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Improving online instruction with self-regulated learning: A case study of kinematics graph interpretation

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Abstract

The objective of this study was to determine if students' skills interpreting kinematics graphs could be improved in an online instruction environment by using the Self-Regulated Learning (SRL) framework. The gain in skills was measured by comparing pre-test and post-test results of the objective Test for Understanding Graphs – Kinematics (TUG-K) for N=19 students. The average score of the post-test was 62% better than the average score of the pre-test. The difference between the two average scores was statistically significant ($p < 0.05$). In addition, an opinion survey of the students – conducted before and after the SRL intervention – showed a statistically significant ($p < 0.05$) improvement of 15% regarding the students' own sense of self-efficacy, and their capacity for delayed gratification (self-control). These two intra-personal skills, in addition to metacognition, are addressed and developed by the SRL framework. SRL also develops self-instruction skills which opens further possibilities of using class time to provide feedback and to thoroughly assess student knowledge with oral exams. These initial results provide a positive outlook that the development of SRL skills contributes to improvements in online instruction.

Keywords: online instruction, self-regulated learning, kinematics graphs, self-instruction

Resumen

El objetivo de este estudio fue determinar si las habilidades de los estudiantes para interpretar gráficos cinemáticos podrían mejorarse en un entorno de instrucción en línea utilizando el marco de aprendizaje autorregulado (SRL). La ganancia en habilidades se midió comparando los resultados de la prueba previa y posterior del "Test for Understanding Graphs – Kinematics" (TUG-K) para N = 19 estudiantes. El puntaje promedio de la prueba posterior fue 62% mejor que el puntaje promedio de la prueba previa. La diferencia entre las dos puntuaciones medias fue estadísticamente significativa ($p < 0.05$). Además, una encuesta de opinión de los estudiantes, realizada antes y después de la intervención SRL, mostró una mejora estadísticamente significativa ($p < 0.05$) del 15 % con respecto al propio sentido de autoeficacia de los estudiantes y su capacidad de gratificación diferida (auto-control). Estas dos habilidades intrapersonales, además de la metacognición, son abordadas y desarrolladas por el marco SRL. SRL también desarrolla habilidades de autoaprendizaje que abren más posibilidades de utilizar el tiempo de clase para proporcionar retroalimentación y evaluar a fondo el conocimiento de los estudiantes con exámenes orales. Estos resultados iniciales brindan una perspectiva positiva de que el desarrollo de habilidades SRL contribuye a mejorar la instrucción en línea.

Palabras clave: instrucción en línea, aprendizaje autorregulado, gráficos cinemáticos, autoinstrucción

Introduction

This study was motivated by the Covid-19 pandemic. Ready or not, in March 2020 the academic world was suddenly forced into the online instruction mode. The loss of face-to-face interactions with students significantly reduced the author's level of confidence regarding gains in students' knowledge. Some of the questions raised were: How can students become better learners in an online environment? How can instructors feel confident that they are thoroughly assessing students' knowledge in an online environment? What is the most effective way of conducting online learning?

This article addresses the first question, i.e., how can students become better learners in an online environment? The hypothesis that guided this study was that students can become more efficient learners if they develop Self-Regulated Learning (SRL) skills. The results are encouraging.

The following section briefly introduces SRL. It is followed by a brief primer on kinematics graphs interpretation which is the specific learning topic in which the SRL framework was embedded. The references lead to additional sources of information.

The other sections of this article are Methodology, Results, Discussion of Results, Limitations, Conclusions, Further Research, Acknowledgments, and References.

The Self-Regulated Learning (SRL) Framework

Some people learn more quickly than others and are usually referred to as "intelligent"; however, it has been found that "intelligent" people tend to naturally master the skills of self-regulated learning (SRL) that were developed by Zimmerman (2002) after taking apart and understanding everything that went into an efficient learning/studying session. Contrary to "pure" intelligence, which is innate, self-regulated learning is an acquirable skill. It is applicable in any learning environment and for any topic.

Self-regulated learning is defined as "the processes and beliefs that precede, accompany, and follow efforts to learn, which in turn affect subsequent cycles of learning" (Nilson, 2013).

The three stages of SRL (precede, accompany, and follow) are addressed by Nilson (2013). In the first stage (precedes learning) the student plans, establishes learning goals, and formulates strategies to achieve the goals. Emotional issues are also important. Students should feel intrinsically motivated, i.e., they should find the topic appealing and interesting. Extrinsic (external) motivation is also powerful, such as the desire to earn an A in the course or the desire to land an excellent job after graduation.

Self-efficacy beliefs are also important. Self-efficacy refers to how adequate, competent, and efficient a person feels when facing a challenge (Bandura, 1997). Summarizing stage 1 of SRL, good planning and a good emotional disposition provide an excellent starting point for learning.

