Using Online Synchronous Interschool Tournaments to Boost Student Engagement and Learning in Hands-On Physics Lessons

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Abstract. We present the results from a 90-min session in which 196 fourth grade students from 13 classes from 11 schools performed a series of engaging, hands-on activities. These four activities were designed to help students understand how rockets fly. During the activities, students use skateboards, toy cars, springs, balls, and water rockets to model the physics behind a rocket launch and predict the proportion of water that will lead to maximum elevation. A subset of the classes took a post-test involving 22 basic physics questions, presented in the form of a 60-min online synchronous interschool tournament. The other subset of classes also answered the same questions online in sixty minutes, though in this case they were not presented as a tournament. The students who participated in the tournament improved significantly more than the rest. Moreover, students with weak academic performance who participated in the tournament improved the most, reducing the gap with the academically stronger students. Lessons involving hands-on experiments using skateboards, toy cars and water rockets are already highly engaging. However, this experience shows that using technology to connect schools synchronously through an online tournament is a powerful mechanism for boosting student engagement and learning in core science concepts. Furthermore, we compared learning outcomes with a previous year face-to-face interschool tournament. With the online synchronous interschool tournament, students learned twice as much as they did with the face-to-face interschool tournament.

Keywords: Technology-enhanced learning · Affective and motivational effects · Interschool tournaments · Collaborative learning · STEM teaching and learning

1 Introduction

Teachers are facing enormous challenges due to several new demands. There are new, deeper and more cognitively demanding contents and practices to teach [1]. There is also an emphasis on using and developing crosscutting concepts. In addition to this, there are new requirements to increase integration among the different science disciplines, as well as integration with mathematics and other subjects [2]. Achieving such

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integration is not easy for teachers that have been educated in specific contents and trained to teach isolated subjects, with no strategies to connect with the content from other subjects. There is also increasing emphasis on implementing student-centered teaching strategies [3], teaching kids how to learn by themselves, and a hands-on approach to learning. Furthermore, there is also a demand to teach so-called 21st century skills [4]. These radically new skills are now highly valued and needed in order to create a competitive advantage, while older skills are becoming obsolete due to increased automation of the economy. This means that teaching teamwork and collaboration has become increasingly relevant, as well as developing students' interpersonal strategies, such as turn taking, social sensitivity and empathy [5]. On the other hand, all of these demands must be implemented in a completely new class environment, where students have ubiquitous access to individual mobile devices. These devices are loaded with highly attractive and addictive apps, such as messaging apps and online games. This means that the teacher is in constant competition for the students' attention. This competition inside the classroom is entirely new and incredibly powerful. Such competition simply did not exist, even just a couple of years ago. On the other hand, teachers have to teach to a more diverse population from wider cultural backgrounds and with increasing demands for social inclusion.

However, teaching practices have proven to be somewhat out of line with recent changes. Several studies of classroom practice show that almost no change has taken place over the last century [3, 6]. Teachers are used to teacher-centered strategies, and some of them can be very effective when using such strategies. For example, on the Programme for International Student Assessment (PISA), the top-performing Organization for Economic Co-operation and Development (OECD) countries use more teacher-centered teaching practices in mathematics than other countries [7]. This is a good strategy, one that can be considered as being locally optimal. Furthermore, it is a very well proven and robust solution. Leaving this local maximum requires huge leaps, and this can be risky.

In order to prepare and adapt to these challenges, teachers constantly receive methodological and technological suggestions. Recently, [8] suggest 26 effective teaching strategies. For some of them, there have been extensive empirical studies of their effect. For example, in a comprehensive study of science teaching, [9] studied 23 programs. Seven inquiry-based teaching programs using science kits did not reveal any positive outcomes in terms of student achievement in science (effect size of 0.02 standard deviations). Six programs that integrate video and computer resources and are based on cooperative learning revealed positive outcomes. Although these studies cover a wide range of strategies, none of them are based on the idea of interschool or interclass tournaments.

