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Flipped Classroom in Organic Chemistry Has Significant Effect on Students' Grades

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The flipped classroom as a form of active pedagogy in postsecondary chemistry has been developed during the last 10 years and has been gaining popularity with instructors and students ever since. In the current paradigm in science, technology, engineering, and mathematics education, it is widely recognized that active learning has significant positive effects on students' grades. Postsecondary organic chemistry is a difficult course for students, and the traditional way of teaching does not foster students' active involvement. Implementation of active pedagogy could increase students' achievement in this course. However, few quantitative data are available on the impact of active pedagogy in general, or flipped classrooms in particular, on learning in organic chemistry at a postsecondary level. Thus, in this study, we evaluated the gain on final grade scores in organic chemistry after implementing a flipped classroom approach to promote active learning in this course. We encouraged students to be active by having them watch educational videos before each class and then having them work during class time on problems that focused on applying the concepts presented in the videos. Exams were the same as those completed by students in the traditional classrooms of our college. In an *a posteriori* analysis of our students' grades, we compared final grades in traditional classrooms (control group, $N = 66$) and in flipped classrooms (experimental group, $N = 151$). The sample was stratified in three categories depending on students' academic ability in college, from low-achieving to high-achieving students. Our results show that students in the experimental group have significantly higher final grades in organic chemistry than those in the control group, that is, 77% for students in the active classroom vs. 73% in the traditional classroom ($p < 0.05$). The effect was the greatest for low-achieving students, with final scores of 70% in the active classroom compared with 60% in the traditional one ($p < 0.001$). This difference in performance is likely due to students spending more time solving problems in a flipped classroom rather than having the questions assigned to them as homework.

Keywords: flipped classroom, organic chemistry, higher education, active learning, educational video

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INTRODUCTION

Organic chemistry has always been considered a difficult topic (O'Dwyer and Childs, 2017). Some authors attribute this to the new and non-familiar tasks organic students are required to perform (for example, drawing and interpreting tridimensional molecules on a two-dimensional surface, or predicting the products of a reaction based on the nature and reactivity of the reactants) and because organic chemistry is usually very fast paced due to the large quantity of topics to be covered in one semester (Fautch, 2015). Around the world, general chemistry is typically a prerequisite for enrollment in organic chemistry. However, topics studied in these two courses are very different. While general chemistry largely relies on mathematical analysis, organic chemistry focuses more on the relationship between structure and reactivity (Halford, 2016), and on more difficult intellectual tasks that are more prone to alternative conceptions (Rushton et al., 2008; McClary and Bretz, 2012). Reinforcing understanding of organic chemistry's relationships and tasks requires practice. Traditional teaching approaches address this concern through out-of-class homework exercises and reserve in-class time for lecturing. Conversely, the flipped-class approach uses in-class time for reinforcement and moves the lecturing out of class.

As remarked by Lasry et al. (2014), from a strictly economic standpoint, the most expensive resource in a classroom is the teacher. But this resource is not always used the most economically: when a teacher merely lectures from the textbook, his or her greater asset, helping the students to actively construct and apply their knowledge, is not employed. Following this consideration, several educators have undertaken the task of encouraging active engagement from their students during class time. Reviewing several studies conducted in science, technology, engineering, and mathematics (STEM) education; Freeman et al. (2014) concluded that any active pedagogy in STEM education improves students' grades. Their definition of active pedagogy is very wide and includes class activities as diverse as "occasional group problem solving, worksheets or tutorials completed during class, use of personal response systems with or without peer instruction, and studio or workshop course designs" (Freeman et al., 2014, p. 1). Their observation implies that science educators should concentrate their efforts on modifying their lesson plans and having students be more active in their learning. This, as they suggest, can be done in many ways.

Most organic chemistry educators are in favor of having students become more active in class. However, with a full syllabus, it can be difficult to free class time to do so. The flipped classroom solves this problem.

Several authors describe the flipped classroom, its purpose and the way it is implemented by teachers. As defined by Smith (2013), "flipping the classroom, at its simplest, involves pushing lecture material outside the classroom as a form of homework or other pre-class preparation, leaving more time in class for interactive or engaging exercises" (p. 607). There is a real challenge in implementing the flipped classroom, which is the necessity to integrate work at home and work in class into a pedagogically sound teaching approach that fosters the best learning outcome for students.

In a flipped classroom, direct instruction is moved outside of class (Flipped Learning Network, 2014), usually by assigning videos as homework. The flipped classroom is not merely distance education. Class time is crucial, and activities done in class are central in the approach. Therefore, implementing the flipped classroom involves having the instructor "redesign the curriculum so that the videos watched before class are integrated into each class with active learning pedagogies" (Albert and Beatty, 2014, p. 422). Moreover, "the practice of flipping involves activities pre-class, in-class, and post-class" (Estes et al., 2014), which should be designed by the instructor to form a coherent, engaging and effective pedagogical approach.

Abeysekera and Dawson (2015) define more precisely the flipped classroom as follows: a "set of pedagogical approaches that (1) move most information-transmission teaching out of class; (2) use class time for learning activities that are active and social and (3) require students to complete pre- and/or post-class activities to fully benefit from in-class work" (p. 3). Students receive the content in advance, generally through educational videos that they view at home, and then they are asked to perform higher-order learning activities in class while the teacher can help them instead of lecturing to them (Smith, 2013; O'Flaherty and Phillips, 2015). Benefits of the flipped classroom are multiple: students at home can pause and rewind the videos and are therefore less likely to fall behind than during a live lecture; class time is no longer passive; the teacher is available to guide students when they encounter difficulties, increasing their chances of persevering; and students receive feedback from teachers immediately, improving their self-awareness and confidence (Horn, 2013).

Feedback was reported by Hattie and Timperley (2007) as 1 of the 5 most effective factors influencing achievement in school, based on a review of 12 meta-analyses of almost 200 studies. They proposed that feedback is so effective because it helps "reduce the gap between current and desired understanding" for students (Hattie and Timperley, 2007, p. 86). These authors suggest that important aspects of feedback are thus to provide the students with a clear goal (answering the question "Where am I going?"), an appreciation of their current understanding (answering the question "How am I going?") and to design specific challenging problems as targets, or to set with them a target of greater automaticity in completing problems (answering the question "Where to next?").

Flipped classrooms are being used more and more as a pedagogical approach in higher education (O'Flaherty and Phillips, 2015). As reported by researchers, most implementations of the flipped classroom are occurring in STEM education (Roehling et al., 2017). However, not all STEM disciplines are equally aware of the effectiveness of this approach and studies on the impact of the flipped classroom on grades are still relatively few in number (Ryan and Reid, 2016). A review of 28 studies about the use of flipped classrooms in higher education (O'Flaherty and Phillips, 2015) reports implementation of flipped classrooms in a wide variety of disciplines, most of them in STEM, namely, in health sciences courses (15 out of 28), in applied sciences (6 out of 28), and in pure sciences (only 2 out of 28, 1 in chemistry and 1 in mathematics), the rest of the studies being in humanities and social science education.

Research results show that students generally seem to appreciate the flipped approach (O'Flaherty and Phillips, 2015). McNally et al. (2016) studied the correlation between the appreciation of flipped classrooms and grades. They observed an improvement in grades with flipped "endorsers" and flipped "resisters," pointing toward the interpretation that "preferences alone may not be the most informative aspect on which to evaluate a flipped classroom environment" (McNally et al., 2016, p. 292). Several studies conducted on the evaluation of flipped classrooms in the past years concentrated mostly on students' appreciation of the approach (Critz and Wright, 2013; Butt, 2014; Yeung and O'Malley, 2014; Young et al., 2015) and did not evaluate other aspects of its potential effectiveness.

