When teacher-centered instructors are assigned to student-centered classrooms

Nathaniel Lasry,^{1,2} Elizabeth Charles,^{2,3} and Chris Whittaker⁴

¹*Department of Physics, John Abbott College, Montreal, Canada H9X 3L9*

²*Center for the Study of Learning and Performance, Concordia University, Montreal, Canada H3G 2V8*

³*Dawson College, 3040 Rue Sherbrooke W, Montreal, Canada H3Z 1A4*

⁴*Department of Physics, Dawson College, 3040 Rue Sherbrooke W, Montreal, Canada H3Z 1A4*

(Received 30 June 2013; revised manuscript received 6 March 2014; published 21 May 2014)

Technology-rich student-centered classrooms such as SCALE-UP and TEAL are designed to actively engage students. We examine what happens when the design of the classroom (conventional or teacher-centered versus student-centered classroom spaces) is consistent or inconsistent with the teacher's epistemic beliefs about learning and teaching (traditional or teacher-centered versus student-centered pedagogies). We compare two types of pedagogical approaches and two types of classroom settings through a quasiexperimental 2×2 factorial design. We collected data from 214 students registered in eight sections of an introductory calculus-based mechanics course given at a Canadian publicly funded two-year college. All students were given the Force Concept Inventory at the beginning and at the end of the 15-week-long course. We then focused on six teachers assigned to teach in the student-centered classroom spaces. We used qualitative observations and the Approaches to Teaching Inventory (ATI), a self-reported questionnaire, to determine the teachers' epistemic beliefs (teacher-centered or student-centered) and how these beliefs affected their use of the space and their students' conceptual learning. We report four main findings. First, the student-centered classroom spaces are most effective when used with student-centered pedagogies. Second, student-centered classrooms are ineffective when used with teacher-centered pedagogies and may have negative effects for students with low prior knowledge. Third, we find a strong correlation between six instructors' self-reported epistemic beliefs of student centeredness and their classes' average normalized gain ($r = 0.91$; $p = 0.012$). Last, we find that some instructors are more willing to adopt student-centered teaching practices after using student-centered classroom spaces. These data suggest that student-centered classrooms are effective only when instructors' epistemic framework of teaching and learning is consistent with a student-centered pedagogy. However, the use of the student-centered classrooms may change instructors' epistemic frameworks over time. Further research should focus on how to better support teachers with shifting epistemic frameworks as well as helping students with lower prior knowledge in student-centered classroom spaces.

DOI: [10.1103/PhysRevSTPER.10.010116](https://doi.org/10.1103/PhysRevSTPER.10.010116)

PACS numbers: 01.30.Ib, 01.40.Fk, 01.40.gb, 01.50.H-

I. INTRODUCTION

It has become somewhat of a truism that students who are actively engaged will learn better than students who passively listen to lectures [1–4]. One of the main goals of technology-rich collaborative classroom architectures (like North Carolina State's SCALE-UP or MIT's TEAL classrooms) is to design a classroom environment that optimizes student engagement with the course content and with each other [5–8]. We will relabel these student-centered designed learning spaces as sociotechnological classrooms [9] to highlight their emphasis on student collaboration and educational technologies and to avoid discussing the differences between various implementations.

Sociotechnological classrooms differ from conventional classrooms in a number of ways. Conventional classrooms are designed around a transmission model of teaching—instructors are experts that transmit knowledge to the less knowledgeable (and presumably receptive) students.

Hence, conventional classrooms are teacher centered by design—an instructor is in front of the classroom and all students face the instructor. In contrast, sociotechnological classrooms are student centered by design. There may not be a “front” of the classroom *per se*—students sit in small groups, generally facing each other around a table. Sociotechnological classrooms facilitate student collaboration, making peer interactions substantially easier than in conventional classrooms. Additionally, they make use of technologies that facilitate peers working together on shared problems. The construction of such shared problem spaces [10] is designed to promote the coconstruction of knowledge [11–13] through the use and production of jointly shared artifacts [14,15].

Published by the American Physical Society under the terms of the Creative Commons Attribution 3.0 License. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI.

II. RESEARCH QUESTIONS

Instructors differ in their conception of teaching [16–18]. Some instructors may view teaching as a process centered on what the teacher does (teacher centered) while others will view the process as being centered on what students do (student centered). We consider these kinds of teachers' beliefs as their *epistemic framework of teaching and learning*. Sociotechnological classrooms are designed and have been shown to facilitate student-centered learning [5–8]. The central question we pose is, What is the interaction between the design of learning spaces and teachers' epistemic frameworks of their students' conceptual learning? This leads to the title question of our paper: What happens when teacher-centered instructors are assigned to student-centered classrooms?

