this in the analyzed forums. Likewise, instances in which students felt that other team members were making insufficient contributions were also coded for (“stating or implying that others should contribute more”). This also had a very low incidence (0.02%, i.e., a single contribution). The low incidence of forum contributions in these areas may indicate that none of the teams experienced such issues. Alternatively, it may reflect a recognition on the part of students that such contributions, if made to a team

forum, are likely to be damaging to the group dynamic and were therefore avoided. Some support for this latter interpretation comes from the fact that this issue was reported in the student interviews (see Sec. IV D).

3. Time variation of forum interaction

Because forum postings are date-stamped, it is possible to examine how differently coded contributions vary over the duration of the projects. Figure 6 shows the week-by-week variation of several coding categories and subcategories for the SDSS and PIRATE projects (since the ROVER activity operates on a much shorter timescale, it was omitted from this analysis). Note that there is a “break week” between weeks 6 and 7 (due to the Easter public holidays that occur in the United Kingdom at this time). This was not an enforced break, so students could still continue to work at this time if they so desired.

As noted above (Sec. III B 2), this analysis used the third-level coding of peer learning into discussion, “asking for help or information,” and “providing help or information.” The first of these identifies exchanges in which there is some negotiation over a topic of interest, while the latter two refer to simple (request and respond) transactions of information. Contributions in the discussion subcategory seem to be prompted at weeks 3 and 5 for the PIRATE and SDSS projects, respectively. These correspond to the points at which teams have to consider important decisions about data acquisition, namely, target selection for PIRATE and quasar sample selection for SDSS. The more transactional asking and providing help and information subcategories show a rise in week 3 for PIRATE, and for SDSS, a sharp rise occurs in week 6. This rise for SDSS is probably linked to the fact that this is the point at which teams have to start processing their data. It is noticeable that these contributions then decline as students get past the point of generating their composite quasar spectrum (week 8). “Project management” themed contributions are relatively evenly spread across different weeks for the PIRATE project, whereas for SDSS there is a steep increase to a maximum in week 6. Again, this is likely linked to the coordination needed in SDSS teams as they select and process data at this time. It is also notable that, as measured by project management contributions, SDSS students continued working at a high rate into their break week while there is a dip in the activity of PIRATE students. This probably reflects the fact that the data processing plans for the SDSS groups were made immediately prior to the break week, and students were likely anxious to progress through this work as soon as possible.

Finally, the key feature of the feelings theme is that for the PIRATE project it shows a sharp peak at week 6, which is toward the end of the observing period. This is the point at which frustrations about issues in data acquisition are likely to become acute. Despite the observing site having 60%–70% clear nights, some teams may get to this point