The one study in chemistry education from the aforementioned review (O'Flaherty and Phillips, 2015) was conducted in two Physical Chemistry courses in the UK (Yeung and O'Malley, 2014). All the lectures were filmed in screencasts lasting between 20 and 40 min. Problems were submitted each week to students, who had to work them on their own and could get help from professor during in-class optional workshops. At the end of the semester, students were questioned on their appreciation of the approach. While most of them reported having preferred the flipped classroom to a traditional course (the preference for the flipped classroom was around 80% with a response rate of around 50%), some students still report that the screencast videos were not as engaging as a live lecture and that they did not allow for students to ask questions.

A few other studies were conducted in undergraduate college chemistry education with flipped classrooms. Ryan and Reid (2016) implemented flipped classroom in general chemistry. They questioned students on their appreciation of the approach as Yeung and O'Malley (2014) did before but designed their study to be able to measure academic improvement as well. One part of a student cohort was enrolled in a traditional, lecture-based course, while the other part was enrolled in the same course using a flipped classroom approach. The two populations took the same standardized test at the beginning of the study and another version of the same test at the end of the semester. The setting of the flipped classroom in that study included educational videos of screencast PowerPoint slides to be viewed before class, and cooperative activities conducted during class time, but no traditional lectures at all, while the control group met in class for traditional lectures during the entire semester. Authors reported a significant improvement of academic grades for the lowest-achieving category of students in the flipped classroom setup, but no statistical difference for the entire population studied was observed. They interpreted this finding as follows: "Our results are consistent with the idea that active learning holds particular benefits for students who are capable but less well prepared" (Ryan and Reid, 2016, p. 21). Furthermore, they noted a significant diminution of withdrawal rates from 23% in the control course to only 6% in the flipped classroom, as a likely result of students being more engaged by the setting of the flipped classroom. This seems to be contrary to what was observed by Yeung and O'Malley (2014), who reported less engagement with the flipped classroom. This difference might be explained by the fact that Yeung and O'Malley's flipped setting was only long screencasts of lectures without a particular device developed to use during class time. On the other hand, Ryan and Reid described discussions and activities conducted during class time to complement shorter videos to be watched pre-class. The integration of activities might be the reason why students felt more engaged in the latter setting.

In organic chemistry, Christiansen (2014) conducted a very small-scale study with one group of seven students in a flipped classroom and one group of six students in a traditional classroom. Flipped-class students were required to watch screencasts of the PowerPoint presentation of the lecture at home before the course and class time was used to work problems in groups with the help of the professor when needed. To encourage students to watch the videos, a quiz was included at the beginning of every other class. No difference was noted between the experimental and the control groups, although this is perhaps due to the very small number of participants.

Also in Organic Chemistry, Mooring et al. (2016) studied the effect of flipping a large-enrollment university course on students' grades and attitude toward the course. They had students watch pre-class videos and answer pre-class online quizzes. In class, students worked in small groups on worksheets. Each class started with a traditional lecture of around 20 min. Students also had to participate in weekly out-of-class exercise sessions with teacher assistants. The authors reported an increase in A and B scores in the flipped course when compared with historical data. However, this study was conducted with only one instructor, and the sample consisted of only one group in one semester. Also, the out-of-class sessions with teaching assistants in the flipped setting replaced online homework in the traditional classroom. The authors warn us that it is impossible to disentangle the effect of these sessions from the effect of the flipped classroom in itself. Also, students' results in a standardized exam were not significantly different between flipped instruction and traditional instruction.

Overall, very few studies have been conducted in chemistry, much less in higher education chemistry and organic chemistry. Most studies report flipped-class use in high schools (Fautch, 2015). Still students seem to appreciate this method of teaching and more and more educators around the world are beginning to implement this approach. It is surprising that so few studies have been conducted in chemistry since the popularization of the flipped classroom approach owes a great deal to two chemistry teachers, Bergmann and Sams (2012), who published a book recounting their experience of developing and implementing flipped classrooms for high school chemistry teaching. An ever-increasing number of educators have followed their example since then in a very wide array of disciplines.

The current lack of data demonstrating the effectiveness of the flipped classroom have drawn some criticism, with authors asking the research community to provide actual data before spending time and resources on its implementation. Abeysekera and Dawson (2015) describe this issue with lucidity: "flipped classroom approaches are being adopted with much enthusiasm despite the paucity of specific evidence about their efficacy" (p. 10). The keen interest in flipped classrooms is sometimes motivated by budget preoccupations in countries where universities may "see the flipped approach as a means of delivering cost-effective, student-centered curricula in the face of increasing student numbers" (O'Flaherty and Phillips, 2015, p. 86).

While budget considerations are always a concern, this was not our motivation for the implementation of a flipped classroom approach. We based our choice on pedagogical reasons, recognizing that flipped classrooms have the potential to make the students more active, to free class time for significant activities, to offer more flexibility for students to learn at their own pace, and to increase student responsibility toward learning. Research also pointed toward the fact that it might be an effective pedagogical approach albeit with insufficient data on its efficacy, particularly in higher education and in chemistry (Ryan and Reid, 2016).

Following the cautionary notice provided by O'Flaherty and Phillips (2015), "one of the greatest obstacles [is] related to staff capacity to design, implement and evaluate the effectiveness of their flipped classrooms" (p. 94), we decided to verify the impact of the flipped classroom approach we implemented in our organic chemistry class on our students' grades. This led to the formulation of the following research question:

> Have our organic chemistry students' grades improved since we implemented the flipped classroom?

This research question follows one of the calls for research from Abeysekera and Dawson (2015), who suggest that quantitative studies should be conducted to evaluate the impact of small-scale interventions, to answer the question, "what is the efficacy of the flipped classroom approach in this discipline, this classroom, with these students?" (p. 11). Data analyzed were students' grades before and after the implementation of the new pedagogy.

In addition to this main question, we pursued a second question in this study:

> Did the students appreciate the flipped classroom we implemented?

However, before answering this, it is necessary to provide a full account of our pedagogical approach to the flipped classroom, since several types of flipped classroom exist, and their differences do not reside only in the use of educational videos.

This study is different from previous studies since it reports on flipped classrooms in higher education organic chemistry in a small-enrollment course with different instructors through four successive semesters. It also compares students' grades in traditional and flipped classroom by considering a measure of academic ability as a moderating factor.

MATERIALS AND METHODS

This research reports from an *a posteriori* analysis of data collected during the normal course of our teaching of organic chemistry to verify if the flipped classroom we implemented had a significant effect on students' grades. In this section, we first describe the learning environment in which this research falls, and then we present the method employed to answer the research question.

Learning Environment

Quebec's Colleges and Organic Chemistry

This study was conducted in a postsecondary college in Montreal, Canada. In Canada, education is under the responsibility of the provinces (CICIC, 2017). Quebec, the province where Montreal is located, has a unique postsecondary system. All students in Quebec must obtain a 2-year college diploma prior enrolling in university. Colleges offer both 2-year pre-university diplomas and 3-year vocational diplomas. This study was conducted in the pre-university 2-year science program. Furthermore, education in this college is conducted in French, the first language in the province of Quebec.

Organic chemistry is an optional course in the science program. About two-thirds of science students select it, since it is a prerequisite for several health and pure science university programs in Quebec. Students enroll in this course during their third semester, after having studied General Chemistry in the two previous semesters.

The organic chemistry course as designed in our college consists of 5 h/week of class time split into one block of 2 h and one of 3 h. Lab periods, lasting 2 h, take place during the 3-h block approximately once every 2 weeks.

Organic chemistry taught in Quebec's colleges is very similar, in terms of content and difficulty level, to what is taught in undergraduate programs elsewhere in the world. Results collected in this study could therefore be of interest for educators outside of Quebec.