Having asked if the effectiveness of sociotechnological classroom designs depends on the instructor's epistemic framework, we turn to the question of whether their effectiveness depends on their students' prior knowledge. Sociotechnological classrooms provide technologies with multiple modalities of learning and a rich social context. The affordances of sociotechnological classrooms are designed to distribute knowledge across students and technology. However, these affordances might increase the cognitive load [19–23] of students with lower prior knowledge who may struggle to coordinate between the various modalities of the technology while navigating the inherent social context of the classrooms. Though it may be difficult to distinguish between lower prior knowledge due to a lower working memory capacity or due to never having studied physics, compensating for lower prior knowledge may be an important factor in the cognitive load. We therefore treat the question empirically and ask, What is the effect of prior knowledge on conceptual learning in student-centered pedagogies and in sociotechnological classrooms?

Last, we assess instructors' views of learning and how they change. We ask, Is there a link between instructors' self-reported epistemic framework (student centeredness or teacher centeredness) and their students' conceptual learning? We also document qualitatively changes in instructors' perception of learning after having used sociotechnological classrooms.

III. METHODS

A. Instruments

1. Force Concept Inventory

Students' conceptual learning was assessed using the Force Concept Inventory (FCI) [24] during the first and last week of the term. We used the FCI mainly because it is among the most studied and widely used instruments in physics education research [25] and because it is (somewhat surprisingly) reliable [26]. We then calculated average normalized gains for each student in each section [2,27].

While normalized gains have been widely used in physics education, the standard approach in education research is to use an analysis of covariance (ANCOVA) to compare differences in post-test scores between groups while correcting for their pretest scores. Given that normalized gains do not follow a normal distribution pattern, we may expect differences between analyses done with ANCOVA and those done with normalized gains. We show normalized gains side by side with ANCOVA results and find that they are generally congruent, though occasional differences occur.

2. Approaches to Teaching Inventory

Instructors participating in the second phase of this study were asked to complete the Approaches to Teaching Inventory (ATI) [16]. The ATI was developed from qualitative studies that found a substantial relationship between teaching orientation and the student's approach to learning [28,29]. Specifically, students who perceived their teachers as using a transmission approach often used a surface approach to their learning, while those who perceived their teachers as using a facilitator of learning approach used a deep learning approach. The first instrument developed was a 16-item inventory to capture the varying approaches to teaching used in higher education [16]. Further research on the instrument has resulted in the current 22-item inventory [30,31].

The 22-item ATI is a self-report instrument that assesses the degree of student and teacher centeredness. The 22 items can be broken down into two subscales of 11 items. The first subscale assesses how conceptual change and student focused (CCSF) the instruction is. The second subscale assesses to what extent the instruction is centered on information transmission and teacher focus (ITTF). An example of a CCSF question is, "*A lot of teaching time in this course should be used to question students' ideas.*" An example of an ITTF question is, "*I provide the students with the information they will need to pass the formal assessments.*" The ITTF and CCSF scales are fairly reliable with Cronbach's alpha 0.73 and 0.75, respectively [16]. In a study done in 2006, Prosser and Trigwell [30] collected ATI data from approximately 1000 university instructors of various disciplines in four different countries. Their factor analysis revealed a two-factor structure consistent with the two ITTF and CCSF subscales.

Other studies that have used the ATI to investigate the relationship between teaching and learning show that the teaching approach, at the level of the class, affects students' approach to learning [17,32,33]. Additionally, there is evidence that taking a surface approach to learning is strongly and positively correlated with an information transmission and teacher-focused approach to teaching. At the same time, taking a deep approach to learning is positively correlated to a conceptual change and student-focused approach [33].

We find the ATI interesting because instructors answer simple questions that allow researchers to assess how teacher centered or student centered their instruction is. We therefore use the ATI to assess the epistemic beliefs about teaching.

B. Study design

1. Phase one

We used a quasiexperimental 2×2 factorial design to compare two pedagogical approaches (student centered versus teacher centered) and two forms of classroom designs (conventional versus sociotechnological) using as our outcome measure students' conceptual learning as measured by the FCI [24].

We observed six instructors' pedagogical approaches qualitatively in the semester prior to the study. A qualitative assessment was done by adapting a rubric [34,35] to identify the extent to which instructors used student-centered strategies. We then classified teachers as either student centered or teacher centered independently of the ATI. When categorizing dichotomously as either student centered or teacher centered, our observations matched the results obtained with the ATI.

2. Sample

We studied eight sections of a first semester introductory calculus-based mechanics course in a publicly funded Canadian two-year college. Introductory mechanics courses typically have enrollments of over 500 students. In our institutions, these courses are broken down into smaller sections, each with its own instructor. Each instructor is assigned a section that can have anywhere between 30 and 45 students.