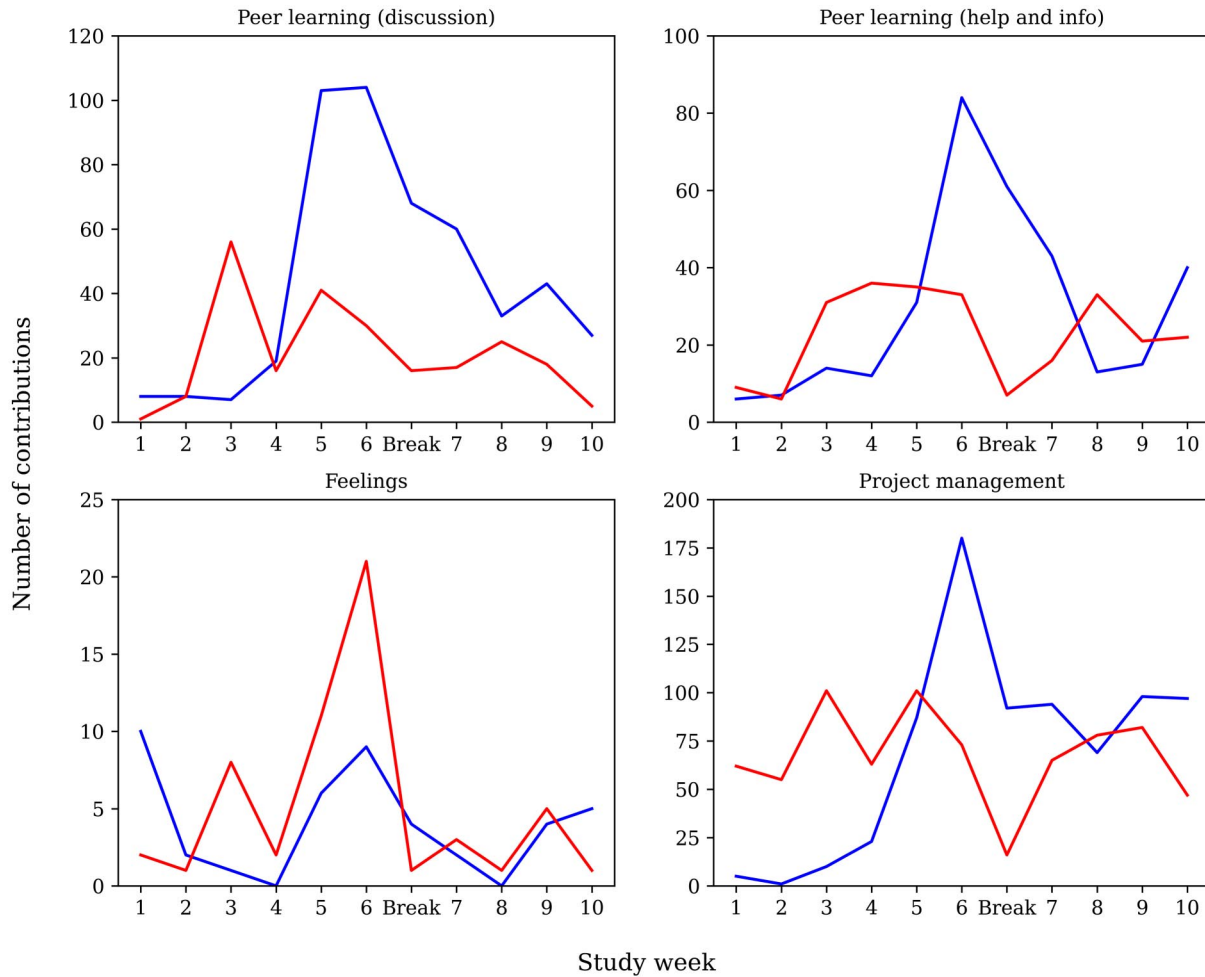


FIG. 6. The time variation of the number of contributions by various categories and subcategories for the coded PIRATE (red) and SDSS (blue) groups. Note the existence of a break week between study weeks 6 and 7.

having had only one usable observing session. This can result in anxiety in the team about whether their team task can be achieved using data that they have acquired themselves.

IV. STUDENT EXPERIENCES AND PERCEPTIONS

While the content analysis described above gives insights into the nature of student interactions during team-working, apart from the small number of contributions about issues or achievements, it yields only very limited information about student perceptions of their experience. To investigate this aspect of the team activities, we used a series of structured conversations (interviews) that prompted students to report and reflect on their experiences (see Appendix for the cue questions). The student responses are used to explore four aspects of the team-working activities, these being: prior views of team-working, the perceived authenticity of the activities, experiences of peer learning, and reflections on the assessment tasks.

All students within the scope of this study were invited to participate: from these 162 students, 14 volunteered and

were interviewed (Table I). Interviewees are referred to here using an anonymous four-character identifier where the first two characters are a team identifier (SA for SDSS-A, etc.) and two digits. The interviews were carried out several weeks after the end of the team-working activities and were conducted by one of the authors (S. M. C) who had no direct teaching involvement with these students. It is notable that many of these volunteers were very active in their team forums (nine have a forum posting rank $R = 1$ or 2) and so cannot be considered to be a representative sample of the entire cohort. Analysis is based on transcripts of the recorded interviews. A separate analysis was carried out for each of the four areas of interest, with coding conducted on the basis of identified themes within these areas.

A. Prior attitudes to team-working

Interviewees were asked to recollect their feelings about team-working before the activity began and to summarize their actual experience after completion. All 14 reported that on completion they had an overall

positive sentiment towards their team-working experience. Most (11 respondents) reported that they had had a mixture of positive and negative sentiments prior to commencement of their activities. Two students reported purely negative prior sentiments, while one had only a purely positive view.

The positive prior attitudes tended to focus on interest in the topic area,

I suppose I was quite interested and excited about the prospect of doing it, particularly given the topic that would be covered. PC03 (PIRATE-C)

and on previous positive experiences of online collaboration,

I felt quite confident as we had already done a collaborative week to do with another part of the course ... and I'd also done other [UKOU] courses which required online collaboration. RB02 (ROVER-B)

Negative attitudes reflected various concerns about team-working. Five (of 14) students reported previously having (or knowing other students who had) poor experiences in online collaborative teaching activities. One concern is being in a team that is insufficiently active, leaving the burden of work on the small number of active participants. There was also anxiety about the reliance on others for the assessed work.