Traditional Classroom vs. Flipped Classroom

Class time in the traditional (control) setting used to be devoted to lectures either supported with PowerPoint presentations or printed course notes and a textbook. These were interspersed with some professor-led exercises on the board and some exercises that students could practice, for which the professor provided the answer. Then, as homework, students were assigned end-of-chapter exercises and problems from a textbook to consolidate their knowledge.

As Jensen et al. (2015) explained in their paper about the comparison of traditional and flipped classrooms in a university biology course, the difference between these two types of pedagogy is principally the moment the students are first in contact with new subject matter and the platform through which this first contact is made. In our traditional setting, students first learned about new topics in class, in the presence of the professor. At this moment, students would be engaged toward the material, they would explore the contents and the professor would explain to help facilitate learning (Jensen et al., 2015). After class, students in the traditional classroom would be asked to apply their knowledge to novel situations, that is, by practicing textbook problems at home. They would be evaluated during summative examinations, but no formal formative assessment was included in the course and homework were not graded. Students were responsible to verify if they were able to complete textbook problems and to see the professor outside of class time for any questions about the course content.

In the traditional as well as in the flipped settings, the layout of the classroom was a traditional seating arrangement, with tables facing the board and grouped in two- or three-table pods.

In our organic chemistry course in a flipped classroom, the engagement, exploration, and explanation phase would occur before class time, through a series of video on an online platform. Then, during class time, students would participate in face-to-face activities to apply the new knowledge. After class, students were still assigned end-of-chapter exercises and problems as homework. These homework exercises were not verified nor graded by the instructors. The three moments of the flipped classroom setting (pre-class, in-class, and post-class) are described in the following sections.

Pre-Class: Videos

Students enrolled in the flipped classroom organic chemistry course were required to watch videos before coming to class. Typically, three to five videos were assigned each week, for a total video time of 30 min. The videos are of four types: theory, exercises, laboratory techniques, and software use. Our teaching staff, consisting of 2 professors, with the sporadic help of 2 other professors and 1 laboratory technician, prepared all 75 videos during the Fall semester of 2013. Most videos are about theory (57 videos), principally showing one or both professors in front of a white board, explaining concepts to the camera or to each other and noting key concepts or examples on the board; a small number of videos are rather screencasts of a PowerPoint presentation with a voice-over by one of the professors (see **Figure 1**).

Videos were shot with special attention to their length, which was kept as short as possible. Mean video length is in fact 6 min and 13 s (SD = 2:19). Guo et al. (2014) conducted an empirical study about features of videos used in massive open online courses on students' engagement and observed that normalized engagement stayed high with videos up to 6–9 min long, but that it dropped significantly with longer videos. Each of our videos was constructed around one topic, allowing students to find the topic they were looking for easily.

Most videos prepared for this organic course also have a "pause-solve-resume" feature. That is, professors would suggest an exercise, and invite students to press pause, solve the exercise on paper, then resume the video for the solution. This feature is rather low-tech, considering the abundance of interactive tools to segment videos for this purpose (for instance, http://EDpuzzle.com). However, using the low-tech version of a "pause-solve-resume" feature was less time consuming for the professors and allowing students to get immediate feedback on their understanding and ability to solve simple problems on new content. As was reported in the literature, students are less engaged in the outside-of-class activities of a flipped classroom if these activities lack interactivity or feedback (O'Flaherty and Phillips, 2015). The "pause-solve-resume" feature can provide a minimum of interactivity and feedback to students.

Students were encouraged to take notes while watching the videos, and to note any unresolved questions they had. These notes and questions were then used in class, as explained in the next section. However, no incentive was used to ensure students would watch the videos nor did we verify if they did. Since students would have to use their notes to complete classroom activities, we noticed when a student had not watched the videos. However, it rarely occurred as the semester progressed since students rapidly learned that not watching the videos would impede the work they would be able to do during class time.

In-Class: Questions, "Portfolio" Exercises, and Micro-Lectures

In the flipped classroom, the course flow was constructed as follows: first, professors would answer students' questions about the videos they watched before class, for periods ranging from a few minutes to 15–20 min, depending on the number of questions from students. Second, students would work on a sheet of exercises, called "portfolio exercises," brought to class by the professors. These exercises were a direct application of the topics covered in the videos. Students were encouraged to work in pairs and to ask the professors questions whenever they needed help. This practice, having students work in class on face-to-face activities was recommended by Strayer (2012) as a means to strengthen and apply students' understanding of more formal notions seen in videos. Depending on the length of the portfolio exercises, 15–30 min would be devoted to this activity, at the end of which students were asked to give them back to the professors for a formative assessment. Several types of exercises were designed. Practicing organic nomenclature, reaction mechanisms, and forms of drawing molecular structures were part of them.

Typically, after the portfolio exercise, a micro-lecture would be given by the professors on a subject that was not covered in the videos. In fact, some topics were intentionally reserved for micro-lectures, often because they were more difficult or needed a subtler understanding (Sweet, 2014). For example, the explanation of the factors used to predict if a chemical reaction would undergo a nucleophilic substitution or an elimination mechanism was given in a micro-lecture in class, with several examples and the possibility for students to ask questions immediately. These micro-lectures were variable in length, typically lasting between 20 and 30 min.

After the micro-lecture, another portfolio exercise sheet would be distributed to students about topics covered in the micro-lecture. These exercises would then be completed, handed in to the professors and formatively assessed. Approximately one portfolio exercise sheet was thus distributed every class hour.

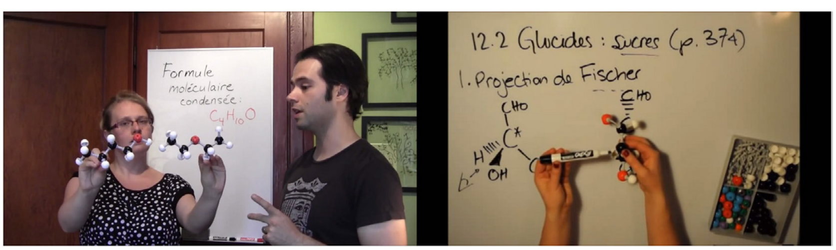

FIGURE 1 | Screenshot of two videos filmed for this flipped classroom. Left panel: an example of a theory video; right panel: an example of a solved exercise.

Between classes, professors formatively assessed the portfolio exercises by indicating where students had made mistakes, but without giving the right answer. Portfolio exercises were handed back to students at the beginning of the next class. Students then had to put the portfolio exercises into their portfolio (a cumulative report) and, outside of class time, they were required to correct their mistakes. Prior each exam, students handed the corrected portfolio in for grading. Only remaining mistakes lost them points. A very small mark was allotted to the portfolio (5% in total), but it was sufficient for students to comply with these requirements. The formative assessment of portfolio exercises provided prompt feedback to students and the format allowed them to make mistakes without being punished. The portfolio was seen by students and professors as a learning tool and not as an evaluation tool. Students are more likely to benefit from the approach if their professor integrates assessment into the design of the flipped classroom (McNally et al., 2016).

As reported by Jensen et al. (2015), this flipped setting allowed students to receive more explanation since they are provided with answers to their questions about the videos at the start of the course and to their other questions during exercise time. Furthermore, it allows a phase of evaluation of knowledge that is not possible with traditional classroom, the immediate feedback the students receive while applying their new knowledge in class.

Post-Class: Consolidation Exercises

After class, teachers suggested exercises in the textbook for students to continue practicing the problems worked on in class and to consolidate their knowledge. Students were autonomous in these exercises, and their completion was not verified during class. These exercises resembled the portfolio exercises and since the textbook was also written by the professors of several sections of the experimental sample (Voisard and Cormier, 2013), they were relevant to the topics studied and adequate to the level of the course.

