The flipped classroom for Physics teaching

Patricia Ruiz-Galende[1,2], Mónica Montoya[3], Iciar Pablo-Lerchundi[1], Patricia Almendros[3], Juan Carlos Losada[2], Fabio Revuelta[2]

patricia.ruiz@alumnos.upm.es, monica.montoya@upm.es, iciar.depablo@upm.es, p.almendros@upm.es, fabio.revuelta@upm.es

[1]Grupo de Investigación ForPROFE y Grupo de Innovación Educativa Didáctica de la Química, Instituto de Ciencias de la Educación.

[2]Grupo de Innovación Educativa Física Interactiva y Grupo de Sistemas Complejos, Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas

[3]Grupo de Innovación Educativa Química y Análisis Agrícola, Departamento de Química y Tecnología de Alimentos, Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas

Universidad Politécnica de Madrid
Madrid, España

Abstract- In this work, we present an on-line educational experience with first-year university students. Flipped classroom was used to study kinematics of rigid solid. Our results show no statistical differences when compared with other parts of the Physics module nor with the results obtained last year, when the educational process was not virtual but face-to-face.

Keywords: flipped classroom, active methodologies, rigid solid, Physics

1. Introduction

COVID-19 pandemic has certainly introduced a dramatic change in our teaching practices, as both students and teachers were forced to interact in a new on-line environment. At first glance, this changing scenario may look as adequate to facilitate an interactive atmosphere for the students. Nevertheless, the circumstances where it took place, the necessity of a quick implementation as well as the lack of previous experiences for most of the participants have rendered, in general, worse results (Dhawan, 2020). In this sense, active methodologies are remarkable for virtual teaching as they involve students more actively, even in this complex time we are living.

According to Bloom's taxonomy, active methodologies incorporate higher cognitive abilities (Santiago, 2019). However, sometimes their implementation is very difficult, due to the lack of experience (as mentioned before), the preference for traditional teaching, and the complications implicit in the new practice, such as the role played by the teacher and the required commitment of the students (Fidalgo-Blanco et al., 2019; Torres-Belma, 2020). All in all, a great effort must be made in order to improve traditional teaching which, up to a certain point, favours passive attitudes in the students, who tend to learn memoristically. Instead one should benefit from on-line practices to incorporate active methodologies, which allow learning by discovery, constructivism, and a deeper and more significative learning in general (Konopka, 2015; Torres-Belma, 2020).

The flipped classroom is a prominent active-learning example (Fidalgo-Blanco et al., 2019) as it improves students' engagement and facilitates on-line teaching. This methodology was popularized by Jonathan Bergmann and Aaron Sams, who used it to reduce the high absenteeism rates present in Woodland-Park High School (Colorado, EE. UU.) . The flipped classroom consists in performing the activities that are traditionally conduced in the classroom outside it (especially through video-lessons), and use the classroom time to clarify doubts and solve practical exercises.

Therefore, the flipped classroom has been implemented as a reaction to the COVID-19 pandemic, mainly due to its easy implementation for the students in our current context. Let us list, among others, the following advantages (Tang et al., 2020):

- Temporal and spatial flexibility. The videos provided can be visualized by the student anywhere at any time, as many times as necessary, this enabling asynchronous teaching.
- Learning depends mostly on the student. As a consequence, he/she becomes a more active agent, which induces a deeper and more significative learning (Fidalgo-Blanco et al., 2017).
- The classroom time is much more effective. Here, the role of the teacher is transformed into that of a mediator who supports and guides the students.

In this work, we describe the implementation of the flipped classroom in the teaching-learning process of kinematics of the rigid solid (KRS). It is part of the Physics I module of the Degree in Agroenvironmental Engineering of the Universidad Politécnica de Madrid. For this purpose, we first describe the context within which the experience has been conducted. Next, in section 3, we briefly introduce the implemented methodology. Section 4 is devoted to the main results of our work. Finally, we sum up the article by summarizing the main conclusions.