In quasiexperimental studies such as ours, students are not randomly assigned to treatment groups. However, in first year courses our registrar arbitrarily assigned all first semester students to a section of the course and was unaware that different sections would be exposed to different instructional contexts. No statistical differences in pre-FCI scores ($p > 0.4$) were found between the four conditions studied ($N = 214$); see Table 1.

TABLE I. Number of students, sections, and teachers in the four conditions studied.

	Sociotechnological classroom	Conventional classroom
Student-centered active learning	$n_{\text{students}} = 56$ $n_{\text{sections}} = 2$ $n_{\text{teachers}} = 1$	$n_{\text{students}} = 49$ $n_{\text{sections}} = 2$ $n_{\text{teachers}} = 1$
Teacher-centered instruction	$n_{\text{students}} = 51$ $n_{\text{sections}} = 2$ $n_{\text{teachers}} = 2$	$n_{\text{students}} = 58$ $n_{\text{sections}} = 2$ $n_{\text{teachers}} = 2$

3. Phase two

We focused on six teachers who agreed to participate in this phase of the research and were assigned to teach in the sociotechnological classrooms. Three of these instructors were not part of the first phase of our study. Ethnographic methods were used to conduct classroom observations that included field notes as well as audio and video recordings. The field note data were coded using the method described below to determine the teachers' epistemic beliefs about teaching and learning, and the students' types of engagements.

Two members of the research team carried out classroom observations of the six participating instructors—four observations per teacher spread throughout the first half of the semester. We used five-minute intervals for coding the beginning and end of events. We defined a change in activity as a point at which the teacher and/or the students changed their focus of attention. Every shift in activity was coded within the five-minute period. Two or three indicators (signals) were coded simultaneously within a time interval. For example, we coded what the teacher was doing and how the students were responding. Therefore, if the teacher was lecturing we would indicate “lecture” and look simultaneously to see whether the students were “attending/listening” or “asking questions” or “off task/sleeping” and so on. If the teacher or students changed their activity during the five-minute block, that change was noted as an additional code. We recorded the variations in the quality and quantity of engagement in a given class from the number of codes used as well as the quantity of each code.

Both coders attended several of the same classes and separately coded their observations. They discussed their differences at the end of each session and came to consensus on the meaning of the codes (refining the code key) and/or added or deleted certain codes (modifying the code list). Inter-rater reliability on a training portion of the coding schema was 87%. This was based on the two raters coding an overlapping 25% of data. After this training process, one coder subsequently collected the majority of the observations using the agreed upon coding rubric. We also collected postinstruction reflections from debriefing sessions with instructors after each class observed. Those notes completed and confirmed the accuracy of our classroom field notes.

All six teachers were also asked to complete the self-report ATI questionnaire to gauge their perception of how teacher centered or student centered their instruction was. We then compared the resulting ATI scores with our classroom observations to verify whether teachers' self-reported perceptions matched our observations. We then determined the correlation between the teachers' ATI scores and their students' conceptual learning, as measured by the average class normalized gain.

Last, we documented qualitatively how the teachers' epistemic beliefs evolved over time using a series of three

teacher interviews, each conducted at the end of three consecutive teaching semesters. Interview questions consisted of closed and open-ended questions designed to assess perceptions and gather recommendations for iteratively improving the use of the sociotechnological classroom.

IV. RESULTS

A. Classroom design and teachers' epistemic framework

We compare conceptual learning across the four conditions shown in Table 1. Students instructed by teachers that used student-centered pedagogies achieved statistically significantly larger normalized gains than students in traditional teacher-centered instruction ($g = 0.44$ vs $g = 0.24$; $p < 0.001$).

We also compare the difference in normalized gains between students in both types of classroom settings. Students in sociotechnological classrooms achieved normalized gains of $g = 0.32$, whereas students in conventional classrooms achieved normalized gains of $g = 0.36$. The marginal difference was not statistically significant ($p = 0.71$) and suggests that students' conceptual gains do not depend on the classroom setting alone. We reanalyzed these data using an ANCOVA (see Fig. 2) and found very similar results to those found with normalized gains.

Figures 1 and 2 compare our four groups on normalized gains and ANCOVA adjusted mean post-FCI score, respectively. Both figures suggest that pedagogy has a significant effect while the classroom architecture by itself does not. Note that sociotechnological classrooms yield both the greatest and the smallest changes in conceptual learning. The largest gains are found in sociotechnological

FIG. 1. The difference pedagogy makes on conceptual normalized gain is significant. Classroom settings alone do not contribute significantly to conceptual gain. Error bars represent the standard error to the mean.