Using tournaments is an effective strategy that was first proposed in the seventies, albeit as an intergroup tournament within a single class [10]. However, this strategy has not been widely adopted by schools. Interclass or interschool tournaments are easier to handle for the teacher, since he/she is the coach of the whole class. Interschool tournaments are an effective engagement strategy that activates inter-group social competition and collaboration mechanisms. These social mechanisms are hardwired and were very powerful during hunter-gather tribal life [11, 12]. The hunter-gatherer brain is particularly well adapted to collaborating and learning from others in order to compete with neighboring groups. Cooperation is a very powerful weapon for competition. With interschool tournaments the strategy is to activate this social mechanism and the students' sense of belonging to their class or school [13–15]. Doing so boosts student engagement, collaboration, teamwork, and learning.

In this paper, we focus on a strategy based on student collaboration and social mechanisms to increase engagement. The strategy consists of online synchronous interschool tournaments. Such a strategy depends heavily on communication technology in order to link different classes and schools synchronously. The goal of this paper is to research whether existing levels of student engagement and learning with a tried and tested, hands-on lesson can be further enhanced using an online synchronous interschool tournament.

2 Methods

Since 2013, thirteen low Socio Economic Status (SES) schools from two districts in Santiago, Chile, have been developing a hands-on activity in fourth grade. This activity is carried out in a lesson based on what is known as "modeling instruction" [16], where students have to learn to use, adapt and build models. In this particular lesson, students do experiments using different models in order to understand how rockets fly. The students study a sequence of four experiments during a 90-min lesson. The main goals of the lesson are to help the students understand basic notions of physics, such as motion and forces, as well as some basic scientific practices, such as modeling, making predictions with models, using empirical measurements to validate or reject a model, explaining the results and carrying out a peer review process with the written explanations. One of the experiments involves jumping from a skateboard (Fig. 1). The students experiment by jumping under different load conditions, such as having different loads in their backpacks. This experiment is a modeling instruction activity, where the jumping student models the water, while the skateboard models the rocket. This experiment is an initial hands-on activity that introduces the students to the concept of the conservation of momentum. A second experiment involves balls and a toy car used as a cart, as shown in Fig. 1. This is another way of modelling water rockets, where the balls model the water, and the cart models the rocket. This experiment provides the students with a second view of the concept of the conservation of momentum. The third experiment involves a cart with a spring and a ball, as shown in Fig. 1. Students experiment using different numbers of balls, while reflecting on how this is similar to the water rocket. In this case, the cart models the rocket, the ball models the water, and the spring models the air pressure inside the plastic bottle (the rocket). The fourth experiment consists in throwing the bottle after pumping air to a certain pressure. This is done in 5 different conditions. Each condition corresponds to a fraction of water, which goes from without water, a quarter of water, half of water, three quarters of water, to the bottle filled with water. Each of the first 3 experiments takes about 15 min, but the last lasts 25 min.

Every year, the students take a pre-test and an identical post-test comprising 15 multiple-choice questions that look to measure conceptual understanding of each of the four experiments. Most questions have 5 options but some of them have 3, others 4 and

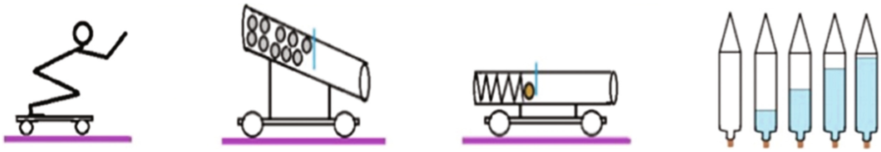

Fig. 1. Four types of question on the pre-test and post-test. For the first type of question, the students have to say in which direction and at what velocity will the skateboard travel. For the second type of question, they have to say where the cart will go and at what velocity when the balls are released under different conditions (i.e. number of balls). The third type of question asks the students where the cart will move when the spring is released under different conditions. Finally, the fourth question is about water rockets, such as the proportion of water that is needed in order to reach maximum elevation.

others 6 or more. Each question is graded on a scale of 1 (minimum) to 7 (maximum). This is the standard scale used in Chile. For questions 1 to 15, answering at random produces an average score of 2.1, whereas for questions 16 to 22 random answers lead to an average score of 2.2. Student performance on the pre-test has been only slightly above the results obtained by answering at random, although the difference is statistically significant. There are some questions with intuitive answers, where the level of the students' responses was well above the random score. However, other questions are more difficult. Therefore, the students' performance on these questions has traditionally been below the random score.