2. CONTEXT

In March 2020, the COVID-19 pandemic made traditional on-site teaching unavailable, extending this situation over the 2019-20 academic term. Consequently, the pre-pandemic face-to-face teaching has been only partially re-stablished over the 2020-21 academic term. Our institution made the decision that undergraduate teaching should be solely on-line conducted. As a result, teaching had to be adapted to this new reality. Thus, we decided to implement the flipped classroom in the teaching-learning process of the KRS unit of the Physics I module of the Degree of Agroenvironmental Engineering, which had the following contents:

1. Vector Calculus
2. Kinematics of the point
3. Kinematics of the rigid solid (KRS)
4. Relative motion
5. Statics (equilibrium, center of mass, and inertia moments)
6. System dynamics

In order to assess the correct application of our innovative experience, in particular, and a proper on-line teaching, in general, students were asked at the beginning of the term whether they had adequate devices to follow the virtual lessons. All participants had them, except one student, who was given a laptop, so he could properly follow the lessons, having then less difficulties than using only his smart phone and tablet, as he previously used to do).

3. DESCRIPTION

A series of 10 short videos was created for the implementation of the flipped classroom on the KRS teaching-learning process. Each video had a duration of less than 5 min, as shown in Table 1. The access to the videos was enabled through Moodle platform. Students had to visualize the videos over two weeks (while the topics of relative motion and point dynamics were studied in the on-line classrooms). In the first video (V_0), a brief explanation of the flipped classroom was provided. The remaining videos were devoted to a particular concept of KRS, as listed in Table 1.

Table 1: *Contents of the videos V_1-V_9 used for the flipped classroom, along with their duration (t_d), limit time to answer the questionnaire (t_c), and relation to the exercise associated with the kinematics of the rigid solid of the partial and final exams of the academic terms 2020-21 (Q_1-Q_6) and 2019-20 (Q_1-Q_5).*

V	t_d	t_c	Content	Q
V_0	2’ 4’’	-	-	-
V_1	3’ 5’’	30’	What is it?	-
V_2	4’ 9’’	30’	How can it move? (translation and rotation)	
V_3	3’ 17’’	20’	How are traslations composed?	Q_1
V_4	3’ 20’’	3’ 5’’	How are rotations composed?	
V_5	4’ 6’’	30’	How is a pair of rotations composed?	
V_6	1’ 19’’	-	How are traslations and rotations composed?	
V_7	3’ 31’’	-	How is the velocity of a point related to the velocity of another one?	Q_2
V_8	4’ 11’’	60’	What are the invariants?	Q_3 (& Q_6)
V_9	4’ 14’’	-	How is the instantaneous axis of rotation calculated?	Q_4 & Q_5

In order to improve the motivation of our students towards Science-Technology-Society relations, in the exercise associated with the V_6 video, the students were asked to visualize two videos with people doing skate and parkour. Subsequently, they were asked to draw the translation and rotation velocities at two particular time instants.

In the 2020-21 academic term, 46 students were enrolled in the Physics I module, being 38 of them freshmen. The assessment was conducted as follows. After visualization of each video, students were asked to fill out a brief questionnaire in Moodle, which could be time-limited or not (see Table 1). In order to assure a correct teaching-learning process, once the visualization period was finished, an on-line session of 1 hour was devoted to the most abstract concepts. In this session, the teacher clarified, through a master class, the most complex concepts, such as “what is a pair of rotations” or “what is the instantaneous axis of rotation”. Let us remark that this last concept requires quite a long explanation, in contrast to the brief (and usually simple) explanations presented in the remaining videos previously visualized at home. Furthermore, once all the videos had been visualized, two sessions of 1h 15min long were organized, where, first, the teacher and, second, the students solved the most complicated problems associated with the KSR unit. These problems where similar to those appearing in the exams, which combined several of the concepts introduced in the video lessons and were evaluated through specific questionnaires. The teacher was always accessible to solve the students’ doubts both during the previous lessons, as well as over the duration of the whole experience, which lasted three weeks. Moreover, the most motivated students had the chance to get extra points by solving two optional exercises (like those discussed in the last two sessions with the teacher). Last, after the three on-line sessions with the teacher, students were given one week of additional time to repeat those tests where they had been less successful (after letting them know their marks) or do the questionnaires for the first time, in case they had not filled them out at the proper time. This way, we could assure that the assessment was performed once all the students had had a chance to solve their doubts and questions. Likewise, they could also correct the errors when answering some of the questionnaires. Finally, in order to examine their opinions, students were asked to complete a satisfaction survey formed by 15 questions about the methodology, the required time, the materials, and possible improvements of the experience.

