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A positive student experience of collaborative project work in upper-year undergraduate chemistry

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Demands are placed on undergraduate courses in chemistry to develop transferable skills, such as teamwork, alongside subject content and technical skills. Such skills can be developed by implementing pedagogies which involve students working together. Such pedagogies can, however, pose various challenges, including unfavourable student perceptions and experiences including the occurrence of dysfunctional student teams. This article presents a research-informed group project assignment delivered as part of an upper-year undergraduate chemistry course which has been found to overcome these challenges. The instructional activity is characterized by a high degree of structure and support for teamwork. Student perceptions, collected by survey and interview, and peer- and self-evaluations of contributions to the work of the groups reveal that students have experienced the activity positively. Many perceived disadvantages of working in a team to complete a project were either reportedly not experienced or could be overcome by the students, while perceived advantages were often reported to be experienced. Dysfunction within teams did not represent a significant issue.

Introduction

Undergraduate programmes in chemistry are expected to develop not only content knowledge and technical skills, but also other skills needed by professional scientists such as problem-solving, communication, and teamwork (Quality Assurance Agency for Higher Education, 2014; American Chemical Society, 2015). It has been reported that employers tend to be satisfied with the technical knowledge and skills of graduates while being dissatisfied with the level of so-called 'transferable' skills, such as the ability to work with others, that they bring with them to the workplace (Archer and Davison, 2008), including employers of chemistry graduates (see Overton and McGarvey (2017) and references therein). A recent survey revealed that employers of chemists reported interpersonal skills, teamwork, and a strong work ethic as the three most desirable attributes of new hires, with 76% of respondents reporting that teamwork and interpersonal skills are more important than grade point average (Kondo and Fair, 2017). In the same survey, 95% of respondents reported that they expected or desired that explicit training and feedback on teamwork skills be part of chemistry programmes, and the data indicated that team experiences relating to chemistry topics were valued more highly than those obtained in relation to other areas of study or through military or sporting activities. Such skills development, however, presents a challenge in higher education contexts in chemistry, where chemical knowledge and skills may tend to be prioritized (Hanson and Overton, 2010), and educator-fronted pedagogies may be common (Stains *et al.*, 2018).

To develop skills such as communication and teamwork effectively, it is necessary to adopt pedagogies which allow students to practice these skills and to receive feedback on their progress (see for example Bransford *et al.* (2000) and references therein). Several established pedagogical approaches provide a tested means to develop these skills, including Process Oriented Guided Inquiry Learning (Moog and Spencer, 2008), and Team Based Learning (Michaelsen *et al.*, 2004). These pedagogies offer ways to structure classroom environments to support the development of process skills alongside disciplinary learning.

Practice and feedback in process skills can also be provided by assigning appropriately-designed project work, offering the opportunity for student groups to work together over extended periods of time. Various applications of group project-based pedagogies in undergraduate settings in the sciences (for example Bartle *et al.*, 2011) and chemistry (for example: Nowak, 1998; Davis *et al.*, 1999; Van Ryswyk, 2005; Tribe and Cooper, 2008; Logan *et al.*, 2015) have been documented. At the same time, a systematic review of literature on teamwork pedagogy suggests that such activities have received a greater degree of attention from instructional designers and researchers when situated within contexts such as business or engineering degree programmes than within chemistry courses (Riebe *et al.*, 2016).

The inclusion of a collaborative dimension to assigned work in undergraduate programmes is not necessarily straightforward. Several obstacles must be navigated by educators and students. A major category of these obstacles relates to student

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perceptions. Riebe *et al.* (2016) identified expectations of students as a theme of the literature on teamwork pedagogy in higher education, present in eight of 57 published articles reviewed. It has been reported that students have concerns around the grading of individual and group efforts (Boud *et al.*, 1999; Gueldenzoph and May, 2002; Pfaff and Huddleston, 2003; Oakley *et al.*, 2004; Bacon, 2005; Burdett and Hastie, 2009; Burke, 2011; Clarke and Blissenden, 2013), dealing with so-called 'free-riders' who obtain academic credit without contributing to the work of their group (McCorkle *et al.*, 1999; Pfaff and Huddleston, 2003; Pieterse and Thompson, 2010; Maiden and Perry, 2011), and report dissatisfaction with workload and/or working with others (McCorkle *et al.*, 1999; Colbeck *et al.*, 2000; Pfaff and Huddleston, 2003; Pauli *et al.*, 2008; Burdett and Hastie, 2009; Shimazoe and Aldrich, 2010; D'Alessandro and Volet, 2012; Lee *et al.*, 2015).

Student expectations and experiences are significant for several reasons. They are known to affect engagement in instructional activities, including at the course level, and hence their effectiveness for learning (Trigwell and Prosser, 1991a; Trigwell and Prosser, 1991b). The potential influence of negative student experiences on instructor evaluations is of concern to educators in higher education, where such evaluations are often of consequence for retention and promotion. Managing student expectations and experiences can be viewed as both a cost associated with teamwork pedagogy and an obstacle to its implementation, and as a critical part of ensuring its effectiveness for learning.

Encouragingly, there is evidence that group projects in the sciences can be received positively by students (for example: Nowak, 1998; Davis *et al.*, 1999; Tribe and Cooper, 2008; Logan *et al.*, 2015), and that the challenges associated with teamwork pedagogy can be overcome through instructional design. Design features of group work pedagogy in undergraduate courses have been shown to have an influence on student perceptions and instructor evaluations (Pfaff and Huddleston, 2003; Kidder and Bowes-Sperry, 2012; Jackson *et al.*, 2014). Kidder and Bowes-Sperry (2012) reported significant relationships between design decisions and student learning and experiences of group work activity. Riebe *et al.* (2016) noted the role of workload and educator preparedness in determining student perceptions, with unreasonable workloads and inadequate preparation contributing to negative perceptions. Despite the influential role of design, some researchers have noted a tendency for effective design of team projects to receive insufficient attention (Kidder and Bowes-Sperry, 2012).

This work was motivated by a desire to capture the potential benefits of collaborative project work for learning in the context of an undergraduate course in chemistry, while avoiding common student concerns and fostering a positive student experience. This account presents a research-informed group project assignment and evidence that student concerns have been avoided to a large extent, while perceived advantages of such work have been captured. We also consider how students responded to important aspects of the instructional design.

The instructional activity is an extended (semester (13-week)-long) investigative research project to be carried out by students working in teams. Compared with similar participative teamwork pedagogies that have been reported in the context of undergraduate science education (noted above), this represents a relatively highly-structured approach, involving multiple reporting events and several opportunities for feedback, and one in which more emphasis is placed upon the teamwork dimensions.

This study seeks to demonstrate how teamwork assignments can be configured in such a way that they are received positively by students. This is an essential pre-condition to the implementation of such pedagogies and positive engagement with them by students. The exploration of the effectiveness of the instructional activity with respect to the student experience was guided by the following questions:

- *To what extent are student concerns about teamwork pedagogy borne out under the conditions of this assignment?*
- *To what extent are perceived benefits of teamwork pedagogy experienced under the conditions of this assignment?*
- *To what extent are student groups functional under these conditions?*
- *How did students respond to the feedback offered during the assignment?*
- *How did students respond to the support for teamwork offered during the assignment?*

Context

The group project assignment formed part of a course for ~120-150 upper-level undergraduate students offered by the department of chemistry at a large research-intensive university in North America. The course was developed to provide the opportunity to approach content knowledge from an alternative perspective and to develop transferable skills. The course focuses upon the role of chemistry in addressing global challenges, aiming to highlight the importance of chemistry in society, drawing on topic areas such as agriculture, human health, and energy. It aims to provide opportunities for students to make links between their chemical knowledge and practical applications and to develop transferable skills including information literacy, communication and teamwork. Specific learning goals targeted by the assignment include the ability to: (i) *Use scientific databases, effectively read literature, and evaluate scientific claims dealing with chemical matters*; (ii) *express in written and oral form why chemistry and chemical research is important in society*; (iii) *competently discuss contemporary issues in chemistry with varying audiences*; and (iv) *work effectively as a member of a team of scientists*.

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The course is a compulsory component for students enrolled in a majors programme in general sciences who opt to specialize in chemistry during their third or fourth year, and serves as an elective course for students majoring in chemistry and other sciences. The course involves three 50-minute whole-class meetings per week for 13 weeks. Groups work on the project assignment presented here outside of class time.