In 2016, there was a change in the activity, with the introduction of an online synchronous interschool tournament. The tournament was conducted using a STEM platform in the cloud. This is a platform where the classroom teacher and a remote teacher track student performance in real time, detect which students are having difficulty, and provide just-in-time support using a chat function included in the platform. This platform has the ability to synchronize whole courses from different schools to perform online and synchronous tournaments between schools.. In this paper, we analyze the effect of this technological intervention. The activity was held in November and December of 2016. A total of 367 fourth grade students took the pre-test during a single session. In the following 90-minute session, the students then went to a science lab to take part in the experimental lesson. This lesson included four experiments. During December, 239 students took the post-test. Several schools could not take the post-test during December due to time constraints that are typical at the end of the school year. In total, 196 students took both the pre-test and post-test. The statistics shown in this paper will be restricted to these 196 students. Of the 196 students, 88 were girls and 108 were boys. For the purpose of our analysis, we also classify students according to their academic performance. In order to do so, we use their Grade Point Average (GPA) for the year in science and math. Those with a GPA below their class average are classified as academically weak students, while the rest are considered academically strong. Therefore, using this classification method there are 96 academically weak and 100 academically strong students.

Not all schools could participate in the online synchronous interschool tournament. Given the time and scheduling restrictions, only three classes were able to participate.

Therefore, 31 students from these three classes participated in the online synchronous interschool tournament, while 165 students answered the same questions online using the same platform, although not in tournament mode.

It is important to note that during the pre-test and the 4 experiments conducted in the science lab the students knew that there was a tournament. However, they did not know whether they were going to be able to participate in the online synchronous interschool tournament. The classroom teachers also did not know whether their students would participate in the tournament. Nevertheless, all of them knew that their average performance was going to be automatically published on the online platform and listed alongside the average performance of the other classes. Throughout the year, the class' average performance in every session is automatically published on the online platform. Furthermore, it is listed alongside the average performance of the classes from the other schools.

As mentioned previously, this exact same lesson has been taught in the same schools since 2013. The only difference in this case was the inclusion of the online synchronous interschool tournament. In 2013, students did not participate in an online synchronous interschool tournament. However, they did participate in a face-to-face tournament that took place in the municipal gym. A total of 204 students participated that year and took the same pre-test and post-test as the students in 2016. The post-test was taken a couple of days before the tournament. We will therefore also compare the effects of both types of tournament.

3 Results

First, we analyze the results from 2016. As shown if Fig. 2, the 165 students that did not participate in the tournament (no tournament condition) performed only slightly better on the post-test when compared with the pre-test. In that sense, the learning is moderate. The effect size is 0.11 standard deviations and is statistically significant. On the other hand, the 31 students that participated in the online synchronous interschool tournament (tournament condition) enjoyed a high level of improvement. The effect size is 1.09 standard deviations, and it is also statistically significant. It is important to

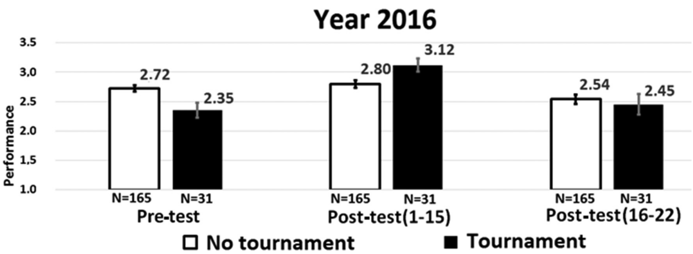

Fig. 2. Performance on the 15 questions on the pre-test and post-test, as well as the 7 extra questions on the post-test, for both the group of 167 students that did not participate in the tournament, as well as the 31 students that did participate in the online-synchronous interschool tournament.

note that the students who participated in the tournament did much worse on the pre-test than the other students. However, on the post-test they did much better. Nevertheless, on the 7 completely new questions (questions 16 to 22), which measure generalization and a deeper conceptual understanding, both groups performed similarly. Although there is a small difference, it is not statistically significant. Given the poorer performance on the pre-test by the students who participated in the tournament, the fact that the students performed similarly on questions 16 to 22 suggests that the improvement was greater for the online synchronous tournament group.

It is interesting to compare learning according to gender. As shown in Fig. 3, girls in the no tournament condition did not improve. The effect size is −0.02. However, in the tournament condition the effect size was 0.65. On the other hand, boys in the no tournament condition improved and the effect size was 0.25 standard deviations. However, boys in the tournament condition enjoyed a marked improvement. In this case, the effect size was 1.48 standard deviations.