The performance of the experience has been accomplished using two sets of reference results. On the one hand, we have compared the marks obtained in the flipped-classroom questionnaires associated with the KRS unit with each of the exercises related to units 1-4 of the partial (celebrated in November 2020) and final (February 2021) exams of the 2020-21 academic term. The partial exam had eliminatory character, and, consequently, those students who passed it (with a mark larger or equal to 5.0 out of 10 points) did not have to be re-examined of those units in the final exam. Table 1 lists the relation between the different questions Q_1-Q_6 of the exam exercise on KRS and the flipped-classroom videos V_1-V_9. The marks on the units 5 and 6 have not been considered since they are solely evaluated in the final assessment. The comparison between the previous results allows to determine the performance of the flipped classroom compared to the rest of the units, which were also on-line but still *more* traditional, as they were based on a combination of master classes, practical solving, laboratory practices, etc.

On the other hand, to identify possible deviations due to the peculiar current situation (on-line teaching, little interpersonal contact among students, possible anxiety and stress situations, etc.), the marks of the 2019-20 academic term have been similarly revised. This kind of comparison permits the contextualization of the teaching-learning process of the KSR unit compared to the remaining ones, with no on-line underlying effects. Let us note that in that academic term, the exam exercise on KRS had one question less than this year, and, therefore, it was formed by 5 questions (lacking question Q_6 on minimum velocity, which appeared in 2020-21).

The data analysis has been performed by introducing the matrices with the students' marks in a MS Excel sheet. For a proper comparison of the individual exercises, all marks have been normalized to 10 points.

4. Results

As previously mentioned, after visualizing of each of the KRS videos, the students had to answer a brief questionnaire. Even though the mark obtained was taken into account for the continuous assessment, most of the students did not fill out all the questionnaires. Actually, only one of the students answered all of them. Furthermore, 25 students (54% of the total) participated at least once in the flipped-classroom experience. Nevertheless, the average number of participants was around 13 (28% of the total), being one of them a repeating student, as listed in Table 2. When comparing the marks achieved by the students with the duration of the videos as well as the answering time of the questionnaires, we conclude that these two variables have a negligible influence on the performance of the students.

Table 2: *Number of students (N) that fill out the questionnaires for the assessment of the teaching-learning process using the flipped classroom after the visualization of the videos V_1-V_9 during the 2020-21 academic term, and average marks (μ) and standard deviations (σ) obtained. The number in parenthesis (N') indicates the number of students that answered the questionnaire after the 3 on-line sessions with the teacher (repeating it or filling it out for the first time).*

V	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9
N (N')	20 (1)	15 (0)	15 (3)	16 (1)	10 (0)	5 (0)	19 (2)	10 (2)	9 (3)
μ	7.8	8.2	7.4	2.8	9.0	10.0	6.3	3.8	2.7
σ	1.8	2.0	4.0	3.6	2.1	0.0	2.7	2.9	2.2

First, the large dispersion in the data, which, in general, exceeds 2.0, is noted. This value could be explained by the high disparity in the students' background. Thus, the following conclusions of our work must be considered with some care.