Prior to introducing the project assignment, assessment for summative purposes involved three examination papers (two mid-terms administered during the term and one at the end of the course) and an individual written assignment on a topic of each student's choosing. To align the work required of students more closely with the learning objectives, the individual assignment was replaced with the project assignment described here. This replacement addressed a departmental consensus that more opportunities should be made available at the undergraduate level for developing communication skills. It also formed part of a broader institutional effort to align instructional strategies in science courses with findings from research on learning (Chasteen *et al.*, 2015), and hence was accompanied by changes to in-class learning activities and other assessments. Class time involves a range of activities including instructor presentations, small-group and whole-class discussion, and small-group activities such as concept mapping.

Instructional design

The project assignment involves students working together in groups of four to research a topic of their choosing relating to the theme of the course but which is not directly covered during whole-class instruction. At the end of the semester, each group presents their findings visually and orally during a poster session. The design of the project assignment was guided by research on learning and a desire to optimize the student experience by avoiding student concerns reported in the literature. The concerns addressed here relate to:

- Grading of individual and group efforts;
- dealing with 'free-riders';
- workload;
- working with others; and
- managing interpersonal conflict.

The instructional activity is characterized by several key features. Firstly, it is participative, in that students are actively engaged in activities aligned with the course learning objectives, providing the opportunity for students to progress towards achieving the objectives associated with information literacy, communication and teamwork. Secondly, a high degree of structure is present - as well as assigning the ultimate outcome of the project, a series of intermediate 'deliverables' are required over a number of weeks. The duration and structure facilitate the use of effective feedback practices, in that feedback is received throughout the project and when it is possible to use it to revise and guide further work and hence practice in relevant skills (Gibbs and Simpson, 2004-05). Thirdly, the activity is collaborative, and hence provides the opportunity to capture the benefits of peer interaction, known to have the potential to be effective for learning (see for example Froyd (2008) and references therein). Finally, teamwork aspects are supported throughout, both to optimize collaborative learning, and to support the learning of teamwork.

Assessment and grading practices have been designed to support effective engagement of students with the key features of the assignment. To ensure a reasonable student workload and to manage perceptions of workload, the project was explicitly positioned as an alternative to a final exam.

Whole-class meetings foster a culture supportive of the aims of the project and provide practice in relevant skills, for example through small-group discussion-based activities. In turn, the project assignment acts to support these ways of working by providing a platform for students to discuss scientific ideas outside of class.

We now describe in detail the instructional sequence, support for teamwork processes, assessment and grading practices, and the managing of student workload.

Instructional sequence.

A structured sequence of deliverables is intended to support facilitation of effective feedback practices, management of student workload, and teamwork. The sequence of deliverables and other events is presented in Table 1**.** The instructional activities were adapted to a limited extent over three academic years; the evolution of the activities is summarized in Table A1 in Appendix A1. The project components and sequence are similar to those described by Tribe and Cooper (2008), however here teamwork aspects are supported through peer evaluation of contributions, and peer assessment of work products is used to a greater extent. The group project is introduced to students at the first whole-class meeting of the course; students are provided with an overview of the key project events and deliverables and information on searching for literature using online tools and academic libraries. Students must complete several individual and several group tasks; early tasks are completed by individual students before placing them in teams for the remainder of the project.

The first deliverable is an individual proposal describing a topic to be researched, supported by a literature review. Secondly, students are required to review the proposals of two of their peers by answering a series of questions about each submission with reference to a detailed rubric (see Appendix A2.1). Each student hence receives two reviews of their proposal and is required to resubmit a proposal that has been revised in light of this feedback. These revised proposals are reviewed and scored by three peers. This process is intended offer the opportunity to develop skills of written communication through the giving of, receiving of, and acting upon feedback (Gerdeman *et al.*, 2007; Lundstrom and Baker, 2009). Including a peer-review process is supportive of offering a greater quantity of feedback than if it were produced by the instructor alone.

Students are then placed in groups of four by the course instructor. It is attempted to form groups comprising individuals who considered similar topics in their initial proposals. At the same time, best practices in forming student groups are considered, for example gender balance (Feichtner and Davis, 1984; Smith, 1996; Slavin and Cooper, 1999; Oakley *et al.*, 2004), and this means that occasionally students with diverse topic interests are grouped together.

The first group deliverable is a written group contract, outlining the group consensus upon the topic the group will research, the aims of the group, for example their targeted grade for the project, how they will work together, and the consequences of not adhering to the agreed-upon team processes. The form of the contract was inspired by that designed by the University of Arizona Department of Mathematics (n.d.). The requirement to produce a group contract is intended to engage teams in 'transition phase' activities, such as setting goals and establishing team norms, reported to be part of effective teamwork (Marks *et al.*, 2001), and to reduce the potential for interpersonal conflict at later stages (Page and Donelan, 2003; Oakley *et al.*, 2004; Hunsaker *et al.*, 2011). Furthermore, this activity was intended to provide implicit instruction in key teamwork processes and skills. Groups are next required to submit a progress report to form the basis of a 30-minute in-person meeting with the instructor. Discussion at these meetings has tended to focus upon refining the topic under investigation, for example to ensure that it is sufficiently focused upon the discipline of chemistry and not too heavily upon the economic or political dimensions of global challenges.

Next students assess their own and their team members' contributions to the team's work, around the midpoint of the project when there is still time to act upon the feedback they receive from their peers. This process is intended to mitigate a previously-reported barrier to effective collaborative work - the expectation that some students will not contribute sufficiently, so-called 'free-riding' (Pfaff and Huddleston, 2003; Maiden and Perry, 2011). It was reasoned that making students aware of how their contributions were perceived by their teammates would allow them to address any concerns and at the same time improve their awareness of and ability in teamwork. The software system used to manage this process is described in *Methodology* below. The instructions provided to students are included as Appendix A3.

The next deliverable is a draft of their poster, accompanied by an annotated bibliography, which is reviewed by three other groups (see A2.2 for rubric). Feedback from these peer reviews can be used to inform the production of their final poster, to be presented at a conference-style poster session after the end of the taught-component of the course. All students are required to attend the poster session, and team members alternate between 'manning' their poster (presenting their findings orally to fellow students and the instructor and/or a graduate teaching assistant (GTA)) and reviewing the posters of three other groups using a custom rubric (see A2.3). Finally, students once again assess their teammates' and their own contributions to the work of their team.

Table 1. Sequence of *events* (shown italicized) and deliverables for the project assignment, including individual and group components; whether the assessment typically considered completion of a task or involved a judgment of the quality of a product; and the person or people upon whose judgment of quality the marks awarded were based.

Week of semester	*Event* / Deliverable	Individual / group basis	Completion / quality basis	Grader (person / people grading)
1	*Project presented on first day of class*	-	-	-
3	Draft of individual proposal	Individual	Completion	-
4	Review of individual proposals of two peers	Individual	Completion	-
5	Revised individual proposal	Individual	Quality	Instructor, informed by reviews and scores of three peers
5-6	Review of individual proposals of three peers	Individual	Completion	-
6	Groupings announced	-	-	-
7	Group contract	Group	Quality	GTA
8-10	Progress report & *Instructor Feedback Session*	Group	Quality	Instructor
10	Assess contributions of team members & self	Individual	Quality	Team members
10	Poster draft	Group	Quality	Instructor, informed by reviews of three groups
12	Group review of poster draft of three other groups	Group	Completion	-
13+	*Poster session* Present poster	Group	Quality	Instructor, GTA, peers (combined)
	Review of posters of three other groups	Individual	Completion	-
	Assess contributions of team members & self	Individual	Quality	Team members

Support for teamwork processes.

The instructional process involves considerable support for teamwork processes, for example team contracts, and opportunities to give and receive feedback on contributions to the work of the team. These supports were intended to mitigate potential concerns, for example to circumvent interpersonal

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conflict within teams (Riebe *et al.*, 2016), and to support effective engagement in working as a team and learning of teamwork skills. The establishment of intermediate deliverables also addresses a previously-reported barrier to effective collaborative work - students favouring leaving work to the 'last minute' rather than working consistently over time (Waite *et al.*, 2004).

Assessment and grading.

The assessment and grading practices were designed to support effective engagement of students, and to support aspects of teamwork. Assessment offers the opportunity to provide targeted feedback which is supportive of effective learning, and to communicate which aspects of the work are valued by the educator. Managing student perceptions around grading of group projects has been reported to affect student satisfaction with teamwork pedagogy (Burdett and Hastie, 2009; Kidder and Bowes-Sperry, 2012; Riebe *et al.*, 2016). For example, limiting the marks assigned to group work has been found to be associated with positive student perceptions (Kidder and Bowes-Sperry, 2012). Perceptions of justice regarding grading seem to be important to students. For example, Maiden and Perry (2011) found a concern amongst students that some team members could fail to contribute to the team effort and yet receive academic credit.