I also was worried about how it works because, obviously, it's a group project where the way we all interact to some extent affects our final performance which is part of our individual score ... PC03 (PIRATE-C)

Even when previous experiences had been positive, one student reported feeling a lack of confidence about online interaction,

I'm quite a shy person and group experiences before ... they've been enjoyable, but I've sort of done the least amount possible, do you know what I mean? Some people are quite forthcoming and they're, sort of, born leaders of the group whereas I'm not, so I was a bit nervous to be honest ... SD02 (SDSS-D)

Other anxieties about team-working relate to the move from independent to collaborative learning,

I was a little daunted to be honest because you get into a bit of a habit with the [UKOU] of being very independent in your study and needing not only [sic] to rely on others in order to complete a group project. SD01 (SDSS-D)

Two students reported that not knowing what would be involved was a source of anxiety ahead of the team-work, although this was dispelled on starting the activity, with one of them stating,

there was certainly some apprehension on reading the handbook and reading information about it, and it just didn't become clear until we actually started it. RC08 (ROVER-C)

Overall, the major causes of negative sentiment around team-working seem either to be linked to anxieties about relying on others or their own confidence in engaging in a group setting. These negative aspects of online collaborative working are well known and have been reported in other similar contexts, such as technology education [29].

B. Authenticity of team activities

Although interviewees were not asked directly about the authenticity of their activities, they were prompted to reflect on whether they thought it was important for students to engage in an online team activity and to explain their views (Appendix, Question 15). Three themes emerged from these responses: authenticity of the scientific investigations, development of team-working skills relevant to employment, and the effect these activities have on engagement with learning.

A majority of interviewees (8 of 14) commented on how the activities aligned with the way in which scientific investigations are carried out in an academic or research environment. This was the case for all three activities. A PIRATE student commented on the goal of their work,

When it came to what we were studying, I think it was very appropriate and it made you feel like you were contributing something scientific to—to the scientific community even if, you know, we never have anything come of what we did. PC01 (PIRATE-C)

While an SDSS student reported on how their team had come to appreciate how they were achieving authentic outputs,

when we went out looking for comparison papers from professional astronomers and professional organizations and comparing what we'd got and what they had produced and published, it slowly dawned on us that we were actually at the cutting edge of this study. We were using the latest data there is, we're doing analysis the same as professional astronomers are doing. OK, they're a bit further on than we are, and they've got whizzier [i.e. better] techniques for doing it but

the nuts and bolts of it, we're doing the same as they are. SE01 (SDSS-E)

Rather than outputs, for the ROVER activity, students tended to concentrate on the method of working,

they [the team] are doing this as a real world simulation as they would with a Mars Science Laboratory team meeting, so it's real work. RB02 (ROVER-B)

Five interviewees noted that the team-working skills developed in the activities would be relevant to future employment within a scientific or technical context, such as,

... a number of students will be interested in carrying on their work in science and some of those would want to go into research roles, and I'm struggling to imagine in this day and age, a research role that doesn't involve you working, in some way, as part of a team. SD01 (SDSS-D)

and, in relation to a work placement,

I've actually just started an internship in [a location] this week, ... and one of the first things they did on my first day was introduce me to a team who are working on a big project very similar, slightly different topic of science, but a very similar team project. SB02 (SDSS-B)

Four of these interviewees also noted that team-working skills are valued in wider contexts of employment, as exemplified by,

... it's a key skill that's important to employers in the real world, ... but, yes, I think it's important to do that, particularly if someone hasn't and needs to get the experience with it. PC03 (PIRATE-C)

In all of these cases, it is the team approach itself that was highlighted as being valued because of its authenticity.

Although interviewees were not asked directly whether the activities had had an effect on their engagement, three did comment on this, with one reporting that,

It was more engaging definitely than just reading about it. ... It was just a really good way to learn because I wasn't really interested in Mars, I have to say, before it started. ... but as soon as I started working on it, I became more interested in how the instruments worked to get the information and stuff like that. RC01 (ROVER-C)

C. Learning in a team-working environment

Two interview questions asked about peer learning (Appendix, Questions 4 and 5). All interviewees stated that they themselves had learned something through peer interaction and 11 participants stated that they had helped another student (or students) to learn something. These questions prompted further exploration of the experience of peer learning.

Five interviewees offered positive sentiments about the opportunity to engage in academic discussion, as exemplified by the comment,

It's really nice to talk and, like, actually discuss concepts with people. I think it makes things clearer. PA01 (PIRATE-A)

with the implication that this is particularly valued in a distance learning environment,

there's a lot to be said for that experience of being able to just a build a little bit of a peer group up, even if it's only for a time limited period, I think it's very helpful. SD01 (SDSS-S)

With regard to interaction with their group, there were a variety of reflections on how individuals engaged in a way that led to peer learning. For instance, one described as asking for help for pragmatic reasons,

towards the end there were several points where I got quite stuck for things or I hadn't—didn't, sort of, have the time to go back and read everything again just to answer a simple question, so posting questions and helping each other out on the forum was, kind of, really important. SB02 (SDSS-B)

This example highlights how a time-pressured environment may lead to greater team interaction because it is an efficient course of action. This pressure may well act to overcome some of the reticence that many students have to ask questions that might expose their ignorance. Another student reported being more relaxed about asking questions even if there was a risk of showing ignorance. They justified their approach as being a likely benefit to others:

I'd had a bit of difficulty understanding concepts such as measuring the flux with a part of the SDSS research ... I certainly noticed through the forum that once I'd been brave enough to ask what I was sure was a fairly naïve question, there were then a few others saying: "Ah, right, I get it now." SD01 (SDSS-D)

This was taken even further by another student who highlighted that those providing explanations also benefit from such exchanges,

I had to have some things explained to me that I didn't quite understand on the ... scientific background and I hope that helped them, yes, with their scientific knowledge because once you explain something to someone it, sort of, makes it, the ideas, more solid in your head. PC01 (PIRATE-C)

From the point of view of responding to discussion, one student reported a sense of reward from being able to use prior skills and knowledge in support of their team. This can be the case even if this knowledge has only just been acquired,

but there were a couple of people who were, I think, like me—who were not that confident and not that *au fait* with Excel or maths and because I—they were a couple of steps behind, I think, and they were asking questions and I was the first person to post a response a couple of times, you know, helping them. And, yes, it does feel pretty good. SD02 (SDSS-D)

The importance of the exchange of knowledge or skills between students with different academic backgrounds or skill sets was commented on, or alluded to, by seven interviewees with the implication that this leads to valuable learning. This was particularly noted for the ROVER activity,

The two members that were in my [ROVER] sub-group were engineers, so I got to pick up a great deal of knowledge about engineering which is something I have no knowledge about, and also in a team sense, I learned that it was OK to be able to do small bits and not be expected to have to manage a whole load of stuff. ... My two sub-team members had no experience of geology so rather than just going ahead and saying that all of the definitions and the other things, we met up and we went through basic [geological] terms. RB02 (ROVER-B)

This echoes the mutual benefit of peer learning across different discipline areas in other contexts of online multidisciplinary team-working [30].

Interviewees also interpreted being asked about “helping others to learn” in a broader context than a transactional exchange of knowledge and technical skills and that other types of input are valued. This may be in terms of contribution to tasks or organizational skills,

I think I helped a bit with the editing side of things and putting the report together and probably time management because I'm pretty good at that. But when it comes to the scientific side of things, I felt a little bit like I was playing catch up more than some of the other people. SB02 (SDSS-B)

or supporting others when needed,

Well, I certainly felt I helped someone out. Possibly because he wasn't handling the stress as well. Because it was a stress[ful] situation. ... It was just sort of like doing what we needed to do but bringing him along with it. RA10 (ROVER-A)

A number of interviewees reported that some of their learning had been about team-working itself and that they had developed by overcoming challenges presented to them. As has already been noted, some students were not naturally comfortable with the prospect of team-working. One reported that after engaging, they perceived the experience to be beneficial,

you have the online teamwork as well and I'm not a particularly good team player so for me it's slightly out of my comfort zone, but I got more from it than anything else ... If you let me have a choice, I wouldn't do it and then would be really grateful when I was made to. RB02 (ROVER-B)

Another challenge that was identified is dealing with the sense of responsibility to the team,

It is definitely a challenge, especially when you're taking on a lead role of any description—trying to coordinate things and time management is extremely important because you've got other people depending on you. You can't always do everything in your own time. You've got to think about everybody else's deadlines and things as well. So, it's definitely a challenge but a positive one. SB02 (SDSS-B)

Yet another comes from comparison of their performance with that of other members of the peer group,

You might think you know everything and when you come in to contact with people who know more than you do, you think, well, hang on a minute, I need to up my game. SC04 (SDSS-C)

This final example reveals an aspect of learning through a community that is often implicit but seldom voiced,

that reflection on one's own position may, in some cases, act as a spur toward more central participation.

D. Assessment

As noted above (in Sec. II C), two distinct assessment models were used in these team activities. PIRATE and SDSS students produced a group output and individual progress reports describing their contributions, while ROVER project students conducted a reflective self-evaluation of their performance in their respective teams. Interviewees were asked directly about assessment (Appendix, Question 13), with eight providing information about PIRATE and SDSS and six about the ROVER assessment model. All students were interviewed prior to receiving their grades.