Co-Teaching

Some classes taught in the flipped classroom were also taught by two professors in co-teaching. This co-teaching consisted of both professors being present during class time, alternatively answering students' questions, giving micro-lectures, and helping students during portfolio exercises. The experimental group was therefore of two types: of the seven classes taught in flipped classroom for this study, four were co-taught while the remaining three were taught by a single professor.

Co-teaching was done on a volunteer basis, meaning the extra amount of class hours were not considered in the teachers' remuneration. However, since the workload of implementing a flipped classroom approach can be demanding (O'Flaherty and Phillips, 2015), co-teaching, particularly in the numerous hours spent preparing videos, was greatly appreciated by both professors.

Research Method

We compared grades in organic chemistry in our college before and after the implementation of the flipped classroom. This was done by an *a posteriori* analysis so the actual evaluation was conducted after students had completed the course either in traditional or flipped settings. As noticed by O'Flaherty and Phillips (2015) in a large review of studies on flipped classroom in higher education: "the majority of articles evaluated student outcomes by comparing an existing course taught in a traditional manner with a course imbedding a flipped class" (p. 89). Several authors have used historical data to find the effect of the flipped classroom, in particular Ryan and Reid (2016) in higher education chemistry. This research approach was also used in this study, where historical data were used as the control sample to which outcomes of the flipped classroom were compared.

Population

Since we worked with two consecutively enrolled populations of students, the sample is the entire population of organic students between 2012 and 2014. **Table 1** presents the two groups we compared. In total, 74 students were enrolled in the control sample, but 8 of them (10.8%) withdrew during the semester. Students who withdrew were not included in the analysis since the reason of their withdrawal was not documented. Similarly, 13 students from the experimental sample withdrew from the course (7.9%) and were not included in the analysis.

Class size was similar between traditional and flipped classrooms: the traditional sample of 66 students was distributed into 3 classes of 22 students on average, while the flipped sample of 151 students was distributed into 6 classes of 25 students on average.

The composition of both samples regarding the sex of the students is slightly different with proportionally more women being enrolled in the experimental sample. This difference in composition is, however, not statistically significant (Pearson's $\chi^2 = 1.093$, $p = 0.296$).

The last information presented in **Table 1** is the *R*-Score means of each sample. This measure of academic ability will be explained in the next section.

Organic Chemistry Grades and *R*-Scores

Quantitative data collected for this study are students' organic chemistry final grades. The final grade is on 100 points, the passing grade being 60%. These grades include theoretical evaluation (exams) for 65% of the total ponderation and laboratory evaluation (lab reports and lab exam) for 30% of the total ponderation. The remaining 5% is allotted to either a group homework in the traditional setting or the portfolio in the

TABLE 1 | Description of control (traditional) and experimental (flipped classroom) samples.

	Control sample	Experimental sample
Years of data collection	2012	2013–2014
Number of students	74	164
Number of groups (classes)	3	6
Number of withdrawals	8 (10.8%)	13 (7.9%)
Number of students included in analysis	66	151
Gender	56.1% F, 44.0% M	63.5% F, 36.4% M
R-Score mean (SD)	27.6 (3.96)	27.0 (3.86)
R-Score median	27.5	27.2

flipped setting. This difference is somewhat minor (only 5%) between the traditional and flipped classrooms, thus the final grades can be compared.

Since historical data were compared with data after the implementation of the flipped classroom, no randomization of samples could have been done. As suggested by Ryan and Reid (2016), the non-randomization of samples was taken into account with a measure of ability of each sample. These authors had both samples take the same pretest and thus demonstrated their equivalence. In the case of this study, since it was not possible to have past students take a test, we chose to compare the control sample (traditional teaching) with the experimental sample (flipped classroom) based on students' academic ability as measured by *R*-Score.

The *R*-Score "is the instrument of choice for analysis of all applications to university programs" (BCI, 2017) in the province of Quebec. It is an improved *Z*-Score in the sense that it considers the group strength and the group dispersion, making it a robust measure of a student's academic ability. It is calculated for every college student, at the end of every semester by college Academic Dean's offices. For this study, *R*-Scores were used as calculated by our college.

Although the theoretical maximum *R*-Score is 50, it is virtually impossible to get such a number. *R*-Scores above 30 are considered "high" and might lead students to be admitted into limited enrollment university programs such as Medicine or Dentistry (BCI, 2017). In addition to students' final grades in all courses they were enrolled in each semester, *R*-Score calculation considers the strength of the group and the dispersion of the group (as measured with high school grades of all students in their groups, for each course). This measurement can therefore allow universities to sort students based on their academic performance, with no regard for the college students were enrolled in. *R*-Scores are also used locally, in colleges, to evaluate the mean academic strength of group classes, for program evaluation purposes, for example. *R*-Scores have a very high correlation factor to all college chemistry courses grades ($r = 0.873$, $n = 229$, $p < 0.001$), including organic chemistry. For this reason, *R*-Scores are used in this study as a measure of academic ability. *R*-Scores are calculated by Quebec's ministry of education, the *Ministère de l'Éducation et de l'Enseignement supérieur*. *R*-Scores used for this study were obtained by the authors from the Academic Dean's office of the college where the study was conducted.

As shown in **Table 1**, mean *R*-Scores for both samples are 27.6 and 27.0. This difference is not statistically significant ($t = 0.951$, $p = 0.343$), thus the two samples can be considered equivalent in terms of academic ability in college, albeit the control group had a slightly better *R*-Score average.

Ryan and Reid (2016) divided students of each sample (traditional and flipped) into three bins of equivalent ability for further analysis upon each of these bins. Following that example, we divided students of the traditional teaching sample and students of the flipped classroom into three academic achievement categories: low achievers, average students and high achievers. Composition and average ability of these bins are presented in **Figure 2**.

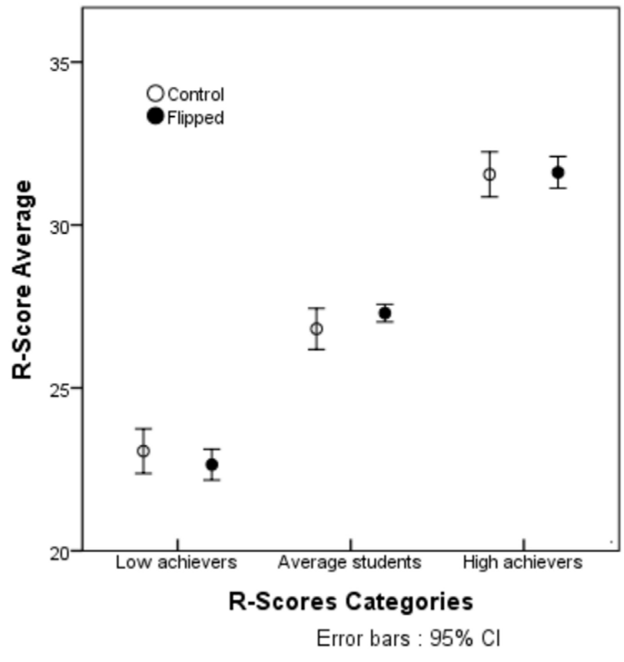

FIGURE 2 | Composition of each *R*-Score category in flipped classroom ($N = 151$) and in traditional (control) classroom ($N = 66$).