As expected, videos V_1 and V_2 were answered by a higher number of students, probably because they involved rather easy and elementary concepts on KRS. The performance of the students has been similarly good on the composition of translations (V_3) since this problem is also quite simple. Contrary, the results have been certainly worse on the composition of rotations (V_4), as this requires a higher abstraction degree. For that reason, the excellent performance in video V_5 is surprising, which is related to the velocity caused by a pair of rotations.

On the one hand, let us remark the superb results obtained in video V_6, among all videos, where the velocity of a rigid-solid point is computed as a function of the velocity of another point. This question is answered error-free by all students. Nonetheless, it is the least answered question as it is completed by only 5 students. On the other hand, notice the answers associated with video V_7. In this case, the students were asked to perform a task of the composition of translations and rotations with a Science-Technology-Society dimension. This question was the most answered (21 students), probably due to its connection to students' interests. Summing up, the performance in the questions related to the last two videos was substantially worse since they involved more complex concepts on KRS, namely the calculation of the invariants (V_8) and the computation of the instantaneous axis of rotation (V_9).

Finally, a low number of students has performed the optional activities to get a higher mark, such as repeating some of the questionnaires or solving two extra problems. Actually, only three students have solved these problems, getting in all cases an extremely low qualification (0, 1, and 2 points out of 10, respectively). This fact questions the good performance of the teaching-learning process that was at first glance expected from the inspection of the encouraging results shown in Table 2.

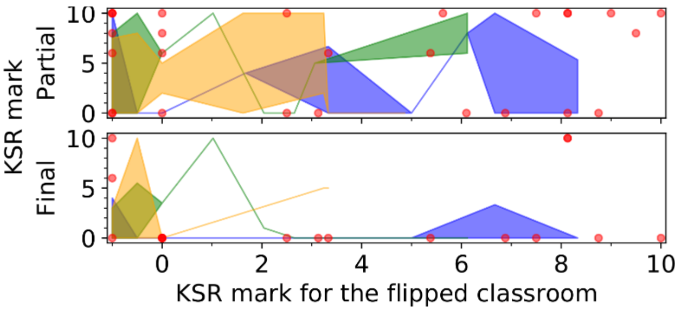

Figure 1: *Mark for the questions of the exercise associated with kinematics of the rigid solid for the partial (top) and final (bottom) exams of the 2020-21 academic term as a function of the mark obtained in the flipped-classroom questionnaires associated with those questions (red points: individual marks for the answers associated with question Q_1; blue, orange, and green shaded areas: limits for the marks corresponding to questions Q_2, Q_3+Q_6, and Q_4+ Q_5).*

In order to analyse in more detail the performance of the flipped classroom, we show in Figure 1 the marks for the KRS exercise for the partial (top) and final (bottom) exams for the

2020-21 academic term as a function of the average mark of the flipped-classroom questionnaires. In order to distinguish the answers associated with non-visualized videos from those which have been wrongly filled out, we have assigned negative points to the students who have not answered all the questionnaires, assuming that the corresponding videos have not been visualized. In particular, we have marked with -0.5 (-1.0) points those questionnaires which are partially (completely) unanswered.

As the contents of the questionnaires were not exactly the same ones as those included in the exams, which were in general more difficult due to the combination of several concepts, the relations reported in Table 1 must be established. Likewise, for a better visualization, only the results associated with question Q_1 have been presented in Figure 1 because of the large data dispersion and the considerable number of points. The limits of the remaining results are shown as shaded areas. As can be seen, the data have a remarkable dispersion, up to a certain point due to the different academic background of the students. From inspection of the results, it cannot be concluded that a better performance in the flipped classroom implies better results in the exams. Taking into account that barely 50% of the students filled part of the flipped-classroom questionnaires out, no unambiguous connection between the results in the flipped classroom and in the exams can be established. Still, our data show that, in general, those students who have a better performance in the flipped classroom do also get more points in the exams. In order to study the significance of the different questions forming the KRS exercise of the exams on their marks in this exercise, we present in Figure 2 the total number of points in the partial (top) and final (bottom) exams as a function of the marks obtained in the previous questions. Notice, once again, the significant dispersion in the data. Thus, we introduce in Table 3 the value of Pearson's correlation coefficient to find out the importance of each question on the global marks. As can be observed, this parameter is positive in all cases and rather large, which demonstrates the significance of all questions on the qualifications of the KRS exercise.