In the second stage (accompanies learning) students focus their mind on learning. This requires self-control which is closely related to the concept of delayed gratification, i.e., the ability to postpone an immediate reward for a larger reward in the future. Compartmentalization is also highly effective, i.e., isolating the learning activity from any other challenges that you may be facing (other assignments, for example) so that you can devote your time exclusively to the learning activity that is in front of you.

As progress is achieved, the student should be able to summarize in their own words what they have learned. If the student detects gaps in the summary, the material should be reviewed, and new summaries should be attempted until the student is satisfied with the result. If stuck, can the student identify the impediments? Can they execute strategies to overcome them? This incredibly important process of monitoring mental processes during the learning session is called metacognition and is a key ingredient in self-regulated learning.

Students should also experiment with their surroundings. Is it more efficient to learn in silence or while listening to music? Sitting on a desk or lying down in bed? Alone or in a group? Once the person finds the most efficient way, they should stick with it.

In the third stage (follows learning), the person conducts self-reflection regarding the learning session. One way is to compare the performance against a standard, for example, today's performance may be compared against yesterday's performance. Students may also compare their performance against an established standard.

In addition, if the student erred, to what do they attribute the failure? Emotional issues also enter at this stage. Motivation will suffer if the student thinks it is because they have limited abilities (low self-efficacy). Instead, if the person reacts adaptively, they will remain open to considering different strategies to correct the mistakes.

If the person feels satisfied during the learning process, motivation will remain at an elevated level, and the opposite tends to occur (decrease in motivation) if the person does not feel satisfied. It is greatly beneficial to learn how to find satisfaction in the challenge of overcoming the obstacles that inexorably get in the way of reaching the learning goals. It is essential for students to give themselves the opportunity to try, to err, to confront their mistakes, and to resolve them.

When a learning goal is achieved, students should congratulate themselves and enjoy the accomplishment. Afterwards, the student can move on to the next goal in the plan and restart the cycle of self-regulated learning, as shown in Figure 1.

In this study, the SRL skills were developed through a manual (Morales, 2021) that embeds SRL activities within exercises for learning how to interpret kinematics graphs. The SRL manual addresses the three SRL stages; for example, students answer surveys to determine their pre-assignment and post-assignment levels of metacognitive skills, self-control, self-efficacy, and intrinsic and extrinsic motivation. Students also write brief summaries of what they have learned, and answer guide questions that assists them in improving their metacognition and self-reflection skills.