FIG. 2. Independent of classroom type, students in active learning pedagogies have significantly greater mean post-FCI score, when adjusted for pre-FCI score. Classroom settings alone do not contribute significantly to end of semester conceptual knowledge. Also, students in traditional pedagogies achieve better results in conventional classrooms than in sociotechnological classrooms. Error bars represent the standard error to the mean.

classrooms that use student-centered active learning pedagogies while the smallest normalized gains are also found in sociotechnological spaces, but in those that use teacher-centered pedagogies. Taking the error bars into consideration, Fig. 2 also shows that students in teacher-centered conventional classrooms have significantly greater ANCOVA adjusted mean post-FCI scores than students in teacher-centered sociotechnological classrooms. This suggests that using sociotechnological classrooms with teacher-centered pedagogies may be counterproductive.

B. Effect of prior knowledge on pedagogies

To measure prior knowledge, we analyzed the distribution of beginning-of-term FCI scores among the 214 students participating in the four conditions studied. The distribution appears normal, has a mean of 10.3/30 (34%), and a standard deviation of 4.4 (15%). We split the population according to a standard deviation (SD) around the mean. Students above one-half a SD from the mean (pre-FCI score $\geq 13/30$; $N = 56$) were categorized as having higher conceptual knowledge, those below one-half a SD from the mean (pre-FCI score $\leq 8/30$; $N = 58$) were labeled as having lower conceptual knowledge, and those lying within one SD around the mean ($8/30 < \text{pre-FCI score} < 13/30$; $N = 100$) were labeled as having medium conceptual knowledge. This process resulted in roughly 25% of students being labeled as low incoming conceptual knowledge, 50% as medium, and 25% as high.

Normalized gains and post-FCI (ANCOVA adjusted) mean score are shown in Figs. 3 and 4 for students with low, medium, and high prior knowledge when exposed to student- or teacher-centered instruction. Both figures reveal

FIG. 3. Students in active learning student-centered pedagogies achieve higher normalized gains than students in traditional teacher-centered instruction regardless of whether they have low, medium, or high prior knowledge. Error bars represent the standard error to the mean.

FIG. 4. Students in active learning student-centered pedagogies achieve higher post-FCI mean scores (ANCOVA adjusted for pre FCI) than students in traditional teacher-centered instruction. However, the difference in achievement for high prior knowledge students is not statistically significant. Error bars represent the standard error to the mean.

the effectiveness of student-centered learning pedagogies over teaching-centered pedagogies.

Figures 3 and 4 show that student-centered pedagogies are effective independently of incoming knowledge. These data show once again that pedagogy is paramount because regardless of incoming knowledge, students exposed to student-centered active learning pedagogies achieve greater conceptual gains and have larger mean (ANCOVA adjusted) post-FCI scores than students in teacher-centered instruction. The impact of the pedagogy is weakest for students with high prior knowledge. Indeed, Fig. 4 shows no significant difference between pedagogies for students with high prior knowledge.

FIG. 5. Differences in normalized gain for students with low, medium, and high prior knowledge in either sociotechnological or conventional classrooms. Error bars represent the standard error to the mean.

FIG. 6. Differences in mean post-FCI score for students with low, medium, and high prior knowledge in either sociotechnological or conventional classrooms. Error bars represent the standard error to the mean.

C. Effect of prior knowledge on classroom design

We analyze the effect of prior knowledge on the type of classroom setting, independently of the pedagogy used. Figures 5 and 6 show that the difference between sociotechnological and conventional classrooms is not statistically significant for students with medium prior knowledge (roughly 50% of our sample). Sociotechnological classrooms may offer a small advantage for the upper quartile, though no statistical differences are observed in normalized gain or adjusted FCI score. The data for the lowest quartile, however, are clear and consistent: students with lower background knowledge (lowest quartile in prior knowledge) achieve better results in conventional classrooms.

The result that conventional classrooms may be more effective than sociotechnological classrooms led us to ask whether the statistical difference observed in low prior

knowledge students was due to a hidden effect of pedagogy. We therefore looked at the subset of students with low prior knowledge that were in *teacher-centered* pedagogies. We find no sizable difference in the normalized gains achieved by students in sociotechnological classrooms and those in conventional classrooms ($g_{\text{sotech}} = 0.24$, $N = 21$; $g_{\text{conv}} = 0.27$, $N = 13$). Looking at the subset of students with low prior knowledge that were in student-centered pedagogies, we find that students in conventional classrooms achieve greater normalized gains than students in sociotechnological classrooms ($g_{\text{sotech}} = 0.42$, $N = 7$; $g_{\text{conv}} = 0.59$, $N = 17$). However, given the remaining small sample sizes (in particular, only seven students in the group of lower prior knowledge students that were in student-centered pedagogies and in conventional classrooms), we lack the statistical power to determine whether the differences due to the pedagogy are statistically significant.