None of the SDSS and PIRATE students reported finding the assessment model to be inappropriate. The group report was viewed as being an authentic task, in that it reflects some aspects of how astrophysical research is actually conducted and disseminated,

the whole point is [...] is to get people, you know, working through a group, get people thinking about writing scientific papers. SD02 (SDSS-D)

However, some shortcomings were highlighted. As in other studies of group assessment [31,32], interviewees reported significant variation in individuals' contribution to the group output. Students also commented that the group report is much more time-consuming than the individual progress reports (despite equal weighting in the final grade). Although it was recognized that the two-part assessment (group and individual) does reward students reasonably fairly, it was noted that a lack of contribution from others could have a negative impact for those students who compensate for this shortfall by putting extra effort into the group report,

you're writing the group project together and you know that that's being assessed, when someone isn't pulling their weight, it's really frustrating and even though you get told, oh, yes, but you've got the progress reports and things. I did find I fell behind with my progress reports because I was doing more work [on the group report], maybe, than I should have been. PA01 (PIRATE-A)

This quote may indicate that the true incidence of perceptions of unequal contribution is more widespread than it appears from the analysis of forum posts (Sec. III B 2). The emphasis placed by the student on their feelings of frustration implies that this perception was not effectively addressed during the activity and highlights the need to implement assessment strategies that take better account of varying degrees of student contribution.

Student attitudes toward the individual progress reports were also explored. These prompted students to record and report their work on specific aspects of the project. They were noted as being beneficial by three (of five) SDSS students (with the other two making no specific comments about them). They seemed to be particularly valued by a student who was not confident about their academic preparedness,

... I felt relatively inexperienced in astrophysics so there was quite a steep learning curve for me in terms of the analysis that we were doing as a team, and I found [the progress reports] tremendously helpful. SD01 (SDSS-D)

The PIRATE students did not express objections in principle to the individual progress reports, but two noted that they would have liked to have more guidance about what they should record. These differences between SDSS and PIRATE likely arise from the progress reports being used to record engagement in the self-study section of the SDSS project, whereas PIRATE students were reporting on a selection of tasks in a team-work setting.

The ROVER project interviewees were asked their views of the reflective self-evaluation task. Although one respondent noted that they did not like engaging in self-reflection, all six interviewees acknowledged that the assessment was appropriate because it was based on experience gained in the team,

[the assessment task] seemed like it was fairly easy and straightforward, but in reality, to be able to answer it, to get the points, you would have to demonstrate that you had been a part of [it], that you were learning and you're problem solving and everything else. RB02 (ROVER-B)

Furthermore, the emphasis on the positive aspects of contributions seemed to help one student who was lacking in confidence,

It was really good to have those questions there to guide me to the positives ... I think if I didn't have that guidance and they said to me do a self-analysis, it probably would have all been negative. RC01 (ROVER-C)

The main criticism was an expectation (noted by two interviewees) that there could be explicit assessment of the scientific or technical knowledge that they had acquired,

The negative side of it is, it would have been nice to have had a technical output from the week as well as a psychological output for me. RA03 (ROVER-A)

So although the ROVER activity had the development of team-working skills as a more explicit aim than the PIRATE and SDSS projects, there is some sentiment that the assessment should have concentrated more on the scientific work that was conducted. It is likely that this stems from a view that a scientific or technical output has greater authenticity than a reflective assessment task.

V. DISCUSSION

The starting premise for this study was that online team-working provides an authentic context for practice in space sciences and astrophysics and therefore has the potential to be used as an effective teaching strategy in a distance learning environment. By viewing team interaction from a CoP point of view, we interpret the findings of our research questions to give insights into how this teaching strategy played out in practice and offer pointers to further developments in online learning.

A prerequisite to learning through a CoP is that students must participate in its activities. Students are informed in advance that team-working is a requirement for the modules in this study, but this in itself does not guarantee that all will participate appropriately. The interviews did explore sentiments around team-working but did not systematically seek to assess prior expectations about participation. However, earlier work by Brodeur [33] into the student experience using the PIRATE telescope for a different group activity (studied by undergraduate astrophysics students at an earlier stage than those in this study) found that most students do anticipate that observing is a collaborative activity.

Some indication of the barriers to participation may be implied from our findings of student perceptions, although these are informed by a sample of students who did participate (and indeed were the more active members of their teams). First, previous poor experiences of student group working, whether experienced personally or by someone else, can lead to a certain level of apprehension ahead of team-working. Second, even without prior poor experience of group work, students can still feel (as illustrated by SD01 in Sec. IV A) uneasy about having to rely on others when they are accustomed to a mode of learning through activities carried out on an individual basis. Finally, as exemplified by informant SD02 (Sec. IV A), who described themselves as “shy,” some students are not naturally predisposed to working in groups and may be anxious about the prospect. The prevalence and effects of anxiety for online collaborative working have been investigated in a similar context to this study (for UKOU undergraduate students in computing) by Hilliard *et al.*, who found that over 50% of survey respondents reported anxiety arising from relying on others to complete their team task [34]. That study also found that 32% of respondents were anxious because of a perception of being judged by other members of their

team. Overall, about a quarter of students reported a negative impact on participation or performance that could be attributed to anxiety.