Students' Appreciation

At the end of the semesters of fall of 2013, spring of 2014 and fall of 2014, students were questioned on their appreciation of the pedagogical approach in organic chemistry. Students were sent an email containing a link to an anonymous electronic questionnaire containing nine items (Likert-scale and open ended) regarding their appreciation of the pedagogical formula and the videos and probing them on the number of hours devoted to the course outside of class. Examples of items (translated from French by the authors) are presented below:

- What is your appreciation of the course? [I liked it very much; I liked it; I somewhat disliked it; and I hated it].
- What is your appreciation of the flipped format, that is, watching videos before class and working on portfolio exercises in class? [I liked it very much; I liked it; I somewhat disliked it; and I hated it].
- How many required videos do you usually watch prior class? [All of them; most of them; only a few of them; and none of them].
- What type of video do you prefer? [open-ended item].
- How many hours do you spend on organic chemistry material outside of class time each week in average? [0; 1–2; 3–4; and > 4 h].

This questionnaire that was devised as a means of getting feedback from students for a new pedagogical approach was not sent to the control sample, for which data were collected the year before its implementation.

The questionnaire was answered on a volunteer basis, since no control was exerted on the students and that students who chose to answer did so anonymously. The electronic survey was left open for 1 week after inviting students by email to answer it. Students answered it outside of class time.

Constant Parameters between Traditional and Flipped Classrooms

Two elements were kept constant between the course taught traditionally and by flipped teaching. First, exams were kept the same, with year-to-year slight modifications, to prevent cheating. For example, for one version of an exam, students had to draw the mechanism of an esterification reaction between methanol and acetic acid, while in another version, they were asked to draw a mechanism for the same reaction between ethanol and propionic acid. The same knowledge is necessary to answer both problems, making the exams sufficiently similar for the students' grades to be compared. These exams included items on nomenclature and isomerism, drawing of organic molecules and reaction mechanisms, designing of synthesis schemes, and formulating explanations of properties of matter based on molecular structure.

Second, the same laboratory curriculum was used in both settings, with the same laboratory exam. Lab experiments were based on the practice of synthesis, purification and characterization of organic compounds.

Ethical Considerations

Results collected for this study did not include students' identification, but only their *R*-Score, organic chemistry grade, and their sex. Data were provided by the institution's admission service through a list of file numbers, from the admission database. No analysis necessitated students' identification. Since the analysis of data was done *a posteriori* on data present in a database, and no students' identification was collected nor used, no approval from an ethics committee was required for that type of study, as being the analysis of an archival record. Appreciation questionnaires were answered anonymously and on a volunteer basis. Students were informed that their answers might be used for publication, but that no information that might identify them would be collected nor disclosed.

RESULTS

Quantitative results regarding grades in organic chemistry prior and after the implementation of the flipped classroom are presented in this section, followed by qualitative results of the students' appreciation of this pedagogical approach.

Quantitative Results: Grades in Organic Chemistry

By comparing the traditional classroom and flipped classroom in organic chemistry, we first observed that the latter led to statistically better grades for the overall sample. Indeed, in **Table 2**, the overall results show that flipped students had a grade average of 77.1% in organic chemistry compared with 72.9% for the control sample, even though both samples showed no difference in academic achievement as measured by their *R*-Score, as presented earlier. The effect size of this difference is, however, small, as measured by Cohen's d ($d = 0.32$) (Cohen, 1988).

Correlation between organic grades and *R*-Scores is still very high for both the traditional (control) sample and the experimental (flipped) sample: for the traditional sample, Pearson's correlation coefficient between these two variables is 0.827 ($n = 66$, $p < 0.001$), and for the flipped sample, the coefficient is 0.662 ($n = 151$, $p < 0.001$). Note that the correlation coefficient is smaller in the flipped classroom sample. This might be explained by the result that will be presented in the next subsection, which is that not all students' grades increased with the same magnitude.

Difference in Grades for Low Achievers, Average Students, and High Achievers

To further the analysis, we then proceeded to disaggregate results to verify if subgroups of our sample benefited differently from the flipped classroom approach. For this purpose, we analyzed the three bins of students separately based on their *R*-Score, namely, low achievers, average students, and high achievers. Note that these subsamples had similar composition regarding their academic ability.

This analysis led to the most striking results from this study, presented in **Figure 3**. Lowest-achieving students are the ones presenting the largest difference between control and experimental settings, having their grade average going from around the 60% success threshold mark to almost 10% above of it with the flipped classroom, with a large effect size ($d = 0.94$). Difference is also significant for average students, who show a grade average of 7% higher in flipped classroom than in the control group (69 vs. 76%), with a moderate-to-large effect size ($d = 0.73$); high achievers have also slightly better grades in

TABLE 2 | Students' mean grades in organic chemistry in control (traditional classroom) and experimental (flipped classroom) groups, depending on their level of achievement in college.

	Entire sample		Low achievers		Average students		High achievers	
	N	**Mean grade (SD)**	***N***	**Mean grade (SD)**	***N***	**Mean grade (SD)**	***N***	**Mean grade (SD)**
Traditional classroom	66	72.9 (14.7)	21	59.8 (11.0)	18	68.5 (10.6)	27	86.0 (6.6)
Flipped classroom	151	77.1 (11.2)	51	69.8 (10.4)	55	75.6 (8.6)	45	87.1 (7.1)
t Score	2.053*		3.663**		2.868*		0.651	
Effect size	Small effect (Cohen's $d = 0.32$)		Large effect (Cohen's $d = 0.94$)		Moderate effect (Cohen's $d = 0.73$)		No significant difference	

**Statistically significant ($p < 0.05$).*
***Statistically significant ($p < 0.005$).*

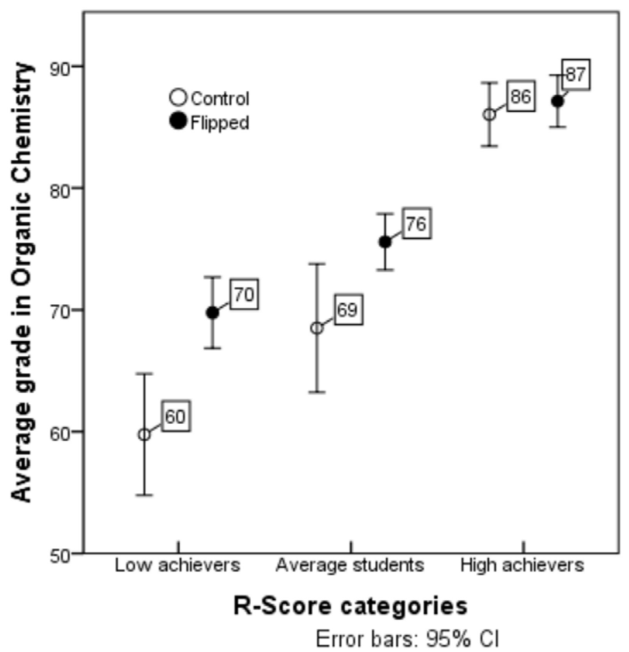

FIGURE 3 | Differences in organic chemistry grades for students in flipped classroom (N = 151) vs. students in traditional (control) classroom (N = 66).

flipped classroom (86 vs. 87%); however, that difference is not statistically different for this subgroup.

Difference in Withdrawal from the Course

As stated earlier, only students who completed the course we considered for analysis in this study. We observed that a smaller percentage of students withdrew from the flipped classroom groups (7.9%) as from the traditional groups (10.8%), the difference being, however, not statistically significant ($\chi^2 = 0.527$, $p > 0.05$). A similar difference in lower withdrawal rates in the flipped classroom was observed by Ryan and Reid (2016), but with a much larger effect size. These authors explained this difference by their flipped format being more engaging to all students than a traditional lecture in a large (300 seats) lecture hall. Due to our groups being much smaller (around 25 students per group) than those in the study by Ryan and Reid, the increase in engagement may not have been as great between traditional and flipped settings as the one these authors observed.