D. Classroom observations and ATI

Over the course of the semester, we made 39 observations of roughly 80-minute classes. Each 80-minute class was broken down into 16 five-minute blocks. We found an average of 71.7 discrete activities or events per observation ($SD = 15.0$; mode = 78), providing a total of 1649 discrete coded activities. We quantified this corpus of qualitative data to characterize instructors as more teacher or student centered. We then compared these data with the teacher's self-reported ATI data. We do not present detailed qualitative findings due to space limitations, but note that our qualitative breakdown of teacher- or student-centered instructors was identical to the breakdown provided by instructors' ATI score.

E. Instructors' epistemic frame and students' conceptual learning

We find a link between the pedagogy used and students' conceptual learning. Instructors' beliefs may shape the pedagogy they use. Thus, we analyze the correlation between the six instructors' self-reported epistemic framework of learning and teaching as measured by the ATI subscales (CCSF and ITTF scales) and the average FCI gain for their class. We do not find a significant correlation between these six teacher's score on the teacher-centered subscale ITTF ($r = 0.33$; $p > 0.2$) and the normalized gain of that teacher's class. However, we do find a large and statistically significant correlation between these six instructors' score on student centeredness subscale (CCSF) and the average FCI normalized gain for their class ($r = 0.91$; $p = 0.012$). These results suggest that a large part of the variance ($R^2 = 0.83$) in average FCI gain for a class can be related to the instructor's own perception of their student centeredness, but not their teacher centeredness.

F. Teachers' views of redesigned classrooms

We conducted interviews of the six instructors on their appreciation of the sociotechnological designs. The interview consisted of seven semistructured questions focused around four themes: (1) perceptions of learning and how that may have changed over the years, (2) attempts to design learning for the sociotechnological environment, (3) perception of the relationship between teaching and learning, and (4) perception of themselves as teachers. Each interview lasted approximately 45 minutes and was video recorded. Recordings were transcribed.

The interview data show that not all teachers were encouraged to change their practices or were willing to use the opportunities of the new technology. Instead some lamented the room's design and perceived that it placed constraints on their teaching, or on how they believed their students should be learning. One of these teachers expressed this as follows:

COMMENT 1: For presenting material, I much prefer [the conventional classroom]. The students are closer to the podium. In [the socio-technological classroom], my experience was that the students at the farthest table from the front, back centre table, had a lot of difficulty staying connected with what was going on in the class, even though they had a clear view of the material projected for them on the back corner screen. (...) They spontaneously moved the desks today to form "rows" and were quite happy.

Over time, most teachers interviewed voiced a willingness to modify their teaching practices and to design ways to integrate the new technology into their instruction. Specifically, when asked whether they perceived a need to change their teaching, half of the instructors surveyed reported they felt the new space gave them a push to try new ways of teaching.

COMMENT 2: The way I see it, these new labs give a myriad of new possibilities and flexibility to the teacher. Therefore this technology gives me an edge; it allows me to optimize what I do.

COMMENT 3: [I'm now telling colleagues] Jump off the cliff. It is not as tall as you fear.

The instructor who made the biggest changes to his thinking reported that the design of the new space and the technology encouraged him to reduce the amount of teacher-centered presentations and increase the amount of student-to-student interactions with activities such as group problem solving. For instance, he began to give his students permission to use the digital whiteboard technology, thereby providing them with a new sense of authority and new ways to participate in his class. He reports that his

students grew to enjoy this way of contributing so much that they looked forward to it and “*literally fought to go to the whiteboard.*” He no longer views his teaching as only designing presentations that transmit knowledge and now also designs ways to engage students in multiple ways of knowing and thinking.

COMMENT 4: [Now] It's completely different ... when I get them to do an activity it's not like you have to encourage them to actually do it. They just go right in. In fact it's hard to stop them. The problem now is that once they get going they don't want to stop. Um so, so yeah there's been a complete difference.

V. DISCUSSION

A. Effect of pedagogy but not classroom design

When designing technology-rich classrooms, teachers and administrators often assume that the technology will enhance students' learning. Empirical studies of technology-rich student-centered spaces have shown benefits such as more meaningful construction of knowledge and deeper understanding [5–8]. A recent study at the University of Minnesota compared the effect of the classroom design on student learning by studying one instructor who taught both in a conventional classroom and in a sociotechnological classroom [36]. The study concludes that “space matters” because students in sociotechnological rooms achieve more learning than expected. Although carefully done, this study was not designed to assess what happens when the teachers' views are not aligned with the intent of the design. To our knowledge, no other study has explored the use of sociotechnological spaces by instructors who may not hold epistemic frameworks that are consistent with the student-centered pedagogy these spaces support.