For the team-working activities in this study, we found a range of interaction between individuals and their teams. The frequency analysis of student engagement in forums (Sec. III B 1), although only a crude measure of interaction, shows an approximately exponential distribution of postings as a function of rank, and with different projects having different typical values of Δ_P . This variation may well be related to the design of these projects and especially the timescales involved. The PIRATE project requires engagement over 9 weeks, and some students may struggle to maintain their input over such an extended period. The SDSS project has a shorter (5-week) period of team-working, which may be easier for more students to engage with. Finally, the ROVER project has a very short (1-week) duration, which demands a burst of intense activity from all students who aim to pass the related assessment task. This is likely to be more achievable than the sustained effort required for longer activities.

An alternative explanation for the variation in Δ_P may be that it is primarily due to group size. This is supported by the observation that Δ_P decreases from ROVER to SDSS to PIRATE as the mean number of group members (N_S) decreases from 13.3 to 8.8 to 7.2, respectively. Based on this observation, it might be concluded that in order to improve the level of communication within groups (i.e., to lower Δ_P) then team projects should use large teams. In some sense, this is borne out by the ROVER activity, which successfully engaged relatively large teams. However, some caution should be expressed here that this activity was designed to be suitable for a large team, since it was split into subteams that contributed to overall team-working, and, as noted, it only operates over a short time. Comparing the PIRATE and SDSS groups to each other, it is possible that increasing the group size for PIRATE teams might have led to more intragroup communication.

Another differing aspect of the design of the activities is the way in which synchronous and asynchronous communications complement one another. In particular, discussions that took place during the PIRATE observing sessions were conducted synchronously. It is possible that students who engaged in this way may have made less contribution to the forum discussion of the office work that was also part of the project. Since student interactions in synchronous sessions were not analyzed, it is not possible to determine whether they had this effect on some students' participation rates.

While we cannot distinguish between the explanations given here (i.e., activity duration, team size, and students concentrating on synchronous communications), we suggest that Δ_P can provide a useful measure of intragroup communication and that team activities should be designed to minimize this quantity.

Moving on to examine the nature of student interaction, as described in Sec. III B 2, our analysis invoked a hierarchical classification scheme that, at the top level, separates the organizational aspects of team-working (project management) from learning and development and purely social (group building and social) interactions. This highlights an aspect of team-working that is not well distinguished in other classification schemes that have been developed for forum content analysis. For instance, under Zhu's framework [35], such interaction would have to be classed as "Scaffolding," while in the scheme developed by Heo *et al.* [36], the focus on the cognitive aspects of the social construction of knowledge [37] leaves no obvious category relating to team organization. The scheme developed by Biasutti [38] does have a theme relating to "Organizing" that corresponds to discussion about execution of the task. It is notable that this scheme was developed, as in our work, from a grounded theory approach.

In the activities in this study, project management is a major component of student interaction, comprising about 35%–40% of contributions across the three activities. Since this type of activity is not clearly categorized in other studies, there is limited scope for comparison with other subject areas. However, Biasutti's analysis of online collaborative activities conducted by pre- and in-service elementary school teachers [38] found between 16% and 26% of interactions were of this nature. This, and the lack of prominence of this aspect of team-working in other studies, suggests that the activities studied here may require more self-organization than is typical for online collaborative learning in other domains. A high level of self-organization would be consistent with the nature of the investigations (i.e., constrained to follow scientific procedures and needing the coordinated efforts of multiple team members) to achieve their goal. Further work would be needed to examine this hypothesis, but it would be interesting to investigate the influence of the academic context of the activity (in our case, conducting scientific investigations) on the incidence of team self-organization.

Within the overall theme of project management, the largest subthemes are "reporting on actions" and "reference to synchronous meetings" (typically setting up such meetings). It is notable that neither of these areas is likely to be particularly contentious: they allow students to participate in discussion based on factors that are within their control (their contribution and their availability, respectively). We suggest that this type of "low-stakes" discussion may be important for drawing in students who may be less confident in working in an online environment, although again, this is an area that requires further study.

The other major component of student interaction is under the category of learning and development (34%–43% of contributions). From an educational perspective, peer learning is of particular interest, and

26% to 38% of contributions fall in this area. The timeline analysis of the PIRATE and SDSS projects (Sec. III B 3) shows that peer learning through discussion can be prompted by requiring teams to make a major decision about their work at a relatively early stage of the team-working. For the PIRATE and SDSS projects, these decisions are about target and quasar sample selection, respectively. The corresponding feature of the ROVER activity is choosing the next target rock. The existence of these decision points highlights the importance of an underlying framework to support the activity. It seems important that this framework is not overly prescriptive and requires teams to make negotiated decisions about how to progress their work. As noted by an SDSS project student,

It was good that they didn't point by point tell you what to do because then you do get interaction with the group, you do bounce ideas around and say: why not try this or why don't you try this? SD02 (SDSS-D)