The project assignment represents 40% of the overall grade awarded in the course (with the rest determined *via* two written examinations). This weighting was chosen, with student perceptions and expectations in mind, to properly recognize the significant amount of work required to complete the project, while allowing a considerable portion to be determined by individual performance on written examinations. Within the 40% awarded to the project, it was sought to strike a balance between assessment of individual and group work and between awarding marks for the completion of process tasks and the quality of work products (see Table 1).

Including individual accountability through the individual tasks is intended to encourage meaningful engagement by all students (Dijkstra *et al.*, 2016). Marks were awarded for completion of each assigned intermediate task associated with the project, for example engaging in peer-review activities, to communicate the value of these tasks. This is at odds with typical practice in undergraduate settings, where products are often assessed without attention to the processes or effort expended in producing them. These 'process' tasks were usually graded on a pass-fail basis, with all marks awarded for completion, to further emphasize that it is engaging in the process that is key. Where marks were awarded for work products an assessment of the quality of the work was carried out. Assessment of product quality was generally carried out by the instructor or a GTA, although peer-assessments were also used as a component of grading when multiple peer reviews for a deliverable were available, for example peer assessments of completed posters. During the poster session each poster is reviewed and graded by approximately 12 students who are provided with a detailed rubric covering aspects of the poster and the discussion held with the presenter (A2.3). The mark awarded is arrived at by combining the marks awarded by the peer reviewers and a mark assigned by the instructor or a GTA. Over three iterations of the assignment various minor adjustments to the grading approaches were trialled – suggested grading basis in terms of quality or completion and suggested graders are included in Table 1.

Aside from the overall quantity of work involved other dimensions of student workload have been reported to influence student perceptions of teamwork pedagogies, for example the perceived fairness of the distribution of the effort and credit awarded between teammates and the presence of free-riders (Burdett and Hastie, 2009; Maiden and Perry, 2011; Riebe *et al.*, 2016). Incorporating a mechanism for assessing individual contributions to group work (Pfaff and Huddleston, 2003) and allowing students input to grading through evaluation of their peers (Kidder and Bowes-Sperry, 2012) have been found to be associated with positive student perceptions of teamwork.

Students are required to evaluate the contributions of their peers and themselves partway through and at the end of the project by distributing a set number of points (here 100 per group member) among their group members, including themselves. This is based on their perception of contributions toward the work of the group. They are asked to explain in one or two sentences their chosen allocation of points to each team member. After each assessment, students could view the points and explanatory comments assigned to them, with the names of each reviewer removed. The distributed points for each student were converted to a mark making up a small proportion of their grade for the assignment, whereby if a student was awarded a mean number of points that was higher than or close to that of the others in the team all marks were awarded, with fewer awarded as the number of points diverged in a negative direction. The peer-assessment process was designed to mitigate both student concerns about, and the occurrence of, free-riding. The process gives students the opportunity to record their views of the contributions of their peers and provides students with feedback partway through the project when there is a chance to act upon it. Having some marks determined by this process means that students have input into grading based upon contributions to the work of the team.

Managing workload.

Studies have shown that expectations and experiences relating to the workload associated with engaging in group project work play a role in influencing student perceptions of their experience (Pfaff and Huddleston, 2003). Burdett and Hastie (2009) found workload to be one of the two strongest predictors of student satisfaction with their experience of assessed group work (the other being perceptions of learning).

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To mitigate this potential concern, this assignment was devised and presented to students as a replacement for another form of assessment (here a final written examination). It was reasoned that it would be the perceived overall workload for the course that would influence the experience of the students, and that the overall workload should not be higher than that of courses which do not involve collaborative project work. As mentioned above, time during whole-class meetings was not allocated to students working together on their projects – instead students worked on their projects during unscheduled time; to support the students in working consistently on their projects under these conditions, the series of intermediate deadlines described above was established.

Methodology

Design.

The study was designed to evaluate the effectiveness of this instructional activity from the perspective of the student experience. The study explored the extent to which student concerns about group project work were bourne out under these conditions, the extent to which perceived benefits were realized, the prevalence of dysfunctional student teams, and the ways in which central aspects of the design (feedback practices and support for teamwork processes) were received by students.

Data collection and analysis.

Three main data collection approaches were used. Student concerns and experiences were explored through student surveys and semi-structured group and individual interviews, while the prevalence of dysfunctional teams was explored by examining the products of peer- and self-assessments of student contributions to the work of the teams. Please see *Appendix* below for the survey items (A4), interview questions (A5), and peer- and self-assessment tasks (A3). Data presented here were collected during the 2015/16 academic year.

Surveys were deployed electronically at the beginning, midpoint, and at the end of the project to collect student perspectives on various aspects of the project assignment and the course, and about group work more generally. The midpoint survey was deployed after the deadline for submitting the group poster draft.

Open-ended survey responses concerning advantages and disadvantages were summarized through a coding process. The process sought to represent with semantic codes all distinct meanings within the responses and the frequency with which each occurred in the dataset. One author (EALG) coded inductively all responses, revising codes and code assignments iteratively as necessary throughout. In most cases one code was assigned per response, however in a few cases one response was judged to contain two distinct meanings and so was assigned two codes. The responses tended to be written in a manner such that assigning a meaning was straightforward - the relatively few responses for which the meaning was judged to be ambiguous were labelled 'uncoded'.

To increase our confidence in the accuracy of the developed codes, a second author (KJK) examined all codings, noting queries and disagreements. These coding discrepancies tended to be minor in nature and interrater agreement was reached for all codes through verbal discussion of the subset of codes for which initial views differed, through either the renaming, combining, or adding of codes, and the recoding, coding or uncoding of student responses. Tables 3 and 4 show the agreed lists of codes and an example student response representative of each code.

In terms of the level of abstraction of the codes, it was sought to produce codes which retained a level of detail of relevance to an instructor or instructional designer using or developing teamwork pedagogy. For example, responses relating to the development of communication, cooperation and collaboration were coded separately, rather than being assigned a more general code such as 'developing teamwork', as these aspects of teamwork may relate in different ways to instructional strategies. Finally, the codes were grouped into broad topical categories for ease of reference through discussion between two authors (EALG and KJK). Judgments about a suitable level of abstraction for the codes and appropriate topical categories and the allocation of codes to certain categories drew upon the familiarity of the coders with the instructional context and the literature on teamwork pedagogy.

To explore possible explanations for data collected via survey and the peer- and self-assessments, interviews were held with a small number of students. The interviews were held after the end of the academic semester, ~20 days after the poster session. Students were recruited by email invitation. The interviews lasted around one-hour, were semi-structured, and were conducted by a researcher who was not an instructor for the course. In total, four individuals participated in the interviews over two meetings. Participants 'C' and 'P' and 'J' were interviewed together. Based upon their comments during the interview, participants 'C' and 'P' were part of groups which appeared to have worked together well. Participant 'J' was from a group in which one student was perceived by the participant to have contributed poorly. The fourth individual involved, Participant 'K', was interviewed alone and was part of a group which reportedly worked together well. The interviews were audio-recorded and transcribed for analysis.

As mentioned above, students completed two self- and peer-assessments of contributions to group work, once at the midpoint of the group portion of the project and again directly after the poster session. The software program *iPeer* was used to manage this process (University of British Columbia, n.d.). The scores and comments assigned by students during this process were analysed to explore dysfunction within the student teams and how students responded to this aspect of the instructional design.

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Participants.

The participants were third and fourth-year undergraduate students studying science subjects at a university in North America. To reveal their previous experience working in groups students were asked early in the course to report how often they had completed group (three or more students) projects in science-based courses. While 66 out of 92 (72%) respondents reported that they had not taken part in group projects in chemistry courses, 83 out of 89 (93%) respondents reported having completed at least one group project in another science-based course, with 41 reporting that they had completed four or more.

As part of the science education initiative underway at the time of this study, science education specialists were embedded into undergraduate courses across the faculty of sciences, as was the case for the course described here. Students at this institution are therefore perhaps more familiar than most with being consulted for their views on teaching and learning and appear to understand that their opinions are used for the assessment of courses rather than themselves. Their exposure and frequent participation in teaching and learning development activities may have influenced the way they think and talk about these matters. They seemed to be comfortable speaking openly and in an informed manner about their opinions on the course, the group project, and concerns about their learning environment.

Ethical considerations.

Ethical approval was obtained from the University of British Columbia (Behavioural Research Ethics Board protocol number H14-01328) and the University of York Department of Education. Students were advised that all responses provided on surveys and in interviews would be compiled by an independent researcher who was not an instructor of their course, and that their instructor would only see summaries of responses not containing identifying information. Students were offered up to 1% towards their course grade for completing a survey. Interview participants received $15 each.