Our results show the primacy of pedagogy: student-centered active learning pedagogies produce larger normalized gains than teacher-centered pedagogies, regardless of the classroom architecture. We find no added value when looking only at classroom architectures (see Figs. 1 and 2). This finding is consistent with past findings on educational technology, namely, that technology itself is not a surrogate for good instructional design and pedagogy [37–40].

Our data also show that sociotechnological classroom designs have both the highest and lowest gains. We find the highest gains in sociotechnological rooms that were used with student-centered pedagogies and the lowest gains in sociotechnological classrooms that use teacher-centered pedagogies. The data in Fig. 2 suggest that sociotechnological environments may have negative effects on students' learning outcomes if used with teacher-centered pedagogies. Teacher-centered instructors that only wish to lecture may be more effective in conventional classrooms. However, greater learning gains can be achieved if teachers come to view learning as a student-centered process.

B. Students with lower prior knowledge

Looking at the beginning-of-term FCI scores, we find that student-centered pedagogy is more effective than teacher-centered pedagogies, regardless of whether students' prior conceptual knowledge is high, moderate, or low. Yet, we find that students with low prior knowledge achieve less conceptual learning in sociotechnological classrooms. Note that the mean FCI score in our sample of two-year college students is already relatively low at 34% (10.3/30). Students with lower prior knowledge were defined as students below half a standard deviation below the mean, that is, having an initial FCI score of 27% or lower, not far from the score students would get by random guessing.

We are not quite certain how to interpret these data. One possibility is that students with low prior knowledge are more sensitive to cognitive load issues [22,41]. Although students with lower prior knowledge in conventional classrooms must contend with a greater number of concepts, they need not attend too much to the classroom context. That is, in conventional classrooms, the script is simple: The instructor speaks while students listen and take notes. In sociotechnological classrooms, there is a rich context that affords learning from a host of resources both human and digital. Some activities are individual, others collaborative, and yet others class wide. Some activities are done in person, others are computer based, and yet others are done online. Students are also asked to produce artifacts that are material, digital, or both [42]. Students with lower prior knowledge may view the tasks assigned as more complex and may thus have more difficulty attending to the affordances that sociotechnological rooms present. Indeed, if the complexity of the tasks assigned overloads some students cognitively, the context richness of sociotechnological classrooms may become an impediment to their learning. Thus, our findings may point to an implicit need for careful design and enactment of properly scaffolded learning activities in sociotechnological classrooms to support the learning of lower prior knowledge students. Some are calling this type of instructional design *classroom orchestration*. Orchestration provides a layer of planning and real-time classroom management that could better support how students navigate the context-rich sociotechnological environments [42–44].

What do these results mean for teachers? They suggest that the students' learning outcomes are better when the teachers' epistemic beliefs are consistent with the design of the learning environment. Most importantly, they suggest that a student-centered pedagogy produces substantially more conceptual learning than traditional teacher-centered pedagogical approaches. Lastly, they show that if we are to use sociotechnologically designed classrooms successfully for all levels of students and with teachers who may be in the process of learning how to use new pedagogies, we will have to focus on forms of teacher support and professional

development. Such pedagogical development would have to include knowledge of how to better orchestrate [42–44] student-centered activities to reduce students' cognitive load [42–44].

C. Teachers' views of learning

We surveyed the six participating instructors using the Approaches to Teaching Inventory. Of the 22 items in the ATI, we analyzed scores on the 11-item subscale assessing instructors' conceptual change and student focus and the remaining 11 items assessing how information transfer and teacher focused they were. Interestingly, instructors do not view teacher centeredness and student centeredness as orthogonal. We find a high and statistically significant correlation between the average course normalized gain and the instructor's student-centered CCSF score but not with the teacher-centered ITTF score. This finding is consistent with a body of literature showing that a surface approach to learning is strongly and positively correlated with an information-transmission and teacher-focused approach to teaching, while a deep approach to learning is positively correlated to a conceptual change and student-focused approach [17,32,33,45,46]. Nevertheless, we remain surprised to find such a high correlation between an instructor's self-reported beliefs and a measure of their students' learning. We find this result interesting and leave an in depth analysis of it for a later paper.

Finally, our qualitative data suggest that instructors do acknowledge how the sociotechnological classrooms facilitate student collaboration. However, instructors who want to lecture in the new rooms may find the design inadequate because they remove the teacher from the center and can impede conventional lecturing. Over time, a number of instructors were attracted by the possibilities offered by the sociotechnological classroom design. These instructors seem to have been "stimulated" by the sociotechnological design into rethinking their view of learning. Of the six instructors, two became highly proficient in the new classrooms and have become prime advocates of sociotechnological classroom designs.