No Effect for Co-Teaching

It was also important to verify if co-teaching, as used in four flipped classes of the experimental sample, influenced students' grades. We therefore analyzed three subsamples with a one-factor ANOVA: traditional teaching (no co-teaching) in a traditional classroom, traditional teaching (no co-teaching) in a flipped classroom, and co-teaching in a flipped classroom. Since one condition is missing from the design (co-teaching in a traditional classroom), it is impossible to conclude with certainty on the impact of co-teaching with the results collected from this study. Still, results show that co-teaching did not significantly influence grades in the flipped classroom: grade average without co-teaching was 78.5%, and grade average with co-teaching was 75.7%, the difference not being statistically significant. Grade average without co-teaching and without flipped classroom (traditional classroom), on the other hand, was significantly lower at 72.9%. Further research would be necessary, but from the results available now, we can suggest that co-teaching in a flipped classroom as we applied it in this particular setting does not significantly influence students' grades.

Yet, other reasons for wanting to practice co-teaching in a flipped classroom environment might still exist and will be explained in the discussion.

Qualitative Results: Appreciation

Students were questioned on their appreciation of the pedagogical approach in organic chemistry through an anonymous questionnaire. Only data from flipped classroom students are available, but even so, some results are interesting enough to be noted even if no comparison can be made with the control group.

Eighty-eight students responded to the online questionnaire anonymously, after the end of the semester upon email invitation by their professors. The questionnaire was sent to the 99 students who were enrolled in the course at the beginning of the semester and did not withdraw before the end. The high response rate (89%) makes it possible to believe that the answers obtained are representative of the experimental sample of this study.

General Appreciation

When asked if they liked the flipped classroom approach, 83% of the students answered positively (either "I liked it" or "I liked it very much"), which is comparable to results from other studies on general appreciation of this pedagogical approach (Smith, 2013). Since a part of the sample was taught by a pair of professors in co-teaching, we also asked students if they appreciated the co-teaching and 97% of them responded positively. We expected the perception of the flipped classroom to be somewhat lower than the perception of co-teaching, as the first involves more work from the students than simply being taught by two professors. It should be noted, however, that the most popular approaches are not necessarily the most effective: indeed, co-teaching, which is highly appreciated, has had no effect on student grades as seen in the previous section.

Most Preferred, Least Preferred Aspects of the Flipped Classroom

Two open-ended questions asked students to comment on the aspects of the course, the most and least preferred. Answers were grouped under categories, and number of occurrences in each category is presented in **Table 3**. Not all students provided answers to these questions, leading to an unequal total of occurrences. The most frequently mentioned preferred aspect is the flipped classroom in general (21 answers). When adding up all the positive aspects of the flipped classroom, we observe that 47% of the positive comments regarded that particular type of pedagogy. On the contrary, the flipped classroom was only mentioned three times as the least preferred aspects of the course. But by adding up all the least preferred aspects relating to the flipped classroom

TABLE 3 | Number of occurrences of most preferred and least preferred aspects of the organic chemistry course in the flipped classroom format as answered by students.

Most preferred aspect	N	Least preferred aspect	N
About the flipped classroom			
Flipped classroom (in general)	21	Flipped classroom (in general)	3
Questions are answered in class	7	Workload	8
Face-to-face exercises (portfolio)	4	Face-to-face exercises (portfolio)	2
Videos	4	Videos	2
		Missing: summary of videos at the beginning of class	5
		Missing: printed notes	4
		Missing: more homework	1
		Clarity of PowerPoint used in micro-lectures	1
About the professors or the co-teaching			
Professor	13	Professor	2
Co-teaching	10	Co-teaching	3
About other topics			
Classroom atmosphere	4	In class: pace (too fast), time on exercises (too short)	7
Subject matter	8	Subject matter	1
Lab curriculum or lab reports	3	Lab curriculum or lab reports	9
"I liked everything"	2		
Total of answers	76	Total of answers	48

as we implemented it (type of work outside of class, face-to-face activities, etc.), the total percentage of the flipped classroom being the least preferred aspect of the course was 54%. Students were therefore writing a lot about the flipped classroom for these two questions, either as it being their most preferred or least preferred aspect of the course. This is understandable: for all students, it was their first time being enrolled in a flipped course. Since it probably appeared very different from the lectures they were used to, they had many comments to formulate on the topic. It is also noteworthy to mention that several students cited one aspect of the flipped classroom as being their most favorite of the course and another aspect as being their least favorite, for example, from two given students:

> Student 1 favorite aspect: "*Professor availability in class allows for more individual attention to each student.*[1]"
> Student 1 least favorite aspect: "*Too much time needed to prepare for class.*"
> Student 2 favorite aspect: "*Videos are nice, since they allow me to learn at my own pace (I can pause or rewind if I did not understand).*"
> Student 2 least favorite aspect: "*The problem is, if videos are not watched prior to the next class, I would feel lost (I don't always have time to watch all videos) […].*"

Those two students appreciated the general format of the flipped classroom, but some aspects or requirements from it were seen more critically from them.

One of the most frequent negative aspects of the flipped classroom mentioned by students was indeed the workload, an aspect that was also reported by other studies on the flipped classroom (Lage et al., 2000; Mason et al., 2013). Another item of the appreciation questionnaire was specifically about the amount of work outside class hours. We asked the students to estimate the average number of hours of work devoted to the course outside class (possible answers being less than 2 h/week, between 2 and 4 h/week, and more than 4 h/week). Most students answered that they devoted between 2 and 4 h/week at home to the course, which does not exceed the expected 3 h/week as prescribed in the course syllabus and remains the same in the traditional classroom. It is possible that students who complained about the workload in the course felt like they were working more than they used to in other science courses, which may be desirable if they were used to working less than the expected number of hours.

Some negative aspects mentioned by students are about elements that might be missing from our implementation of the flipped classroom, namely, the lack of a form of video summary at the beginning of class, of printed notes for students to fill out either at home while watching videos or in class during micro-lectures, and even the lack of graded homework. These elements were suggested by students as possible ameliorations to the course and could be interesting to consider in the future.

Other very frequent negative aspects regarded the pace of the course (seven answers) and the laboratory curriculum or lab reports (nine answers). These aspects are not related to the new implementation of the flipped classroom, since the pace is always perceived as rather fast in organic chemistry (Fautch, 2015), and the laboratory curriculum was not modified in the flipped classroom implementation. Comments from students for these aspects will therefore not be discussed here.

Degree of Preparedness prior Class

Students were questioned on their assiduity in watching videos before class. 72% of the students declared watching all videos before class, and a further 25% said watching almost all of them, so 97% of the students who answered watched all or almost all assigned videos before coming to class. Note that we chose not to check if the students had seen the videos through online or classroom tests, but most of them still seem to have done the preparatory work.

We did not verify the degree of preparedness of students because videos are available on an open online platform (YouTube) on which students do not need to register. Pedagogical platforms that can host videos, such as Moodle, for example, include tools to verify the completion of pre-class work by students, but were not used in this study.

Appreciation of Videos

We filmed different types of videos, as explained earlier, and in the anonymous appreciation questionnaire, we asked students what type of videos they preferred. As this item was open-ended, students' answers were grouped into categories. The most preferred videos, as evoked by 19 students (30% of all answers), were those where the professors appear on screen, as shown on the left panel of **Figure 1**. Typically, these videos were filmed by a camera placed on a tripod in front of a white board, and in which the professors were discussing with each other, taking notes on the board

[1] Student comments are translated from French by the authors.

and explaining how to solve problems. Most of the videos are of this type, which seemed to have been appreciated by students. The flexibility of the format, the naturalness of presentation, and the fact that students knew the professors might have influenced them in their preferences for these videos.