Results and discussion

Student expectations of group project work and reported experiences during this assignment.

Students were asked at the end of the course *via* an open-response survey item to list up to three perceived advantages and disadvantages of working in a team to complete a project, and to indicate whether they had experienced the perceived advantages or disadvantages during this project assignment.

In terms of perceived disadvantages 23 distinct codes were identified in the student responses and grouped into four topical categories for ease of reference (see Table 2, including illustrative student responses). 'Workload' relates to amount or efficiency of working practices. 'Interpersonal' is used to refer to codes which explicitly mentioned interactions with others. 'Achievement' was chosen to represent responses relating to work products or outcomes including grading. 'Affective' refers to feelings and attitudes less directly related to academic work, for example control and anxiety.

The student responses align with the literature, with all of the commonly reported student concerns discussed above featuring in the assigned codes, such as those relating to grading and workload. The topical categories we have chosen to summarize the data and their relative frequency are broadly similar to those identified by Burdett and Hastie (2009), who explored student views about teamwork without reference to a specific group assignment, with disadvantages relating to workload and interpersonal issues reported relatively frequently.

Figure 1 shows graphically the data from Table 2 for the eight most frequently reported disadvantages. It can be seen that for all but one of these disadvantages, most of the students raising it reported that they did not experience it in this context. Furthermore, in several cases where students had experienced a given disadvantage, they reported within their response, without prompting, that they had been able to overcome it. For example, while experiences of interpersonal conflicts were reported by seven students, the conflicts were reported to have been overcome by four of these students. While noting that frequency of report does not equate to significance in terms of student perceptions and experiences, or that the generated list of reported disadvantages is exhaustive, we interpret these patterns of responses as indicative of a subjectively positive student experience of collaborative project work.

The disadvantage most frequently reported to have been experienced but which students did not mention without prompting that they had overcome was difficulty coordinating schedules. When asked about this as part of a survey at the end of the course, 52% of respondents reported that they had indeed found it difficult to find a time when the whole group could meet in person. Encouragingly, 94% of respondents reported that they effectively communicated through alternative means when they could not meet in person. In survey responses and interviews students mentioned *Google Docs* and *Facebook* as applications which played a role in supporting group work. These findings indicate that emphasizing and providing access to and support in using alternatives to face-to-face meetings may be worthwhile, particularly if it is not deemed feasible to devote class time to project work.

In terms of perceived advantages, 32 distinct codes were identified through the coding process, which have been grouped into six topical categories for ease of reference (see Table 3, including illustrative student responses). All four categories of reported disadvantages have been used to group the advantages. Two further categories were included - 'Learning' involves responses which make specific reference to

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improving knowledge or skills, and 'Ideas' collects all codes relating to aspects of working with ideas.

As shown in Table 3, 'division of workload' and 'sharing of ideas' were the two types of advantage most frequently reported to have been experienced here. The overarching categories of advantages identified and their relative frequency are also similar to those identified by Burdett and Hastie (2009), with advantages relating to achievement, workload and learning reported relatively frequently. As shown in Table 3, those reporting perceived advantages reported in almost all cases that they been experienced in this context, indicating that this assignment offers the potential to capture the benefits students perceive of team project work.

These data suggest that many of the perceived disadvantages of teamwork pedagogy reported here by these students were not borne out to a significant extent under these conditions. On the other hand, reported perceived advantages such as sharing of ideas were frequently experienced. It seems that perceptions of teamwork are more negative than experiences under these conditions, a notion supported by reported enthusiasm for completing this project – partway through and at the end of the project 63% and 75% of respondents, respectively, agreed that they were enthusiastic about completing the project.

Table 2. Categories of reported disadvantages of working in a team to complete a project, the frequency with which they were reported, the frequency with which they were reported to have been experienced or overcome within this assignment in 2015/16, and an illustrative example of a student comment representative of each code. 254 discrete responses were identified from 93 respondents

Topical category *Code*	Frequency: Perceived	Frequency: Experienced	Frequency: Experienced & overcome	Illustrative student comment
Workload	126	70	7	
Difficulty coordinating schedules	54	40	6	*Tough to coordinate schedules between all members*
Group member(s) not contributing	33	9	0	*if some members don't do their part of the work*
Unequal workloads	12	6	0	*Not everyone could end up doing the same amount of work.*
Inefficient use of time	8	4	0	*inefficient use of time when working together*
Need to distribute workload equally	8	4	1	*Having to balance the workload evenly.*
Time needed for group meetings	6	6	0	*Having to make time for group meetings*
Coordinating task completion (timing and quality)	5	1	0	*have to check over others work to ensure quality of work*
Interpersonal	87	36	8	
Conflicting ideas	17	5	3	*Conflicting ideas between group members leading to difficulty getting anything done.*
Reaching consensus	17	7	1	*4 different opinions that you have to merge together.*
Interpersonal conflicts	17	7	4	*Disagreements are somewhat challenging at times*
Communication difficulties	10	4	0	*Having trouble getting in touch with a group member.*
Relying on and/or trusting group member(s)	8	4	0	*Having to depend on others*
Group member(s) not meeting deadlines	5	3	0	*having a group member not finish their part on time*
Dysfunctional team dynamics	5	1	0	*Disfunctional* (sic) *team dynamics*
Conflicts over leadership and/or team mechanics	3	2	0	*fight for leadership*
Group member(s) forging ahead	3	2	0	*Sometimes members get too ahead of the game leaving nothing for others who want to contribute.*
Working with strangers	1	1	0	*Working with strangers might be difficult for some.*
Achievement	24	10	0	
Differing standards (work ethic, quality of work, motivation, expectations)	20	8	0	*uneven level of quality of work - some members' work may be seen as unsatisfactory to others*
Grade affected by others	3	1	0	*Your grade relies on how hardworking other people are.*
Do not learn about all parts of project	1	1	0	*We do not get to know much about the part another team mate is working on*
Affective	6	1	0	
Need to relinquish control	3	1	0	*You have to give up a bit of control over the project.*
Anxiety / worry	2	0	0	*Worrying about unhelpful team members.*
Lack of group member(s) dedication lowers morale	1	0	0	*In the chance that a certain member is not dedicated to the team, it can degrade moral*
Uncoded	11	8	2	*varying levels of understanding the topic*

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Table 3. Categories of reported advantages of working in a team to complete a project, the frequency with which they were reported, the frequency with which they were reported to have been experienced within this assignment in 2015/16, and an illustrative example of a student comment representative of each code. 266 discrete responses were identified from 93 respondents.

Topical category *Code*	Frequency: Perceived	Frequency: Experienced	Illustrative student comment
Ideas	66	64	
Sharing of ideas	26	25	*You get a variety of different ideas and point of views that you can mix together.*
Greater number of ideas	21	20	*Get more opinions and ideas*
Variety of ideas	13	13	*Different perspectives and ideas during the brainstorming process.*
Idea generation or development	4	4	*You can work together and grow ideas together.*
Better ideas	2	2	*Better ideas and concepts can be suggested*
Workload	62	57	
Division of workload	40	36	*chance to divide up the workload so it can be lighter for each individual*
Decreased workload	13	12	*Less workload*
Increased efficiency	7	7	*You get work done quickly and efficiently*
Reminders about deadlines	1	1	*remembers deadlines because there are people to remind other members*
Setting deadlines	1	1	*Setting deadlines*
Learning	55	52	
Through feedback from group members	17	16	*Rely on teammates to help with peer review, and obtain key feedback*
Teamwork skills (expressed in general terms)	11	10	*Learning to work together*
Learning from each other	11	11	*good discussions of main themes/topics with others help to clarify concepts*
Communication skills	6	5	*Able to learn how to communicate.*
Cooperation skills	5	5	*Improving cooperating skills*
Collaboration skills	2	2	*You can work on your collaboration skills which will be beneficial as a working scientist.*
Compromise	2	2	*learn to compromise when needed*
Learn about different methods of completing work	1	1	*Get to see/learn about different methods of completing work*
Achievement	42	41	
Improved work through feedback from group members	13	12	*More people to edit the work to catch any errors*
Bringing together skills / strengths	10	10	*Everyone came from a different background with different skills that were all beneficial for the team.*
Assign tasks based on skills / strengths / interests	8	8	*Divide the work based on individual strengths and weaknesses*
Product improved	4	4	*We work together to bring together a polished piece of work*
Input is increased	3	3	*Additional work put into the assignment*
More knowledge	2	2	*Additional knowledge*
Incentive to perfect work	1	1	*incentive to perfect work*
Solve problems together	1	1	*Work around unforeseen problems, together.*
Interpersonal	23	23	
Support from group members	12	12	*You have support from team members. My group was open and we shared our worries about other courses and whatnot and we supported and encouraged each other constantly.*
Connecting with peers	11	11	*Easy way to make friends and we always ended up studying together and checking answers together.*
Affective	13	11	
Sense of accountability / responsibility to group	5	4	*responsibility to finish tasks for not only personal goals but also for the group as a whole*
Fun	3	2	*Fun dynamic*
Sense of confidence / morale / team spirit	4	4	*Sense of solidarity when working together as a group increases morale*
Reduced stress	1	1	*Splitting the work load helps us feel less stressed and not overwhelmed*
Uncoded	5	5	*Teamwork*