VI. CONCLUSION

Sociotechnological classrooms are designed to promote student-centered learning. Sociotechnological classrooms are most effective when used with student-centered pedagogies. A major caveat is that such classrooms should not be assigned without careful considerations of the teacher's epistemic beliefs about teaching and learning. Even then, there are still concerns about how to design learning activities to keep in check the possible cognitive overload, particularly for students with lower prior knowledge. This is an issue that deserves further research. In particular, we will need to address the question of how to better orchestrate student-centered activities and further maximize the potential of these new spaces for all students.

A host of resources are required when building new classrooms. The emphasis is often placed on finding the financial resources to purchase the latest and best technologies. Yet, redesigned sociotechnological environments will not be effective unless resources are also directed towards helping instructors understand why and how to use student-centered pedagogies, thereby promoting a shift in their epistemic frameworks. To broaden the adoption of new pedagogical approaches and improve the use of new learning spaces, more research needs to be done on changing teacher's epistemic frameworks.

ACKNOWLEDGMENTS

This study was supported by a grant from the Province of Quebec's Ministère de l'Éducation Loisirs et Sports, through the Programme d'Aide à la Recherche sur l'Enseignement et l'Apprentissage (PAREA, Grant No. PA 2009-005). The authors would also like to acknowledge support from the Canadian Institute of Physics Education Research (CIPhER). Individual researchers also acknowledge support from their institutions, John Abbott College and Dawson College, as well as support from the Center for the Study of Learning and Performance, Concordia University, Montreal, Canada. We also thank Helena Dedic and Steven Rosenfield for their contributions in helping us analyze these data.

-
- [1] C. Crouch and E. Mazur, Peer Instruction: Ten years of experience and results, *Am. J. Phys.* **69**, 970 (2001).
 - [2] R. R. Hake, Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses, *Am. J. Phys.* **66**, 64 (1998).
 - [3] E. Mazur, *Peer Instruction: A User's Manual* (Prentice-Hall, Upper Saddle River, NJ, 1997).
 - [4] C. Wieman and K. Perkins, Transforming physics education, *Phys. Today* **58**, No. 11, 36 (2005).
 - [5] R. J. Beichner and E. R. I. Center, *Introduction to SCALE-UP: Student-centered activities for large enrollment university physics* (U.S. Department of Education, Office of Educational Research and Improvement, Educational Resources Information Center, 2000).
 - [6] R. J. Beichner, J. M. Saul, D. S. Abbott, J. J. Morse, D. L. Deardorff, R. J. Allain, S. W. Bonham, M. H. Dancy, and J. S. Risley, The Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) project