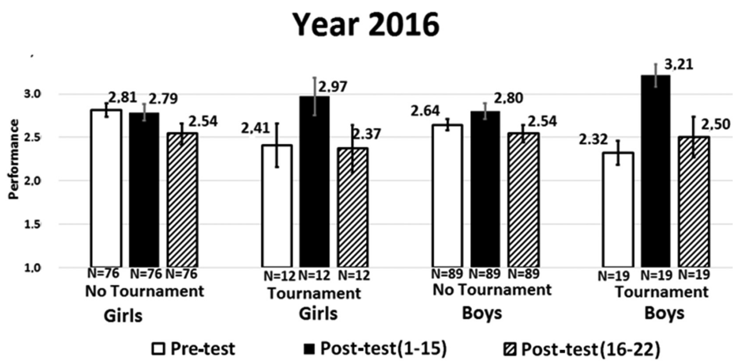

Fig. 3. Performance by boys and girls on the 15 questions included on the pre-test and post-test, as well as on the 7 extra questions on the post-test, for both the group of 167 students that did not participate in the tournament, as well as the 31 students that did participate in the online synchronous interschool tournament.

Let us consider the learning outcomes of the academically weak and academically strong students. As shown in Fig. 4, the academically weak students did not improve in the no tournament condition. However, they improved considerably in the tournament condition. In this case, the effect size was 1.24 standard deviations. On the other hand, the academically strong students improved in both conditions. The effect size for the no tournament students was 0.47 standard deviations, while for the tournament students the effect size was 1.06 standard deviations. It is also very interesting to note that even though the academically weak students in the tournament condition performed much worse on the pre-test than the academically weak students in the no tournament condition, they performed slightly better on the generalization questions (questions 16–22). Although the difference is not statistically significant, the tournament condition made it possible to close the gap that was present on the pre-test.

Now, we will compare the results obtained in 2016 with the results obtained in 2013. Although they are different students, all of them were fourth graders from the

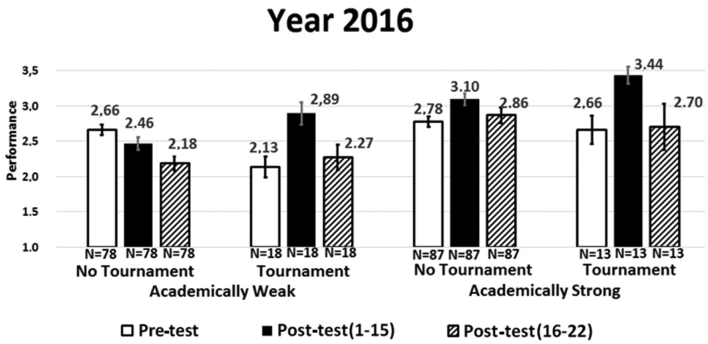

Fig. 4. Performance by academically weak and academically strong students on the 15 questions on the pre-test and post-test, as well as on the 7 extra questions on the post-test, for both the group of 167 students that did not participate in the tournament, as well as for the 31 students that did participate in the online synchronous interschool tournament.

same schools. As mentioned previously, the lesson involved the same four experiments. This lesson has been taught at the same schools since 2013. However, in 2013 a face-to-face tournament was organized instead. A couple of days after taking the post-test, all of the classes met at the municipal gym. These classes participated in a tournament based on launching water rockets. However, the score for each school depended heavily on the post-test. All of the students knew this was the case several days before taking the post-test. This was a highly attractive activity for the students. However, the logistics of organizing the event were not easy, as 13 classes from 11 schools had to be transported at the same time from their respective schools to the municipal gym. Moreover, according to the organizers and teachers, the whole activity was very demanding and exhausting. Therefore, the superintendent decided to cancel the tournament in 2014 and 2015. However, in 2016 the tournament was replaced by an online synchronous tournament. The plan was to connect schools using technology and therefore avoid transporting the classes. It is therefore very important to compare the effect of the face-to-face tournament in the municipal gym with the online synchronous tournament. Figure 5 shows the effect size of both tournaments. In 2013, the face-to-face tournament had an effect size of 0.51 standard deviations, whereas in 2016 the online synchronous tournament had an effect size of 1.10 standard deviations.