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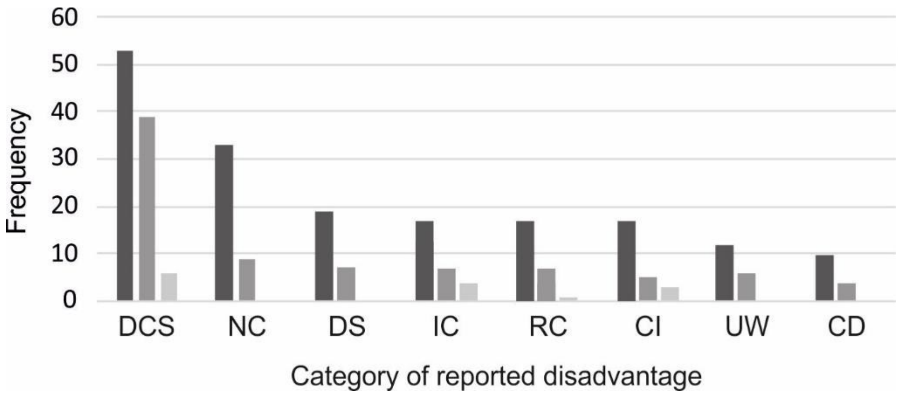

Figure 1. Eight most frequently reported perceived disadvantages of working in a team to complete a project (dark grey), frequency with which students reported experiencing this disadvantage here (mid-grey), and frequency with which they disclosed without prompting that the perceived disadvantage had been overcome (light grey). DCS: Difficulty coordinating schedules; NC: Group member(s) not contributing; DS: Differing standards; IC: Interpersonal conflicts; RC: Reaching consensus; CI: Conflicting ideas; UW: Unequal workload; CD: Communication difficulties.

Occurrences of free-riding or interpersonal conflict.

Aside from the subjective student experience, we are also interested here in whether the student groups were functional. The management of interpersonal issues, for example free-riding and conflict, represents a potential cost associated with teamwork pedagogy, in terms of student time and effort, educator time and effort if they are involved in mediating disputes, and a possible barrier to effective teamwork.

Several instructional design elements were adopted to mitigate these potential costs while making use of possible associated learning. The preparation of team contracts and the inclusion of the peer evaluation process were both intended to allow for the airing of issues in a constructive way, and to allow students to feel assured or to address their behaviours in response to feedback from their peers as necessary while there is still time to make improvements (see *Assessment of own and peer contributions to team* below).

Various scoring outcomes of the peer evaluation process are summarized in Table 4. From the explanatory comments associated with the assigning of points to individual students by a single peer, a score of 80 or lower has been judged here to be associated by most students with perceptions of unsatisfactory contributions to the group effort; example comments include: "*Did minimal work*" (80 points), "*did some research but could not contribute much to the group due to busy schedule*" (50 points), and "*Although [he] could be credited with showing up to meetings, he made absolutely no contribution. Not even a hello/good bye*" (31 points). Here only four students (3%) received a mean score of less than 80 points from their peers at the midpoint, and nine (8%) at the end of the project. These data indicate that perceived free-riding was not a significant problem in this instructional context; with most groups either not suffering from interpersonal problems, or being able to effectively manage them (see also *Student expectations of group project work and reported experiences during this assignment* above).

Table 4. Summary of the mean number of points awarded to individual students by their peers in 2015/16 (number of ratings=368, number of students rated=120, number of groups=30).

Peer evaluation scoring outcome	Peer evaluation timing	
	Midpoint	End-of-project
Minimum mean points awarded to an individual student by their peers	60	57
Maximum mean points awarded to an individual student by their peers	125	124
Number of students receiving: 80 ≤ mean points < 90	3	9
Number of students receiving: 70 ≤ mean score < 80	2	6
Number of students receiving: 60 ≤ mean points < 70	2	1
Number of students receiving: mean points < 60	0	2

Student responses to aspects of the instructional design.

Specific aspects of the assignment are now considered, in order to provide insight into the elements of the design which may have been supportive of positive student experiences. Student perceptions gathered by survey and interview, and peer- and self-assessment responses are drawn upon.

Perceptions of usefulness of feedback on individual and group work products. A key feature of the design is the use of series of deliverables which creates the possibility for multiple feedback events and therefore supports effective feedback practices. Here we provided frequent feedback without unduly burdening the instructor by using peer assessment and

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feedback processes and instructor meetings with groups of students. Here we consider the effectiveness of these assessment practices in terms of the perceived usefulness of feedback on work products (feedback on contributions to team effort is discussed under *Assessment of own and peer contributions to team* below).

Students were surveyed about the feedback they were receiving on the work products of the project, both from peer-review processes and from the instructor. Students were asked to indicate the extent to which they agreed with statements relating to the perceived usefulness of these forms of feedback using a six-point Likert scale. Feedback from the instructor was highly valued by students, with ~90% of students (n=98) agreeing that the in-person meeting was useful for improving their poster or project. This session often served as an opportunity for the instructor to guide the students to refine their topic to ensure that it was both defined with sufficient precision, and that it was suitably aligned with the learning objectives of the course. Encouragingly, students reported making changes based on the feedback received on an open-response item which asked them to describe any changes they made to their project as a result of the instructor feedback session. The two most common responses were representative of narrowing the focus of their topic (49%) and changing the format or layout of their poster (30%). Other types of responses included adjusting the amount of chemistry content, shifting focus completely, or deciding between various topics to pursue.

Students also seem to have valued receiving peer reviews and giving feedback on the work of peers, with ~88% indicating that in the future they will seek feedback from their peers on drafts of their assignments in order to improve their work. Overall, these data indicate that one-to-many feedback through group meetings and peer-review tasks can be used to offer feedback in a way that is acceptable to students (and also makes efficient use of educator time).

Effectiveness of support for and practice in teamwork processes. This instructional process involved considerable support for teamwork processes, for example team contracts, and opportunities to give and receive feedback on contributions to the work of the team. This section will consider the extent to which these supports for teamwork were effective and well-received by students.

Perceived usefulness of team contracts. Groups were required to prepare team contracts to support and provide implicit instruction in transition phase team processes. The student interviews provide examples of how some individuals perceived the value of the preparation of team contracts for supporting the interpersonal aspects of teamwork. Participants were asked to describe the extent to which creating the team contract was useful for their project. All four participants commented on positive aspects of the contract, for example that it brought the team together for the first time, allowed group members to get to know each other, or helped to establish intentions and plans for communicating with each other:

"it was good because it got the ball rolling on the project and kind of kept it in your mind that as well as the assessments there was this project to kind of figure out so I thought it was a good idea…" (Participant P)

"… I guess the one thing that did help was that it got people all of us together and… I guess it also helped us kind of know what our intentions were and what our motivations were behind taking the course…" (Participant C)

"… the initial getting together and then knowing who we were and sort of how we were - like our first impressions of one another..." (Participant J)

"… *one of the good things I liked we had to write a group contract at the beginning of our poster project and that forced us to all meet together all at once in person because before that I didn't know anyone else in our group so we met and after we agreed on the general principles of how we would work together, we all discussed what our individual topics were and agreed on which topic was the strongest, which we chose for our poster*." (Participant K)

At the same time, the interviewees reported that the content of the contract was not particularly helpful, and that they deviated from it during the project *("… we did discuss team roles and team procedures but I don't believe we adhered to any of that…"* (Participant K)). Based upon the response of this small number of students, it seems that while the process of creating the contract may have been perceived to be of value, the content in terms of the agreements made may have been less important. It seems plausible that the creation of a contract can support transition phase team processes, and that requiring students to create their own contracts may be of more value than providing a pre-completed contract. The responses also suggest that encouraging students to return to the contracts in some manner during the project may be of value – it seems it should not be assumed that students will automatically refer to the contracts at a later stage. It is perhaps not surprising that agreements made at the start of a project will need to be revisited as work gets underway - indeed this is aligned with the framework of authentic teamwork proposed by Marks *et al.* (2001), in which teams are argued to engage in multiple cycles of transition processes and activities more directly associated with accomplishing the work to be completed. A process of revisiting agreements made in group contracts may be likely to both support ongoing transition processes and provide further insight and implicit instruction in teamwork.