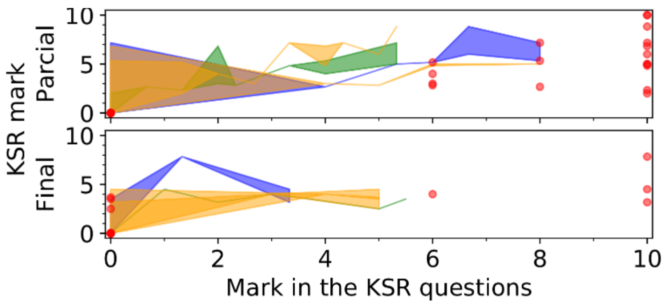

Figure 2: *Average mark for the exercise of kinematics of the rigid solid for the partial (top) and final (bottom) exams for the 2020-21 academic term as a function of the mark obtained in each of its questions (red points: mark for question Q_1; blue, orange, and green shaded areas: limits for the marks for the questions Q_2, Q_3+Q_6, and Q_4+ Q_5).*

Once the individual influence of the different KRS questions was analysed, we compared the performance of those students who took part in the flipped-classroom experience with those who did not. This comparison enables to stablish the real influence of the flipped classroom on the students' achievements. The average mark on the partial exam by the flipped-classroom students was 3.94, while those who were not involved in the experience got on average 2.76 out of 10 points. This remarkable difference is, nevertheless, not significant, as concluded after performing the statistical tests (F- and T-tests). Therefore, the effectiveness of the flipped classroom cannot be assessed.

Table 3: *Pearson-correlation coefficient between the mark on questions Q_1-$Q_{5/6}$ and the global mark on the partial and final exams for the 2020-21 and 2019-20 academic terms.*

Q	2020-21		2019-20	
	Partial	Final	Partial	Final
Q_1	0.8865	0.7982	0.7171	0.7130
Q_2	0.8251	0.6220	0.8043	0.7268
Q_3	0.9225	0.7989	0.8482	0.8357
Q_4	0.7218	0.6334	0.8553	0.8316
Q_5	0.8758	0.8316	0.7330	0.6627
Q_6	0.8359	0.8465	-	-

Similar conclusions can be inferred from the final-exam analysis. When comparing students who participated in the flipped classroom with those who did not, the average mark is similarly quite different (1.47 vs 2.39 out of 10 points) but no significant differences are found. However, let us point out that in this case only 3 students did not experience the flipped classroom (vs 15 who did).

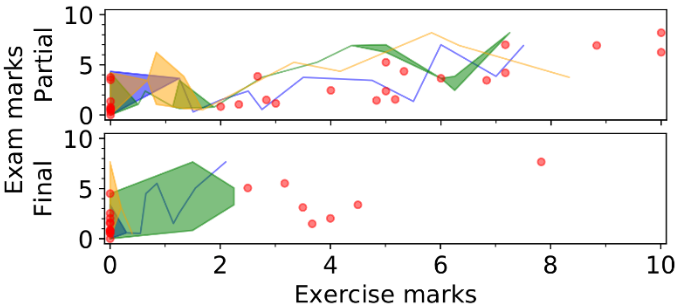

Figure 3: *Average mark for the partial (top) and final (bottom) exams for the 2020-21 academic term as a function of the mark obtained in each of the exercises of those exams (red points: mark for the kinematics-of-the-rigid-solid exercise; blue, green, and orange shaded areas: limits for the marks for the questions associated with kinematics of the point 1, kinematics of the point 2, and relative motion).*