Therefore, the effect size of the online synchronous interschool tournament is more than twice the effect size of the face-to-face tournament. This really is a completely unexpected finding. It shows that technology cannot only solve a logistical problem of a very engaging educational activity; it can also produce highly impressive improvements in learning outcomes.

Let us now analyze how the type of tournament impacts the learning outcomes according to gender and the students' academic performance.

As shown in Fig. 6, the effect size for girls in the 2013 face-to-face tournament is 0.54 standard deviations, whereas for the 2016 online synchronous interschool tournament it was 0.65 standard deviations. This is an increase of 20% in the effect size. In the case of boys, the increase in the effect is greater. In the 2013 face-to-face

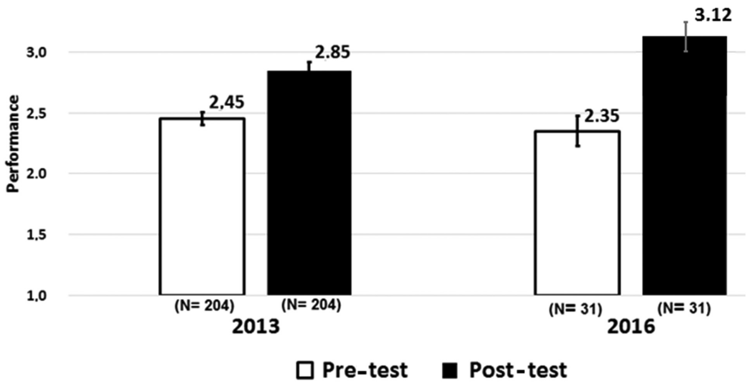

Fig. 5. Performance on the 15 questions on the pre-test and post-test, as well as at the 2013 face-to-face tournament and on the online synchronous tournament held in 2016.

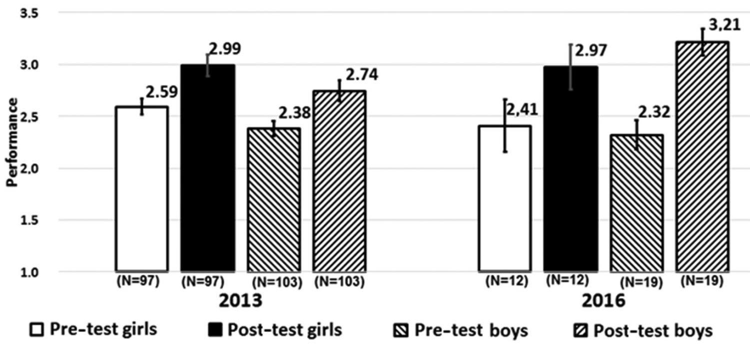

Fig. 6. Performance on the 15 questions on the pre-test and post-test, as well as at the face-to-face tournament in 2013 and on the online synchronous tournament in 2016.

tournament, the effect size is 0.50 standard deviations, whereas in the 2016 online synchronous interschool tournament it was 1.48 standard deviations. This is an increase of 196% in the effect size. This is a huge increase. Given that in the face-to-face tournaments the learning outcomes are similar among boys and girls and that this is not the case with online synchronous tournaments, it seems that the networking technology has a significant effect on boys for tournaments; much higher than the effect on girls.

Figure 7 reveals the performance by academically weak and academically strong students for both tournaments. The effect size for academically weak students involved in the 2013 face-to-face tournament is 0.22 standard deviations, whereas in the case of the 2016 online synchronous interschool tournament it was 1.24 standard deviations. This is an increase of 464% in the effect size. This is a huge increase in effect size. On the other hand, for the academically strong students who participated in the 2013 face-to-face tournament the effect size was 1.00 standard deviations, whereas for the 2016 online synchronous interschool tournament it was 1.06 standard deviations. This means that the effect sizes are similar.