Assessment of own and peer contributions to team. The peer assessments of contributions used here were intended to support positive student perceptions of teamwork (Pfaff and Huddleston, 2003; Kidder and Bowes-Sperry, 2012) and to provide feedback from peers at a time when it is possible for students to act on that feedback, both to circumvent interpersonal costs associated with teamwork and to support learning of teamwork skills. The first condition for this process to have been effective would be for the students to take the

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process seriously and to distribute the 'points' based on perceived contributions rather than strategically or according to prior agreements within groups. The first indication that the process was taken seriously is that only 8% and 7% of students (n=121) failed to complete the assessments at the mid- and end-of-project stages, respectively. Secondly, the number of groups within which all members awarded the same number of points (100) to all members including themselves was three (10%) at midpoint and eight (27%) at the end of the project (n=30). The low proportion awarding the same points at the midpoint implies that strategic or pre-agreed approaches were not applied. The higher proportion at the end of the project could indicate that either strategic approaches were more frequently adopted at this stage, perhaps because of students being familiar with the system, or because by the end of the project there were a greater number of teams in which everyone was judged to have contributed equally.

Based on the student interviews, we can be confident that at least four groups did not adopt strategic approaches. Participants were asked during the end-of-project interviews whether their groups had discussed the peer evaluation process in advance, and their responses did not indicate strategic approaches. The fact that the peer scores did not affect overall grades to a significant extent may have been supportive of non-adoption of strategic approaches.

The variations in the points assigned within and across groups are now considered. As mandated by the system, the mean number of points assigned to each individual at the midpoint was 100 (SD=10, minimum=31, maximum=150), and at the end 100 (SD=13, minimum=37, maximum=160). It was often the case that most members of a group were awarded 100 points, with one student receiving a different mark, and as a result 60% of the individual ratings of self or peer contributions were equal to 100 points at the midpoint, and 63% at the end of the project. Two students were awarded 150 points at the midpoint. In both cases these students were highly scored by more than one member of their group. The students receiving the minimum number of points at the midpoint (31) and at the end (37) were also awarded a relatively low number of points by other group members. The highest number of points at the end (160) was self-awarded, with the other team members awarding this student 112 and 135 points.

Figure 2 shows the mean number of points that each individual student was assigned by their peers at the midpoint and end-of project assessments. Rather than suggesting strategic approaches, the overall pattern of these data appears to capture the expected complexity of perceived and actual individual efforts to teamwork over time, with 40 students receiving a higher mean score at the end (mean change=5.4, SD=4), 29 students receiving 100 points on both occasions, and 46 students receiving a lower score at the end (mean change=7.8, SD=7). This complexity is apparent in the comments accompanying the assigned points; taking for example the comments associated with the two largest positive shifts for an individual – one set was representative of an individual perceived to have contributed well throughout, and one appeared to describe an individual who was slow to make a contribution to the project at the beginning but who made a significant contribution to later parts. The comments associated with the two largest negative shifts appear to describe someone whose contribution was of perceived to be of some concern at the midpoint and which was perceived to have reduced towards the end of the project, and someone who had contributed well by the midpoint but then contributed less well towards the end of the project.

To gain further insight into some of the ways in which students may have decided how to assign points, interview attendees were asked to explain their approach. All interviewees cited effort as a factor in how they decided to distribute their points, with other factors that were mentioned being the quality of work and level of enthusiasm:

"for me it was mostly just how much effort and enthusiasm they put in…" (Participant K)

"so I guess the factors were, yeah, like the effort - could you see that they actually like worked for you to give them full marks kind of thing and was it well put together, was it well done" (Participant P)

"Similarly, if they tried and did, I guess everything that, the tasks that they wanted to do and did they complete it and yeah, it doesn't really matter if they weren't as good at it but it was more of did you try to make an effort towards it" (Participant C)

One participant noted that they aimed to balance more vocal contributions with written work produced:

"… so I kinda figured that out, like, well that person, they spoke up the most in the group and we incorporated their ideas into our project but maybe they didn't write the most, whereas this person [ ] spoke up the least but they wrote the most. So I kind of balanced those two factors in my assessment." (Participant K)

This analysis of the assignment of points suggests that students generally took the process seriously, avoiding strategic approaches, and made a genuine effort to discriminate between self and group member contributions in the distribution of points. These results align with those of Johnston and Miles (2004), who reported similar findings in the context of an undergraduate laboratory course in social psychology. Although not intended to be representative, the interview data provide insights into non-strategic approaches that students may have taken.

Further conditions for this process to have been effective would be for the students to have given useful feedback, and to have taken notice of the feedback comments they received. In terms of the written feedback comments which accompanied the assigned points, these were often sufficiently specific about what had been done well or not well to be useful for identifying areas for development of the teamwork skills for an individual. Examples of particularly specific comments included:

"[She] shared her past experience in making posters which greatly helped in the vision and overall presentation of our

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project. She also went to print and pick up the poster on behalf of the group. She contributed her ideas to different parts of the assignment, especially strategy one and the introduction.”;
“Very good with fine details. Adamant about practicing our presentations and meeting together to work on the project. Always the first one to finish his part of the poster material. Asked many questions to clarify and narrow our topics.”; and
“Unfortunately, [this student] took very long to reply back to group messages, was late to meetings, and did not finish his assignment part before meeting up. He seemed very unsure about what our topic was and asked questions well after the poster was made. Seems to be a hard worker but is preoccupied with other courses. Is more worried about marks rather than working together to finish the project.”

The student interviews provide evidence that the process provided feedback that could be used by students. Participants were asked how they acted upon the outcomes of the assessment, if at all. The responses revealed that while some students may not have viewed their feedback, others were able to take something from the comments; while one participant reported not remembering the results from the peer assessment process, two described positive feelings of acknowledgment and encouragement to maintain their approach:
“I believe one of them was - it was… like my part was done promptly and I appreciated that someone acknowledged that so for the next part, again, my part was done when I said I would get it done. It was kind of like encouragement I guess to keep doing what I'm doing.” (Participant P)
“It was pretty similar (to Participant P). *I think there wasn't any negative feedback - it was mostly positive and people acknowledging ‘keep up the good work’ so we basically just maintained it the same.”* (Participant C)

Our data show that students were able to offer usefully detailed feedback comments through this peer-review process, and, based on the responses of our interview participants, that the feedback comments they received were of a form that could be used.