We conclude the discussion on the flipped classroom by presenting Figure 3, where the marks for the partial (top) and final (bottom) exams in the 2020-21 academic term as a function of the marks on the 4 exercises that constituted the first part of the course (two of point kinematics, one of KRS and one of relative motion) are represented. As previously discussed, the data have a large dispersion. Notice that, in general, the global mark increases with the individual mark on the exercises. Among all exercises, the KRS is the one with the largest average qualification (3.6 points in the partial exam, and 1.6 out of 10 points in the final exam vs 3.1 and 1.0 points, respectively, in the exercise with the second highest mark). This better performance can be also assessed by visual inspection of the KRS results, as there are more points under the y=x line than above it. Nonetheless, the statistical difference is not significant due to the large standard deviation. The KRS exercise is the one that is more strongly correlated with the global exam mark (the regression parameters equal $R^2 = 0.64$ and 0.51, in the partial and final exams, respectively, in contrast to $R^2 \approx 0.52$ and 0.27 for the point kinematics results, respectively). Note that the regression parameter is overall larger in the partial than in the final exam as the latter is formed by more exercises, i.e., it also includes questions related to the other units of the module (see Section 2). The worse performance in the final exam compared with that in the partial exam can be explained because only those students who failed the latter assessment had to be (re-)evaluated of those topics in the final exam.

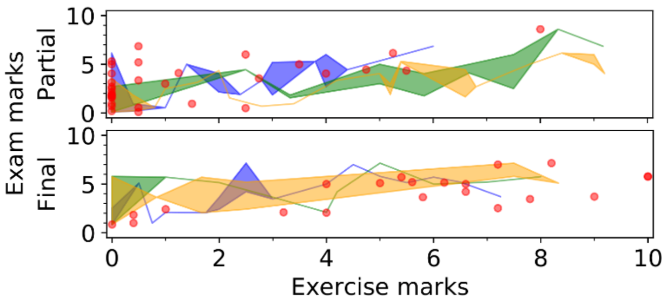

Figure 4: *Average mark for the partial (top) and final (bottom) exams for the 2019-20 academic term as a function of the mark obtained in each of the exercises of those exams (red points: mark for the kinematics-of-the-rigid-solid exercise; blue, green, and orange shaded areas: limits for the marks for the questions associated with kinematics of the point, dynamics of the point, and relative motion).*

Next, in order to contextualize the KSR unit in a broader landscape, we show in Figure 4 the marks for the partial (top) and final (bottom) exams in the previous academic term (2019-20) as a function of the marks obtained in the exercises. The exams were also formed by 4 exercises, but in this case two were associated with point kinematics, one with KSR, and one with point dynamics. As in the 2020-21 academic term, the average mark for the KRS exercise in 2019-20 was larger than for the rest of the exercises (3.5 and 5.4 in the partial and final exams, respectively, versus 1.9 and 2.7 for relative motion, which was the exercise with the second highest mark). Nevertheless, as in the previous discussion, these results must be taken with some care due to the high dispersion (larger than 2.0). To conclude, the regression parameter for KSR has similar values as those previously reported ($R^2 = 0.57$ and 0.52), and, once again, it is larger than for the rest of the exercises in all cases, except for the relative-motion exercise of the partial exam ($R^2 = 0.65$). All in all, the remarkable dispersion in the data hinder a conclusive statement on the impact of the flipped classroom in our teaching-learning process. Still, the results obtained seem to show that the influence of the flipped classroom has been rather modest. Furthermore, recall that over 2020-21 teaching has been on-line (except during two laboratory practices), which has a dramatic influence on the academic and environmental performance of the teaching classes after visualizing the videos.