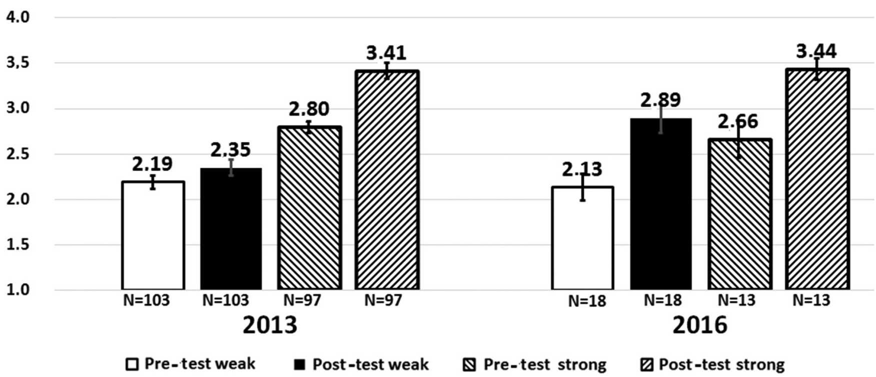

Fig. 7. Performance on the 15 questions on the pre-test and post-test, as well as at the face-to-face tournament in 2013 and the online synchronous tournament in 2016.

4 Conclusions

STEM teaching and learning is a huge challenge. It requires a significant change in teaching practices in order to teach new crosscutting concepts, increase integration across subjects; all within the context of a classroom where mobiles devices are ubiquitously present and constantly competing to attract the students' attention. Several powerful teaching strategies have been suggested. For example, [8] propose 26 "scientifically proven approaches". These include hands-on activities, making or producing practical knowledge, student participation, asking for self-explanations and undoing misconceptions. Hands-on experimental work has been studied in particular [17]. This leads to highly engaging and meaningful activities. Another proposed strategy is to increase the level of excitement, such as in games [18], particularly social games. Games activate the mechanism of social facilitation [15], where people and other animals perform better when other subjects are around [19, 20]. Another important strategy is to activate the mechanism involved in the sense of belonging. This is the sense of being accepted, valued, and included. According to [21] "belongingness appears to have multiple and strong effects on emotional patterns and on cognitive processes" p. 407. This is a great motivational resource available in every school and class. Interestingly, the list [8] of 26 strategies does not include the strategy of running interclass or interschool tournaments. This is a powerful strategy for activating social mechanisms, such as a sense of belonging, teamwork, engagement, and excitement. Moreover, technology can make a big different to implementing this strategy.

Data collected from these tournaments show that online and synchronous tournaments between courses have a greater effect on boys than girls. This effect is consistent with other results from evolutionary psychology. According to Geary [22, 23], boys tend to form larger groups, which is normal when preparing for inter-tribal conflicts. Girls instead tend to form much smaller groups, with more intense and lasting relations. Thus, boys are more easily motivated by large group collaboration in preparation for inter-group conflicts. Therefore, a prediction of evolutionary psychology is that the use of the competition mechanism between courses should motivate more boys than girls to prepare and pay attention in the tournament.

There is an extensive literature on the importance of play for learning both in humans and in other animals [24]. In addition, since at least the decade of the 70, there are studies of the important effects on learning and attitudes of the competitions and tournaments between teams [25, 26]. However, to the best of our knowledge there are two questions that have not been addressed before. Firstly, with the use of technology, do online synchronous interschool tournaments enhance hands-on experimental sessions that are already engaging, such as the ones involving water rockets? The second question asks whether the learning outcomes obtained with online synchronous interschool tournaments is similar to or better than those obtained with face-to-face tournaments, where students from several schools meet at the same physical place in order to participate in an interschool competition? These tournaments are run using strategies from TV shows in order to increase engagement. Students wear school uniforms and display their school flags in order to enhance the sense of belonging. Music and school songs activate the tribal mechanism of intergroup competition. It is not clear whether technology-enhanced tournaments can trigger the same emotional mechanisms and produce the same level of engagement. However, our results from years of interschool tournaments give some preliminary empirical evidence to suggest that technology makes possible to implement online synchronous interschool tournaments that can make an important difference to learning STEM in elementary schools. This finding is very interesting and we do not yet have a definitive explanation. One possibility is that the online and synchronous tournaments between courses, allow to individualize and account with much more precision the contribution of each player. Although the STEM platform periodically announces only the team's score, it nevertheless constantly appoints the student by name and gives him/her feedback on his individual performance and congratulates him personally for his/her successes. That's impossible to do with hundreds of students playing in a face-to-face tournament in a gym. This is a facility that provides technology for online and synchronous tournaments, and offers a great advantage over face-to-face tournaments. In the near future we hope to study this impact in more depth, and also include other STEM contents.