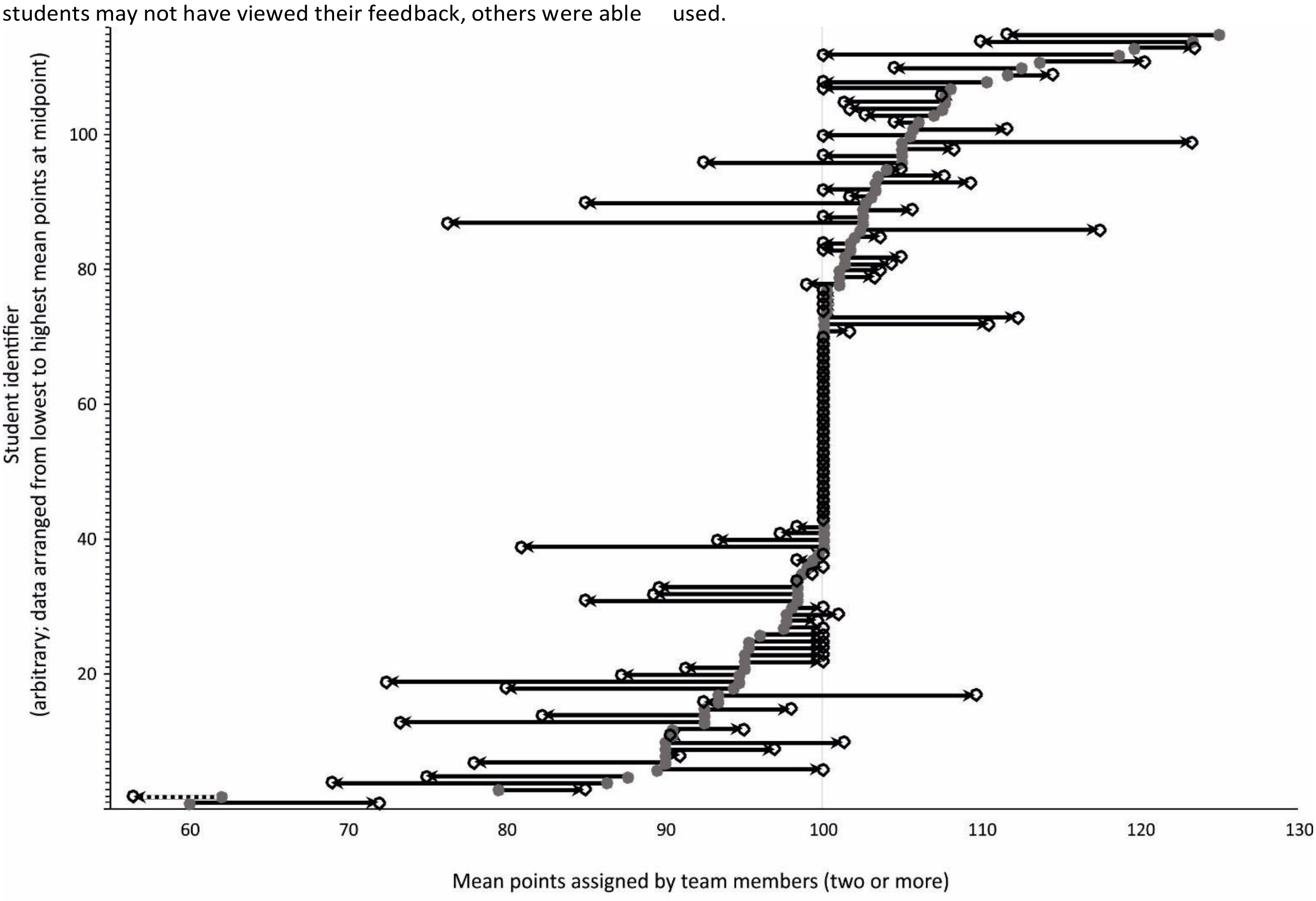

Figure 2. The mean number of points that each individual student received from their peers at the midpoint (grey, closed symbols) and end-of-project (black, open symbols) peer assessment for those individuals for whom at least two team members assigned points on both occasions (representing 115 of 121 students on the course). Arrows indicate the direction of the change in the number of points assigned between the midpoint to the end-of-project.

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Conclusions and implications for practice

The instructional activity presented here addresses calls from employers to develop the transferable skills of chemistry graduates, and challenges associated with teamwork pedagogy reported in the literature. Key features of the instructional design include multiple intermediate deadlines, frequent feedback, support for teamwork, and carefully-considered assessment practices. The effectiveness of the design has been evaluated in terms of the student experience.

The work suggests that it is possible to foster a positive experience of teamwork pedagogy within a classroom-based chemistry course using the framework presented here, including for students who may not have experienced group project work in the context of their other chemistry courses.

This study has not determined the efficacy of this particular activity for the learning of chemistry content or of teamwork and other transferable skills. Rather we have demonstrated a group project assignment framework based on principles of effective learning that was received positively by students, capturing perceived benefits of group project work while avoiding the perceived disadvantages. This is an essential pre-condition to the wider implementation of such pedagogies, and positive engagement with them by students. With this established, further work could aim to inform fine-tuning of the instructional design for optimal learning in various domains.

This work suggests that the following may be worthwhile as part of the design of such assignments:

- Establishing a series of intermediate deliverables and providing frequent feedback;
- including the preparation of team contracts, led by students;
- alleviating the challenge of coordinating schedules;
- providing and supporting the use of online tools to support collaborative work;
- creating the opportunity to give and receive feedback on contributions to the work of the group, with articulation of reasoning; and
- allaying concerns during the early stages of the process, as perceptions may be more negative than experiences, for example by having project assignment 'alumni' speak to current students.

Limitations and further work

This study does not attempt to measure the learning of process skills and disciplinary knowledge through this example of teamwork pedagogy. Having established here a framework that is positively received by students, and which offers elements essential to effective learning (practice and feedback in the relevant skills), a future study could usefully consider learning and measure the relative effects of different instructional conditions to inform the fine-tuning of the work undertaken by students within the project framework to optimize this learning.

Further exploratory work could consider how teams make use of online tools for collaboration within projects such as these, and how teams work together to complete their tasks. Several of the advantages and disadvantages of teamwork noted by our participants have not been addressed here and would be worthy of consideration, for example the bringing together of ideas and reaching consensus. More attention could be paid to the ways in which students have overcome challenges, for example interpersonal issues, within this framework, to establish the extent to which this constitutes a valuable learning experience in relation to the development of teamwork skills.

Most participants reported previous experience with group project work (although usually not within chemistry courses), and the findings may not be generalizable to students without such experience. The work took place within a single national context, characterized by a relatively low power distance and high individualism (Hofstede *et al.*, 2010). The potential influence of cultural context on teamwork and peer evaluation processes has been noted elsewhere (Kidder and Bowes-Sperry, 2012) and as such the generalizability of the findings to culturally-distinct contexts may be limited. It is also worth considering the ways in which skills developed through teamwork pedagogy in educational contexts may or may not translate to employment situations where team composition and conditions may be quite different.

The work has not considered resourcing in detail. There are costs associated with the initial design and implementation of a new participative pedagogy, and with the ongoing delivery. In this case the initial design, and implementation during the first iteration, was supported by an embedded science education specialist, and some support was also offered for modifications and delivery during the second and third years. Collection of student perspectives and other evaluative activities carried out by the embedded science education specialists were important for supporting the implementation and guiding design modifications.

Educator experience has not been explored here. Riebe *et al.* (2016) noted that educators face a range of challenges when implementing such pedagogies, for example negotiating institutional culture and expectations, and assessment of teamwork processes. Preliminary exploration of these themes was carried out *via* a semi-structured interview with the instructor after the end of the 2015/16 iteration. The instructor commented that the use of peer review and the absence of a final examination meant that the marking load was not increased. Here there was not a substantial amount of negative student feedback or interpersonal conflict to address. The inclusion of the instructor meetings was time-consuming, requiring ~10 hours over a two-week period. The instructor reported that the greatest challenge was grasping what form this type of activity takes in practice and which actions need to be taken in designing it. It should be noted that although some arms-length encouragement was available from a science education specialist previously associated with the course for the fourth iteration of the group project, the instructor made the decision not to run the assignment. This suggests a worthwhile line of future enquiry around the interplay between student and educator experiences and resourcing issues. Possible reasons for faculty members ceasing to use implemented research-based approaches have been considered elsewhere (Wieman *et al.*, 2013).

Conflicts of interest

There are no conflicts to declare.

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Appendices

A1 Modifications to the design of the group project assignment over three years.

Table A1. Modifications to the design of the group project assignment over three years.

Iteration	Academic year	Modifications since previous year	Examples of reason(s) for modifications
0	2012/13	First year of the course: No group project assignment; students completed individual written assignments.	
1	2013/14	Introduced group project, including: Individual proposals on topic of choice; one peer review of each individual proposal (conducted on paper); group contracts and group proposals; one peer review of each group proposal; poster presentation session; peer review of posters (each student completes three reviews); peer-assessment of contributions of team members at two stages (midpoint and end-of-project).	To align the work required of students more closely with the learning objectives; to address a departmental consensus that more opportunities should be made available at the undergraduate level for developing communication skills; to introduce evidence-based instructional strategies into the course.
2	2014/15	(No modifications from previous year)	
3	2015/16	Stronger emphasis on use of literature search as part of individual proposal; poster draft required in place of group proposal; multiple peer reviews at individual and poster draft stage (conducted using software ('*Turnitin*': http://turnitinuk.com/); introduction of instructor feedback meeting with each group; the two peer-assessment events incorporated self-assessment.	To address reports from students that receiving a single peer-review on their work limited their ability to make use of the feedback.

A2 Rubrics.

A2.1 Rubric for peer review of individual proposals

	Needs Improvement	Meets Expectations	Exceeds Expectations
Summary of topic	Too general; no detail; reader doesn't learn anything more than they read in the title OR too much out-of-context detail – seems lifted from an article. Summary does not address how the topic relates to a current societal issue.	Clearly worded, informative, and concise summary that expands on title. Relates topic to a current societal issue.	Informative, concise, and engaging, catches the reader's attention. Summary clearly demonstrates importance of topic to current societal issue.
Proposal content and preparation	Proposal shows little to no relationship to chemistry. Chemistry is presented in vague fashion, lacking detail.	Proposal contains chemistry content at a university level.	Proposal contains chemistry content at a university level and demonstrates a sophisticated approach to the research topic.
Literature search	No background source provided. Search terms and/or database searched not listed. Little to no explanation of search method.	Background source(s) provided. Search terms and databases listed. Search terms include key words that are not in the title. Search method clearly described.	Background source(s) provided. Search terms and databases listed. Search terms include key words that are not in the title. References demonstrate sophisticated literature search.
References	Some references included appear to have little connection to topic. OR: Fewer than required number of references. OR: Most references don't appear to be current. OR: Reference citations are incomplete. Sample annotation either not included or is done incorrectly.	Most references listed appear to be relevant to topic at hand. References appear to be from peer-reviewed journals. Some recent citations. Reference information is complete, in ACS journal style. Sample annotation included without error.	All references listed appear to be relevant to topic at hand. All references appear to be from *major* science and chemistry peer-reviewed journals. Good selection of recent citations. Reference information is complete, in ACS journal style.
Link to alternative research area	Proposal either does not contain future research direction OR suggested route is not related to included references.	Future research topic clearly relates to reference included as part of proposal.	Future research topic developed from multiple references included in proposal AND is clearly distinct from original proposal.