A feature of these major decision-making points is that they are open-ended in the sense that there is no unique optimal "solution." Students are informed about the multiple criteria that are important in reaching an outcome, and these have to be applied in a novel situation. This leads to the decision-making process having very similar characteristics to the application of problem-based learning in physics and astrophysics [39]. Indeed, this aspect of the team-work was explicitly mentioned,

So, it really brought us into a problem solving type environment. SE01 (SDSS-E)

While some team-level decisions (such as target and sample selection) are part of the framework, inspection of forum discussion shows that as the work progresses, further challenges emerge. Some of these concern the whole team, but they may also be relevant to a subset of team members. This hierarchy of emergent challenges extends down to the level of exchanges between individuals. It seems likely that the higher (i.e., team-) level challenges play a role in setting a culture that allows students to feel that discussion of issues related to their individual understanding is a valid and appropriate discourse.

I found that my group especially—we were all willing to help each other if there was someone struggling with a certain thing. Just to get online, get on the whiteboard and just, like, draw it out and help each other and explain. Help each other with the understanding of the physics and stuff. It was good. PA01 (PIRATE-A)

The existence of problems to be solved is no guarantee that a team will adopt a supportive and collaborative

approach in addressing such problems. An important concept in discussing the sense in which computer-mediated communications can lead to communities in which learning takes place is that of “social presence.” The term was introduced by Short *et al.* [40] and usefully expressed by Gunawardena and Zittle [37] as the “degree to which a person is perceived as a ‘real person’ in mediated communication,” and this is the definition we adopt here. The idea of social presence was subsequently further developed by Garrison *et al.* [41] in the context of online collaborative critical inquiry (this is somewhat different in nature from the team activities considered here; see, e.g., Ref. [42]). As noted by Kear [43], social presence is important for developing trust and respect between community members, and this is a precursor to meaningful and fruitful discussion.

Within the forum content analysis presented above, social presence is represented by the themes of “group building and social” and feelings. In principle, teams could carry out their work without any such contributions, yet they arise across all three activities and in similar volumes (about 16%–18%). The “acknowledging others” messages (within group building and social) are particularly notable. These are often triggered by reporting on actions subtheme (of project management). Such acknowledgment reinforces the notion that individual contributions are valued by the team and seem to contribute to the sense of mutual enterprise. It is not clear if these contributions are a cause or an effect of the supportive culture. Indeed, it is not even clear that the culture is set by forum interaction since all activities used synchronous meetings, and these may plausibly play the dominant role in defining the community culture. However, given the paucity of such meetings on the SDSS project prior to the most active time of peer learning, this seems unlikely.

So far we have only noted the differences in implementation between the activities. It is significant that there are distinct differences in approach between the team activities in space science (ROVER) on the one hand and astrophysics (PIRATE and SDSS projects) on the other, reflecting somewhat different team-working cultures between these two subdisciplines. The significance of these differences is that they potentially influence what students come to see as the *expert performances* [9] that their CoP is striving to emulate. As noted in Sec. I, within educational team-working settings, there are no genuine “old timers” and hence some norms of practice need to be established through aspects of the design of the activities.

The ROVER activity focuses on rapid analysis of scientific and technical data in order to optimize the effectiveness of a mission-based scientific investigation. As such, it emphasizes the importance of collaboration between scientists and engineers to meet this aim and has an explicit focus on effective team-working that includes a preactivity task in which students read an

analysis of team-working in the context of real space mission operations [44].

The astrophysics activities (PIRATE and SDSS projects), on the other hand, are geared toward conducting and reporting on detailed and rigorous scientific studies. The need for team-work is justified on the basis that it is an effective way to conduct an in-depth scientific investigation. As students begin engaging in team-working, this difference of emphasis continues. At the start of the ROVER mission simulation, the lead instructor acts as a role model and guide for team operations. This *expert performance* is delivered primarily through involvement in synchronous online meetings. An important aspect of this role is that the instructor has experience of MSL operations and uses real-life examples and storytelling to reinforce the link between the simulation and authentic practice. As the simulation progresses, the instructor rapidly reduces their involvement as the team begins to function autonomously. Furthermore, the fact that the activity is a simulation does not appear to detract from the authenticity since such simulation exercises play an important role in space mission operations and students are aware of this.

The PIRATE and SDSS projects, on the other hand, are focused more on the quality of team outputs than excellence in team-working, and there is limited explicit modeling of the latter (noting that for the PIRATE project, the night duty astronomer does act as an expert guide and is a potential role model for the observing teams as they acquire data). Rather, the frameworks for both activities emphasize the need for a team approach in order to complete the multiple stages and contributions needed to generate expected outputs. Given these circumstances, we assert that the *expert performances* for these projects are implied through exemplar outputs rather than expert behaviors. Specifically, students are given an example of a final report, and they also come to view the peer-reviewed papers that they read in carrying out their work as setting the standard for their team output. A possible weakness in this approach is that there is no explicit demonstration to students of actions that lead to the production of such an output. As revealed by the interviews, for some students at least, the assessed individual progress reports were useful in guiding development. This suggests that scaffolding a team activity through an individually focused assessment task, possibly combined with ongoing feedback from an instructor, could play a valuable role in developing skills needed for team-working toward a group output.