Regarding the satisfaction with the flipped classroom, most of the students find the experience positive (average mark 6.2 out of 10 points). Moreover, they also acknowledged that the lessons with the teacher are more useful (average mark: 6.4). This last conclusion, inferred from the satisfaction survey, is yet in agreement with the students' preference for traditional teaching. On average, the students reported devoting 5 hours to the flipped classroom, a time that is found by 27% of them larger than that necessary for other methodologies. Regarding the connection devices, most students have visualized the videos using their own laptops. For a better understanding of the concepts presented in the videos, 73% of the students have seen them more than once, the other 27% needed to consult other materials. In general, they missed the possibility of raising questions straightforward, but, in general, they also believe that the flipped-classroom experience has been adequate.

To conclude, let us remark that all general indicators of the course have declined, probably due to the odd pandemic environment that has surrounded the 2020-21 academic term. In fact, both the yield and the success rates have worsened over around 50% (reducing, respectively, from 32.1% and 56.7% in the 2019-20 academic term to 15.9% and 32.1%). Similarly, the absenteeism rate has also increased, although more moderately, from 43.3% to 50.0% over the same period.

Finally, let us remark that rates in the rest of the modules of the degree have experienced a similar behaviour.

5. Conclusions

In this paper, an on-line teaching experience with graduate students of Physics I (first-year course of the Degree in Agroenvironmental Engineering) has been reported. The work is based on the application of the flipped classroom to study the kinematics of a rigid solid. We cannot conclude that the flipped classroom has an unambiguous positive impact on the learning process, contrary to previous experiences reported in the Literature. This unexpected fact can be explained due to the peculiar circumstances within which the experience has been conducted due to COVID-19 pandemic (on-line teaching, few personal contact among the students, etc.). However, the students assess the methodology as positive, especially due to the better use of the teaching sessions, though they still prefer traditional (face-to-face) teaching.

Acknowledgements

This work has been supported by the Universidad Politécnica de Madrid under Contract of Innovative Education No. IE1920.2002.

References

Aguilera-Ruiz, C., Manzano-León, A., Martínez-Moreno, I., del Carmen Lozano-Segura, M., Yanicelli, C. C. (2017). El modelo flipped classroom. *International Journal of Developmental and Educational Psychology, 4*(1), 261-266.

Bergmann, J., Sams, A. (2012). Flip your classroom. reach every student in every class every day. *International Society for Technology in Education (ISTE)*.

Dhawan, S. (2020). Online Learning: A panacea in the time of COVID-19 crisis. *Journal of Educational Technology,* 49(1), 5-22.

Fidalgo-Blanco, Á., Martinez-Nuñez, M., Borrás-Gene, O., Sanchez-Medina, J.J. (2017). Micro flip teaching – An innovative model to promote the active involvement of students. *Computers in Human Behavior,* 72, 713-723.

Fidalgo-Blanco, Á., Sein-Echaluce, M., García-Peñalvo, F. (2019). Impact indicators of educational innovations based on active methodologies. *TEEM'19 Proceedings of the Seventh International Conference on Technological Ecosystems for Enhancing Multiculturality,* León, España, 763-769.

Konopka, C., Adaime, M., Mosele, P. (2015). Active Teaching and Learning Methodologies: Some Considerations. *Creative Education*, **6**, 1536-1545.

Santiago, R. (2019). Conectando el modelo Flipped Learning y la teoría de las Inteligencias Múltiples a la luz de la taxonomía de Bloom. *Magister,* 31(2), 45-54.

Tang, T., Abuhmaid, A. M., Olaimat, M., Oudat, D., M., Aldhaeebi, M., Bamanger, E. (2020). Efficiency of Flipped Classroom with online-based teaching inder COVID-19. *Interactive Learning Environments,* ahead of print, 1-12.

Torres-Belma, A. (2020). Los procesos de enseñanza-aprendizaje en el contexto de pandemia: reconfiguración de la relación docente-estudiante en la educación superior. *Tierra Nueva,* 17(17), 46-52.