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A2.2 Rubric for peer review of group poster draft

	Needs Improvement	Meets Expectations	Exceptional
Chemistry content	Presentation lacks chemistry content. Science content lacks in-depth chemistry. Details are presented at a "Discovery channel", superficial level.	Presentation contains chemistry content at a university level; good depth and breadth in the topic area.	Presentation has excellent approach to chemistry content. In depth, sophisticated approach to topic area.
Outline organization & technicalities	Lacks coherent organization and/or sections appear primarily organized by research paper consulted. Few to no citations in the outline. No visual cues suggested. Large text sections replaced by charts, figures or graphs.	Mostly clear and meaningful headings and subheadings. Flow of information may be less than optimally organized. Citations mostly align with annotated bibliography. A connection between text and visual cues.	Clear and meaningful headings and subheadings, logical flow of information. Citations align with annotated bibliography. Very strong connection between text and visual cues.
Outline content	Very little information, and/or lacks relevant information, and/or too many gaps in key places.	Content mostly relevant and complete. Some sections may have greater/lesser detail (detail mismatch). Gaps mostly identified.	Concise, informative and focused. Includes only clearly relevant information, and, if there are relevant gaps, clearly identifies them (does not need to be exhaustive).
Figures	Not clear what figures are meant to convey; not particularly relevant to research topic.	Figures are clear and concise; add to understanding of research proposal.	Figures are clear, concise, informative, and add to understanding of research proposal. Conveys scientific nature of project well.
Annotated bibliography technicalities	Incomplete citations, and/or too few references, and/or several references appear to be irrelevant to topic, and/or most references are from non-peer-reviewed sources.	Full citations listed in the correct format. Most references listed appear to be relevant to topic at hand. All references appear to be from peer-reviewed journals (except in exceptional circumstances).	Full citations listed in the correct format. All references listed appear to be relevant to topic at hand. All references appear to be from peer-reviewed journals (except in exceptional circumstances).
Annotated bibliography content	Notes very brief and/or general. Does not clearly identify how the papers will be useful to the project.	Notes describe key points of the reference papers. Most notes show clear relationships to the topics in the outline. May not clearly identify how the papers will be useful to the project.	Notes are concise, informative, and clearly related to research topic. Clearly identifies how each paper will be useful to the project.

A2.3 Rubric for peer and instructor review of poster presentations

	Half marks (50%)	In between (75%)	Full marks (100%)
Appearance (20%)	Title, text, or figures out of proportion, unclear organization or progression of information. Figures not easy to read.	Poster formatting and structure is reasonably well executed.	Well-proportioned, easy to read, logical progression within the poster, figures and text appropriate size.
Content (40%)	Less organized, less concise. Chosen figures don't show primary points well. Figures not clearly linked to text. Main points less clearly articulated.	Figures and text apparently both necessary and sufficient, though not structured so as to deliver message clearly and unequivocally.	Clear, concise, well-organized text throughout. Figure(s) and text mutually supportive and well-chosen to best illustrate main points. Main points clearly articulated. Conclusions justified.
Verbal description (40%)	Presenter had some difficulty explaining parts of the poster, e.g. the information shown in figures, or the implications of the work.	Presenter was reasonably clear in explaining the poster but was less able to answer follow up questions or link different components of the poster together.	Presenter clearly explained the background, data and implications of the paper. Was able to respond to questions about topics that were not explicitly addressed on the poster.

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A3 Peer- and self-assessment tasks.

Students were provided with the following instructions for completing the peer- and self-assessment tasks with respect to contributions to the work of the teams.

- Assess the contributions of your team members towards the poster assignment so far. You have 100 points per student to distribute among the members of your team (including yourself). If some people have contributed more than others, adjust the points you allocate to them relative to other team members as you see fit. Each team member will be able to see the points they have received (not attached to your name) a couple of days after the evaluation has closed.
- As well as allocating points, explain in one or two sentences in the "Comment" section WHY you are allocating that amount to this team member. The team member will be able to see this comment (not attached to your name) a couple of days after the evaluation has closed, so please write something polite and constructive. Aim to write something that the team member can use to improve their ability to work in a team. If they are doing a great job let them know this.
- The allocated points from all team members will be converted into a mark out of 2 for each team member; the mark assigned will take into account the distribution of points across the team members to ensure that you are NOT penalized for being in a group where everyone is contributing well.

A4 Survey items.

The following questions (as discussed in the main text) were asked of students *via* online surveys. The format of the response required is listed in parenthesis at the end of each question.

1. List what you consider to be the main advantage(s) of working in a team to complete a project. (3 free text entries)
2. Using the space provided, indicate whether you and your team experienced each advantage you listed in the previous question while working on the poster project. (free text entry)
3. List what you consider to be the main disadvantage(s) of working in a team to complete a project. (3 free text entries)
4. Using the space provided, indicate whether you and your team experienced each disadvantage you listed in the previous question while working on the poster project. (free text entry)
5. Please indicate the extent to which you agree or disagree with the following statements, as they relate to your experience on this project since you submitted your group proposal and first iPeer (March 16). (six-point Likert scale used; strongly disagree, disagree, tend to disagree, tend to agree, agree, strongly agree)
   - *Statement:* I was enthusiastic about completing this project
   - *Statement:* In the future, I will seek feedback from my peers on drafts of my assignments in order to improve my work.
   - *Statement:* My team's poster presentation was stronger as a result of receiving feedback from another team on our group progress report.
   - *Statement:* My team's poster presentation was stronger as a result of reviewing another team's group progress report.
   - *Statement:* When my team was unable to meet in person, we effectively communicated through alternative means (for example: email, messaging applications, telephone).
   - *Statement:* My team found it difficult to find a time when everyone could meet in person.
6. Indicate which of the following options best describes any changes your team made to your project/the direction of your project as a result of your group session with [*your instructor*]. Briefly explain your selection in the space provided. (multiple choice with free text box)
   Options: We made major changes, We made minor changes, We did not make any changes, Other
7. Indicate which of the following options best describes any revisions you made as a result of the peer review process (please consider both the reviews of your proposal as well as any changes you made as a result of reviewing other proposals). Answer for both "Individual Proposal" and "Poster plan/direction of work". (multiple choice)
   Options: I/We made major changes, I/We made minor changes, I/We did not make any changes, Other

A5 Interview protocol.

Introduction:

- This focus group is being held to explore your experiences of the group project that you completed as part of [*this course*] this term.

Questions:

- Tell me about the project. (Allow themes to emerge)
- How did your team work together on this project?
- How did you decide how to work together? (Probe for knowledge of teamwork, leadership issues)
- How much time did you spend working together compared with on your own?
- What were the major barriers to working together during this project? Why?

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- What factors were helpful for working together? Why?
- In what ways, if any, did your team's approach change over the duration of the project?
- If so, what factors contributed to this change?
- To what extent was creating a team contract useful for this project? Why / in what ways?
- What was the most useful aspect of the team contract? (Remind them of the parts of the contract).
- What was the least useful aspect of the team contract?
- Now that you have completed the project, is there anything you wished you had included in your contract but did not?
- How did you choose your group topic for this project?
- Did you ever consider changing your topic at any point in this project?
- If yes, what factors were involved in your decision?
- How did you feel about group projects before starting this one?
- In what ways has your experience completing this project affected your opinion of group projects, if any?
- When using iPeer, what factors did you consider when distributing your points for the first/second rating?
- Did the importance of these factors change from the first to second rating?
- How did it feel to receive feedback from your teammates through the iPeer system?
- In what ways did you act upon the feedback, if at all?
- To what extent did your group work effectively as a team?
- What aspects of your team experience made you come to this conclusion?
- To what extent was your team successful? How did you reach this conclusion/judgment?
- To what extent does your course grade play a role?
- How could your team have performed better?
- Do you have any suggestions to improve the project experience for future students, in particular with reference to working together in teams?