The ROVER and PIRATE activities rely on remotely operated equipment, and a final consideration is how the activities in our study relate more generally to the field of remote laboratory courses. Reviews of the literature on remote student laboratories seek to compare this modality to hands-on laboratory experiences ([45–47]). Whether this emphasis is warranted was questioned by Corter *et al.*, who suggested in 2011 that “... instead of debating the

relative merits of specific laboratory technologies, future researchers may want to examine how educational goals can be achieved through the improvement of a group's collective learning process" [48]. While educational activities have been developed that do focus on group learning, these are often designed around virtual experiments, simulations, and visualizations (e.g., *CoVis* [49] and *Co-Lab* [50]). This in itself need not be an issue (the ROVER activity is hybrid remote and virtual). Rather, a more important factor may be that of engaging students in investigation that mirrors the working practices and outputs of professional scientists. The ROVER and PIRATE activities are examples of team-working on authentic activities using remote equipment. The SDSS project develops the same outcomes for students using a research database, and this also reflects the way in which professional astronomers work. Student interaction in an authentic context, whether it is an advanced hands-on laboratory or in distributed online teams as in this study, is arguably as important for the development of identity as a practicing scientist as any particular mode of working with scientific apparatus.

VI. CONCLUSIONS

The three team activities described here provide distance learning students in astrophysics and space science with authentic tasks. Our study focused on characterizing participation, the nature of student interaction, and reported student experience.

To analyze student participation in team-working (RQ1), we analyzed the frequency of posting to team forums. We invoked a quantitative measure of variation in individual participation (Δ_p) within a team. From the activities studied here, it is suggested that the factors affecting Δ_p are activity duration, team size, and the relationship between synchronous and asynchronous communications. We suggest that ideally, team activities based on forum communications should be designed to minimize this quantity.

The nature of student interactions in team-working was investigated (RQ2) through content analysis of team forums and revealed broad similarities between the different activities. We found that communication related to the organization of a team's work is at a similar volume to that which is related to learning and skills development. Team self-organization is not commonly highlighted as a feature of interaction in online collaborative learning, but it seems to be an important feature in the context of the practice of a community involved in the scientific investigations presented here. Interactions that are social in nature and act to support team coherence also feature in all the activities in this study. Peer learning within the community of the team is found to be the major component of student interaction related to learning and skills development and is seen to be prompted by major decisions that teams are required to make to progress their work. This finding highlights the

importance of having an underlying framework in such activities that prompts teams to make decisions based on multiple criteria.

The student experience of online team-working (RQ3) was investigated through interviews. Students reaffirmed known challenges associated with online team-working. In particular, students reported anxieties related to participation (all activities) and unequal contributions to assessed group outputs (PIRATE and SDSS), highlighting the need for continued focus on these areas in the design and implementation of such activities. However, students also reported that they recognize the benefits that online team-working can bring. Although the three activities studied here had different structures, the common features of peer interaction and team decision-making in the context of authentic tasks all contribute to facilitating individual learning and the development of skills seen as important for practice as professional scientist.

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DATA AVAILABILITY

The underlying data sets that support the findings of this article cannot be made publicly available because they contain personal data. The reduced data used to generate Figs. 4, 5, and 6 are publicly available [51].

APPENDIX

The structured conversations with all students used the following cues:

1. I want you to think back to before the group project began. Can you remember how you felt about carrying out a group project online before it started?
2. I now want to ask you about the period when you started working together online. Can you remember any early experiences of working together in your group?
3. Would you say that there was an identifiable point at which you felt as though you were starting to work as a team?
4. Moving on to when you were working together. Did you feel as though you learned something from the interaction you had with your group?
5. Did you feel that you helped someone else learn something?
6. Can you remember if you had any disagreements with other members of your group?

7. Did you carry out a specific role or roles within your group? How was that role allocated? Were you happy with the way the allocation was made?
8. What methods did you use to communicate with your team?
9. Tell me about how you felt about communicating with your group using these methods
10. I now want to ask your views looking back over the project as a whole. What did you think of the overall aim of the activity that you were required to do?
11. Could you express what the attitude of the group was toward meeting that aim?
12. Were there aspects of the way in which the activity was structured that were problematic or could be improved?
13. Did you feel that the assessment task (or tasks) was/were appropriate?
14. Overall, how would you describe the experience of working on a group project?
15. Do you think it is important for students to engage in this type of group activity?
16. Is there anything about the team-working that you think is important but which we haven't discussed in detail?

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