- in *Research-based reform of introductory physics*, edited by E. Redish (2007), www.compadre.org/per.
- [7] Y. J. Dori and J. Belcher, How does technology-enabled active learning affect undergraduate students' understanding of electromagnetism concepts?, *J. Learn. Sci.* **14**, 243 (2005).
 - [8] Y. J. Dori, J. Belcher, M. Bessette, M. Danziger, A. McKinney, and E. Hult, Technology for active learning, *Mater. Today* **6**, 44 (2003).
 - [9] S. Allaire, T. Laferrière, J. Gaudreault-Perron, and C. Hamel, Le développement professionnel des enseignants en contexte de mise en réseau de classes de petites écoles rurales: Au-delà de l'alphabétisation technologique, *J. Distance Educ. Rev. Educ. Distance* **23**, 25 (2009).
 - [10] J. Roschelle and S. D. Teasley, in *Computer Supported Collaborative Learning*, edited by C. O'Malley (Springer-Verlag, Berlin, 1995), pp. 69–97.
 - [11] J. Roschelle, Learning by collaborating: Convergent conceptual change, *J. Learn. Sci.* **2**, 235 (1992).
 - [12] M. Scardamalia and C. Bereiter, Computer support for knowledge-building communities, *J. Learn. Sci.* **3**, 265 (1994).
 - [13] L. Lipponen, in *Proceedings of the Conference on Computer Support for Collaborative Learning: Foundations for a CSCL Community*, 2002 (unpublished).
 - [14] W.-M. Roth and A. Roychoudhury, The concept map as a tool for the collaborative construction of knowledge: A microanalysis of high school physics students, *J. Res. Sci. Teach.* **30**, 503 (1993).
 - [15] G. Stahl, *Group Cognition: Computer Support for Building Collaborative Knowledge* (MIT Press, Cambridge, MA, 2006).
 - [16] K. Trigwell and M. Prosser, Development and use of the approaches to teaching inventory, *Educ. Psychol. Rev.* **16**, 409 (2004).
 - [17] K. Trigwell, M. Prosser, and F. Waterhouse, Relations between teachers' approaches to teaching and students' approaches to learning, *Higher Educ.* **37**, 57 (1999).
 - [18] M. F. Pajares, Teachers' beliefs and educational research: Cleaning up a messy construct, *Rev. Educ. Res.* **62**, 307 (1992).
 - [19] T. de Jong, Cognitive load theory, educational research, and instructional design: Some food for thought, *Instr. Sci.* **38**, 105 (2010).
 - [20] R. E. Mayer, *The Cambridge Handbook of Multimedia Learning* (Cambridge University Press, Cambridge, England, 2005).
 - [21] R. E. Mayer and R. Moreno, Nine ways to reduce cognitive load in multimedia learning, *Educ. Psychol.* **38**, 43 (2003).
 - [22] J. Sweller, Cognitive load during problem solving: Effects on learning, *Cogn. Sci.* **12**, 257 (1988).
 - [23] J. Sweller, Cognitive load theory, learning difficulty, and instructional design, *Learn. Instr.* **4**, 295 (1994).
 - [24] D. Hestenes, M. Wells, and G. Swackhamer, Force Concept Inventory, *Phys. Teach.* **30**, 141 (1992).
 - [25] L. McDermott and E. Redish, Resource letter: PER-1: Physics education research, *Am. J. Phys.* **67**, 755 (1999).
 - [26] N. Lasry, S. Rosenfield, H. Dedic, A. Dahan, and O. Reshef, The puzzling reliability of the Force Concept Inventory, *Am. J. Phys.* **79**, 909 (2011).
 - [27] L. Bao, Theoretical comparisons of average normalized gain calculations, *Am. J. Phys.* **74**, 917 (2006).
 - [28] L. E. Greeson, College classroom interaction as a function of teacher- and student-centered instruction, *Teach. Teach. Educ.* **4**, 305 (1988).
 - [29] D. Kember and L. Gow, Orientations to teaching and their effect on the quality of student learning, *J. Higher Educ.* **65**, 58 (1994).
 - [30] M. Prosser and K. Trigwell, Confirmatory factor analysis of the approaches to teaching inventory, *Br. J. Educ. Psychol.* **76**, 405 (2006).
 - [31] K. Trigwell, M. Prosser, and P. Ginns, Phenomenographic pedagogy and a revised approaches to teaching inventory, *Higher Educ. Res. Dev.* **24**, 349 (2005).
 - [32] J. Biggs, D. Kember, and D. Leung, The revised Two-Factor Study Process Questionnaire: R-SPQ-2F, *Br. J. Educ. Psychol.* **71**, 133 (2001).
 - [33] D. Kim and R. Branch, in *Proceedings of the Annual Meeting of the American Educational Research Association (AERA)*, New Orleans, LA, 2002 (unpublished).
 - [34] M. Piburn, D. Sawada, J. Turley, K. Falconer, R. Benford, I. Bloom, and E. Judson, *Reformed Teaching Observation Protocol (RTOP) Reference Manual* (Arizona Collaborative for Excellence in the Preparation of Teachers, Tempe, AZ, 2000).
 - [35] D. Sawada, M. D. Piburn, E. Judson, J. Turley, K. Falconer, R. Benford, and I. Bloom, Measuring reform practices in science and mathematics classrooms: The reformed teaching observation protocol, *School Sci. Math.* **102**, 245 (2002).
 - [36] D. C. Brooks, Space matters: The impact of formal learning environments on student learning, *Br. J. Educ. Technol.* **42**, 719 (2011).
 - [37] R. E. Clark, *Learning from media: Arguments, analysis, and evidence* (Information Age Publishing, Greenwich, CT, 2001).
 - [38] N. Lasry, Clickers or flashcards: Is there really a difference?, *Phys. Teach.* **46**, 242 (2008).
 - [39] N. Lasry, Clickers work well, so do flashcards: Two rights don't make a wrong, *Phys. Teach.* **47**, L2 (2009).
 - [40] E. Mazur and N. Lasry, in *Proceedings of the 2009 AAPT Winter Meeting*, Chicago (unpublished).
 - [41] F. Paas, A. Renkl, and J. Sweller, Cognitive load theory and instructional design: Recent developments, *Educ. Psychol.* **38**, 1 (2003).
 - [42] P. Dillenbourg, Design for classroom orchestration, *Comput. Educ.* **69**, 485 (2013).
 - [43] J. Roschelle, Y. Dimitriadis, and U. Hoppe, Classroom orchestration: Synthesis, *Comput. Educ.* **69**, 523 (2013).
 - [44] M. Sharples, Shared orchestration within and beyond the classroom, *Comput. Educ.* **69**, 504 (2013).
 - [45] J. Biggs, *Student Approaches to Learning and Studying* (Australian Council for Educational Research, Melbourne, 1987).
 - [46] Y. C. Kek, doctoral dissertation, University of Adelaide, 2006 (unpublished).