The second most preferred type of videos mentioned by 13 students (21%) showed the professors solving exercises on the board. In this type of video, the professors were sometimes inside the camera range and other times outside of it, only their arm being shown (see right panel of **Figure 1**). These videos were probably favored because the professors modeled the procedure to solve problems by types, and that the procedure can afterward be practiced by students, either by a "pause-solve-play" feature in the video itself or by suggested exercises in the textbook. No comments concerned the "pause-solve-play" feature of some videos, but it might explain why some students cited the exercise videos as their favorites.

A lot fewer students preferred screencast of a PowerPoint presentation (five students, 8%), showing that seeing the professor is more important than seeing a presentation. A possibility to add personalization to a screencast could be to overlay a video of the professor in the corner of the screencast, thus mitigating the risk of the video being less engaging to the students (Awad et al., 2017).

DISCUSSION

Effectiveness of the Flipped Classroom in Organic Chemistry

Our results point toward the fact that the flipped classroom, as implemented in our course, had a significant effect on learning in organic chemistry, since students' grades improved with that pedagogy as compared with traditional teaching. Very similar exams were answered in the control and the flipped samples, and academic ability of students was controlled in both samples. The only modified factor was the type of pedagogy.

The actual pedagogical device designed for the implementation of the flipped classroom probably has a lot to do with this effectiveness. Indeed, pre-class, in-class, and post-class activities were all integrated to foster mastery in the subject matter. Pre-class videos were short and presented a "pause-solve-resume" feature as means to keep students engaged and reduce cognitive load, as they could go through them at their own pace (Abeysekera and Dawson, 2015).

It is important to remember that we chose not to check that the students had seen the videos by online or classroom tests. The responsibility of being well prepared for class thus lied with students, and even if this responsibility might not be have been taken as seriously by everyone, it was thought to improve self-discipline and the development of students' self-regulation skills (Adnan, 2017, p. 2).

The success of flipped classroom in general is probably dependent on students' self-directing learning skills (Estes et al., 2014). Since our study was conducted in a second-year course, students might have already developed such skills. The same results might not have been obtained by a similar implementation of the flipped classroom with younger students, for instance with first-year general chemistry students. However, with a similar pedagogical device, Ryan and Reid (2016) actually did not see overall improvement of grades in flipped general chemistry. One of the reasons might be the younger students' lack of self-regulation.

We therefore believe that it is not necessary, for second-year college students, to use coercive means to ensure that they watch the videos. The pedagogical device should be sufficient to make them feel that watching the videos is useful and necessary prior coming to class because of the face-to-face activities required from them.

It is recognized that several low-achieving students have less motivation than higher achievers (Horn, 2013) and that that lack of motivation might negatively impact their engagement in pre-class activities. However, our results show the best outcomes for low achiever students. Our interpretation of these results goes in the same direction as a comment made by chemistry professor Christopher J. Cramer, who explained the success of flipped classrooms by the willingness of students to watch videos, more so than reading the textbook prior coming to class. Professor Cramer says: "We're tricking the students into spending twice as much time on the material as they would have otherwise" (C. J. Cramer, reported by Arnaud, 2013). Low achievers, who might spend very few hours outside class doing homework in a traditional setting would have time, in a flipped setting, to do portfolio exercises in class. For some of them, the portfolio exercises might be the only ones they would do, which would still be several more than what they would do in a traditional setting. This extra time and extra practice likely explain the 10% increase of low-achieving students' grades in the flipped classroom.

Some authors propose that the effect researchers observe on students' grades in flipped classrooms probably has more to do to the active-learning setting of the class than the flipped setting in itself (Jensen et al., 2015). This might also be the case in this study. However, we simply implemented the flipped classroom as a model of active-learning environment. Other environments could have been considered, and this study only reports on that one.

Also, our flipped classroom had a higher structure than our traditional classroom, that is, students were graded more frequently, through the portfolio activities, and they had more time to talk to each other and to the professor during class. Increase in structure in the active-learning classroom was reported to have a different influence on some subpopulations, especially first-generation students (whose parents did not go to college) (Eddy and Hogan, 2014). It was proposed that this kind of classroom setting was beneficial because of extra time students devoted to course material and because of a culture of community in class instead of a competitive environment (Eddy and Hogan, 2014). Our classroom setting might also have benefited from these two factors. We did not collect data about parents' schooling for this study, but that could be an interesting question to pursue further.

All students would benefit from a higher time devoted to chemistry outside of class time. We did not verify how many hours students were doing homework in the traditional setting, so we cannot evaluate if they spend more time watching pre-class videos and practicing textbook exercises in the flipped classroom format, but we can postulate that this was the case. In the traditional classroom, students would still have to work the same textbook exercises but did not have to do any pre-class activities.

We were concerned that students in the flipped classroom would therefore have to spend too much time outside of class on our course so we questioned them on that topic in the online questionnaire. For a 5-h college course in Québec, students are expected to work 3 h outside of class each week, as specified by the Ministry of Education program (MELS, 1998, 2000). In average, students in the flipped classroom actually declared devoting around 3 h to the organic chemistry course each week, thus meeting that expectancy. Students may not spend as much time on homework in a traditional setting due to a lack of engagement. The time on task was probably increased with the flipped classroom, but the students still did not exceed the time requirements in the tasks we assigned them. The way our class was designed simply encouraged students to meet the required number of hours expected in the curriculum.

Furthermore, flipped classrooms can improve engagement and motivation because the learning environment they provide are more likely "to satisfy student needs for competence, autonomy and relatedness" (Abeysekera and Dawson, 2015, p. 7).

Another aspect of the effectiveness of our style of implementation of the flipped classroom was probably due to the opportunity, in each class, to provide formative assessment to the students through the portfolio exercises. Prompt feedback is one of the principles of good practice in undergraduate education (Chickering and Gamson, 1987) as it can help students to situate themselves in the learning of the content and it can help instructors monitor individual progression. The way our feedback was designed helped students answer the three questions suggested by Hattie and Timperley (2007): students can answer "Where am I?" by trying portfolio problems, which were designed for the students to be answered right after watching videos. By trying the problems, they had a feedback on the appropriateness of their note taking while watching videos, and by listening to other students' questions at the start of class, they had an appreciation of their level of understanding compared with other students. The question "How am I going?" was answered with the formative assessment of the portfolio exercises, as well as the direct feedback the professors gave students during the portfolio period in class. Finally, the question "Where to next?" was answered by some portfolios exercises that integrated notions from different chapters, for example, chemical synthesis problems. Indeed, videos and regular portfolio exercises were mostly compartmentalized by chapter, and the integration of these chapters constituted a unique challenge to the organic chemistry course. Consequently, by helping students answer these three questions, our flipped classroom approach built on the effective feedback model suggested by Hattie and Timperley (2007).

Students' Appreciation of the Flipped Classroom

Students had a very positive general impression of the flipped classroom course, but still several had critiques regarding certain aspects, mostly concerning the workload it implied. It is interesting to note that Yeung and O'Malley (2014), in their study of flipped classroom in physical chemistry, found that the principal advantage of the flipped classroom as reported by students was the flexibility this format offered to students, and that overall, students were less satisfied with the flipped classroom as with traditional teaching. Conversely, our students reported several positive aspects of the flipped classroom, such as the ease of receiving answers to their questions and the convenience of receiving regular formative assessment through the portfolio. This observation points toward the fact that it is not a single aspect of the flipped classroom (such as the flexibility it offers) that might be sufficient for students to develop an overall positive perception of this pedagogical approach. Our students, when asked if they liked the flipped classroom, considered all the aspects of the approach we set in place to form their opinion. This points toward our understanding of the flipped classroom as not merely a mode of distance education. Its most distinguishing feature, the videos, is not its most important aspect. Rather, it is an entire pedagogical approach developed around the ideal of the most effective use of in-class and homework time.