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References

1. Quinn, H., Schweingruber, H., Keller, T. (eds.): A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. National Academies Press, Washington, D.C. (2012)
2. Honey, M., Pearson, G., Schweingruber, H. (eds.): STEM Integration in K-12 Education: Status, Prospects, and An Agenda for Research. National Academies Press, Washington, D.C. (2014)
3. Cuban, L.: Inside the Black Box of Classroom Practice Change Without Reform in American Education. Harvard Education Press, Cambridge (2013)

4. Avent, R.: The Wealth of Humans. Work, Power, and Status in the Twenty-First Century. St. Martin´s Press, New York (2016)
5. Colvin, G.: Humans are Underrated What High achievers Know That Brilliant Machines Never Will. Penguin, London (2016)
6. Labaree, D.: Someone Has to Fail. Harvard University Press, Cambridge (2010)
7. OECD, Ten Questions for Mathematics Teachers…and How PISA Can Help Answer Them (2016)
8. Schwartz, D., Trang, J., Blair, K.: The ABCs of How we Learn. Norton & Company Inc., New York (2016)
9. Slavin, R., Lake, C., Hanley, P., Thurston, A.: Experimental evaluations of elementary science programs: a best-evidence synthesis. J. Res. Sci. Teach. **51**(7), 870–901 (2014)
10. Edwards, K., De Vries, D.; Snyder, J.: Games and teams: a winning combination. Report 135. Center for Social Organization of Schools. Johns Hopkins University (1972)
11. Henrich, J.: The Secret of Our Success. Princeton University Press, Princeton (2016)
12. Greene, J.: Moral Tribes. The Penguin Press, New York (2013)
13. Araya, R., Jimenez, A., Bahamondez, M., Dartnell, P., Soto-Andrade, J., González, P., Calfucura, P.: Strategies used by students on a massively multiplayer online mathematics game In: Advances in Web-based Learning - ICWL 2011. LNCS, vol. 7048 (2011)
14. Araya, R., Jimenez, A., Bahamondez, M., Dartnell, P., Soto-Andrade, J., Calfucura, P.: Teaching modeling skills using a massively multiplayer on line mathematics game. World Wide Web J. **17**(2), 213–227 (2014). Springer Verlag
15. Araya, R., Aguirre, C., Bahamondez, M., Calfucura, P., Jaure, P.: Social facilitation due to online inter-classrooms tournaments In: LNCS, vol. 9891, pp. 16–29 (2016)
16. Perazoo, J., Pehhypacker, C., Stronck, D., Bass, K., Heredia, J., Lobo, R., Ben-Shalom, G.: Persistent and encouraging achievement gains on math common core items for middle school english language learnrts. Sci. Educ. Civ. Engagem. **7**(2) (2015)
17. Abrahams, I., Millar, R.: Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. Int. J. Sci. Educ. **30**(14), 1945–1969 (2008)
18. Devlin, K.: Mathematics Education for a New Era: Video Games as a Medium for Learning. Peters/CRC Press, Boca Raton (2011)
19. Zajonc, R.: Social facilitation. Science **149**, 269–274 (1965)
20. Zajonc, R.: Attitudinal effect of mere exposure. J. Pers. Soc. Psychol. (1968)
21. Baumesiter, R., Leary, M.: The need to belong: desire for interpersonal attachment as a fundamental human motivation. Psychol. Bull. **117**(3), 407–529 (1995)
22. Geary, D., Byrd-Craven, J., Hoard, M., Vigil, J., Numtee, C.: Evolution and development of boys social behavior. Dev. Rev. **23**, 44–470 (2003)
23. Geary, D.: Educating the evolved mind: conceptual foundations for an evolutionary educational psychology. In: Carlson, J.S., Levin, J.R., Greenwich, C.T. (eds.) Psychological Perspectives on Contemporary Educational Issues, vol. 42. Information Age Publishing, Charlotte (2007)
24. Pellegrini, A.: The Role of Play in Human Development. Oxford University Press, New York (2009)
25. Edwards, K., DeVries D.: The effects of teams-games-tournaments and two structural variations on classroom process, student attitudes, and student achievement (Technical report 172). Baltimore: Johns Hopkins University, Center for Social Organization of Schools (1974)
26. Hulten, B., DeVries, D.: Team competition and group practice: Effects on student achievement and attitudes (Technical report 212). Baltimore: Johns Hopkins University Center for Social Organization of Schools (1976)