Some students reported not liking the flipped classroom, that is, 17% of students answered that they somewhat disliked it (12 out of 88) or very much disliked it (3 out of 88). This result cannot be related to student grades because of the anonymity of the appreciation questionnaire. However, results from other studies can shed light on this observation. McNally et al. (2016) classified students in a flipped classroom as either "flipped endorsers" or "flipped resisters." They reported that "although differences were found between those who endorse and those who resist flipped teaching environments (particularly in their expectations of higher education courses and engagement), this differentiation based on preferences did not correspond to differences in their final grades in a flipped course" (McNally et al., 2016, p. 292). This can explain why we saw such an increase in grades even if 17% of the students did have a rather negative impression of the approach. Since several students reported that the reason for not liking the flipped classroom was the extra workload it necessitates, it is possible that these supplementary hours spent preparing for class would be hours not spent on organic chemistry in a traditional setting.

This can further explain why low-achieving students were the ones benefiting the most from the flipped classroom. Indeed, as reported by Enfield (2013), low achievers are the most likely to report that watching videos outside of class takes too much time, with 42.9% of the bottom-third of their sample mentioned it to be too long, compared with 27% for the entire sample. It might point toward the fact that low-achieving students, who habitually spent less time working on the material at home, are the ones who find the workload heavier than usual and benefit the most from the flipped classroom approach.

Positive Aspects of Teaching in a Flipped Classroom Environment

We decided to try the flipped classroom approach back in 2013 because we saw its potential to free class time by pushing a part of traditional lectures outside of class. To this day, we still view this as the principal advantage of this type of pedagogy. We first thought that this free time could be used to have students practice problem solving while we would be there to help them if need be, contrary to traditional homework. This was exactly what we did, but we did not realize that this free time meant much more than just having students practice in class. Smith describes very aptly what this time is also used for: "much more time was available for explanation, interaction, and conveyance of insight than had been in the past" (Smith, 2013). We now have more time to explain concepts in detail, to present relationships between notions and to provide concrete life examples to increase the relevance of studied topics for students.

Furthermore, we noticed a really significant difference in the time students spent in our office during office hours. Even if this observation is somewhat anecdotal, it is still relevant. When we taught in a traditional setting, we used to receive students during office hours to answer their questions, help them with homework, etc. During a normal week, around five to seven students would come, for a total of 2–3 h of individual consultation each week. By offering more of these interactions in class using the flipped approach, virtually no students come during our office hours anymore. This is a real advantage to all students, since some of them are not comfortable or motivated enough to come talk to their professor outside of class time. Now, all students can ask their questions during class time and benefit from others' questions. This might also be a factor explaining why low-achieving students benefit the most from this approach, since that type of student seldom used to come to office hours.

Downside for Teaching in a Flipped Classroom Environment

The principal disadvantage of teaching in a flipped classroom environment is the enormous amount of time its implementation necessitates, which was also reported by other instructors and researchers (Enfield, 2013; O'Flaherty and Phillips, 2015).

As seen with this study, co-teaching did not influence students' grades. It might then be seen as an investment that is not worth the time needed. Yet this is what allowed the implementation of the flipped classroom. We found early on that working as a team on the design of the pedagogical device, which includes videos but also all the in-class activities, as well as formative assessment of these activities, can alleviate the heavy workload needed.

It should be noted that the investment in time is only necessary during implementation. During the subsequent years, a minimum amount of time was necessary to further the bank of videos since most of them were filmed already, and several office hours were then freed since most students were asking their questions during class time. Office hours were therefore used for formative assessment and improving in-class activities, for example.

Recommendations for Teaching

O'Flaherty and Phillips (2015) deplored, in their review of the literature on flipped classrooms in higher education, that several authors reported on the positive results of the flipped classroom without providing design recommendations for its implementation in small undergraduate classes. Based on the results of this study, we are providing such guidelines (Awad et al., 2017) for educational videos to be used in a flipped classroom environment, with the following main features:

- Keep videos short (6 min).
- Use informal tone of voice, speak enthusiastically.
- Address your students directly to engage them.
- Use signalization (e.g., subtitles) on screen.
- Keep videos simple, avoid complex background or music.
- Provide "pause-solve-resume" features within videos to have students apply their knowledge immediately.

The results of this study also provide the opportunity of suggesting the following recommendations that focus specifically on the need of adequacy between pre-class and in-class activities:

- Every video watched pre-class must be used in an in-class activity.
- Some class time must be reserved to answer students' questions about videos.
- In-class activities must necessitate or encourage collaboration and interaction between students, and between professor and students.
- In-class activities must be devised in a way that allows verification of the completion of pre-class activities.
- Coercive measure to verify completion of pre-class activities might not be necessary with already self-regulated students but probably are with younger/less self-regulated students.
- "Redoing" lectures that were seen in video should be avoided, at the risk of students stop watching videos prior class over time.
- A significant portion of class time should be devoted to active-learning activities (not to lecture).
- In-class activities must be achievable without the express help of the instructor, but the instructor should be available to provide help on demand.
- In-class activities should be the opportunity of giving formative assessment or other form of feedback to help students monitor their progression.
- Faculty should work as a team to implement the flipped classroom, since a lot of time will be necessary.

Other researchers provide relevant recommendations, some of them are noted here:

- Redesign the course to foster active learning, for example, by selecting topics for classroom discussions (Albert and Beatty, 2014).
- Foster students' participation by creating incentives (Albert and Beatty, 2014).
- Explain the flipped classroom model to your students to diminish their resistance (Albert and Beatty, 2014; Estes et al., 2014).
- Flip the entire course (McNally et al., 2016).

The implementation of the flipped classroom as we suggested through this article respects all seven principles for a good undergraduate education as listed by Chickering and Gamson (1987): "1. Encourages contact between students and faculty 2. Develops reciprocity and cooperation among students. 3. Encourages active learning. 4. Gives prompt feedback. 5. Emphasizes time on task. 6. Communicates high expectations. 7. Respects diverse talents and ways of learning" (p. 3).

Recommendations for Future Research

This research considered students' grades and questioned them on their appreciation of the course, but since the questionnaire was anonymously answered, no correlation between grades and appreciation could be measured. Future research could concentrate on elucidating this point, as suggested by O'Flaherty and Phillips (2015): "future research should consider the relationship of other indicators of student engagement in the flipped class (not just examination scores)" (p. 94). Moreover, the effect of the flipped classroom could be evaluated in a true experimental setting, with randomized attribution of students in control and experimental samples. The difficulty of working with a control sample in parallel to a flipped classroom would be the leaking of videos that probably would occur if they were hosted on a public platform such as YouTube. This aspect of design should be considered if such an evaluation would be envisioned.

ETHICS STATEMENT

Academic Dean office of Cégep André-Laurendeau approved the study. Students were informed that their course would be evaluated for effectiveness. Results collected for this study did not include students' identification, but only their *R*-Score, organic chemistry grade, and their sex. Data were provided by the institution's admission service through a list of file numbers. No analysis necessitated students' identification. Appreciation questionnaires were answered anonymously and on a volunteer basis. Students were informed that their answers might be used for publication, but that no information that might identify them would be disclosed.

AUTHOR CONTRIBUTIONS

CC and BV both conducted the research and taught the classes described in the article. They analyzed the data, discussed results, and drew conclusions. They both participated in the creation of the qualitative instrument and in the data collection. CC wrote the paper and BV reviewed and expanded it.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.