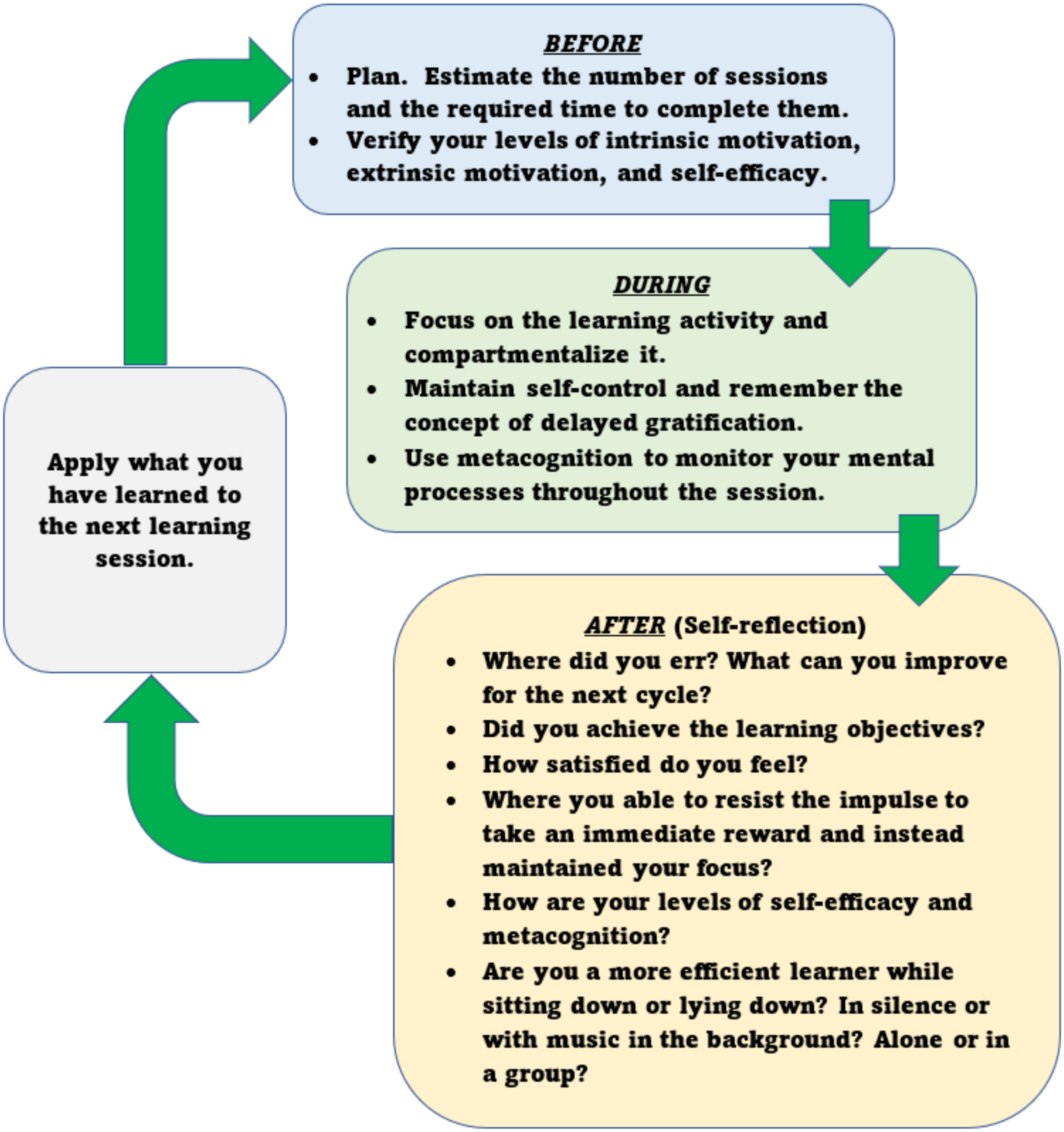

Figure 1. The cycle of self-regulated learning (SRL)

Difficulties interpreting kinematics graphs

Physics and engineering faculty often take for granted the students' ability to interpret and extract the rich content available in graphs. It is often an incorrect assumption (Beichner, 1994). The required skills become more sophisticated after Calculus I because derivatives and integrals have useful graphical interpretations. Graphically, the derivative is associated with the slope of the tangent line of a function at any given point, while the integral is associated with the area under the graph of a function.

Morales (2020a) determined the following three root causes of student difficulties interpreting kinematics graphs:

1. The student is unfamiliar with the three stages of reading graphs. These are: 1.) identify the visual features of the graph, 2.) connect the visual features to concepts, and 3.) apply judgment to interpret the graphs. (Difficulty established by Skrabankova, Popelka and Beitlova, 2020).
2. The student does not know or is unfamiliar with kinematics definitions. (Difficulty established by Trowbridge and McDermott, 1980).
3. The student cannot connect the kinematics graphs to a concrete and visible experience. (Difficulty established by Arons and Redish, 1997).

The workbook Ranking Tasks for Kinematics Graphs of Rectilinear Motion (Morales, 2020b) provides more than eighty exercises that were created to address the root causes. It ties directly into the Manual for SRL Learning of Kinematics Graphs (Morales, 2021).

Beichner (1994) developed the rigorous objective test named "Test for Understanding Graphs – Kinematics" (TUG-K). The test addresses seven objectives and includes three questions per objective for a total of 21 questions on kinematics graphs interpretation. It is a multiple-choice exam with five choices (A through E). All the questions and the solutions are provided in the article. Beichner gave the test to N=524 students and the mean score was 40% with a standard deviation of 22%.

The TUG-K was used in this study as a pre-test and as a post-test.

Methodology

The study was conducted in a senior mechanical engineering course at a private university in Puerto Rico. The course prepares students to pass the FE Exam (the first licensure exam) so the topic of kinematics graphs was relevant. All the students had some prior exposure to kinematics graphs in the Physics I course that is taken in the second year. The course was offered online (due to the Covid-19 pandemic) in the Fall 2021 semester. The author was the course instructor. The study had N=19 participants.

The study was designed within the framework of Scholarship of Teaching and Learning (SoTL). The SoTL questions that guided the study were:

1. How good are the skills of senior students interpreting kinematics graphs?
2. Can students improve their graph interpretation skills by using the Manual of SRL of Kinematics Graphs (Morales, 2021) and the book Ranking Tasks for Kinematics Graphs of Rectilinear Motion (Morales, 2020b)?
3. Will student comments result in improvements to the two books listed above?
4. Will students resist to the self-instruction modality that will be expected of them?

5. Will students find it useful to learn about SRL skills?

The sequence of events was as follows:

1. The students took the TUG-K test as a pre-test during the first week of class of the Fall 2021 semester. The TUG-K questions were copied directly from the Beichner (1994) article into a Microsoft Forms quiz. Students were given 45 minutes to complete the test during class hours. The author did not discuss the test at any point and students were not provided with the correct answers after taking the test.

2. Students worked on seven homework assignments from Week 2 to Week 11 of the semester using the Manual for Self-Regulated Learning of Kinematics Graphs (Morales, 2021) and the book Ranking Tasks for Kinematics Graphs of Rectilinear Motion (Morales, 2020b). The author provided feedback during these 10 weeks. Feedback took approximately 10% of the class time.

3. The TUG-K was taken as a post-test on Week 12 after concluding the seven assignments.

Results

Table 1 includes the pre-test and post-test TUG-K results. For comparison purposes, Beichner (1994) reported a 40% average score with a 22% standard deviation for N=524 students (included in the last column of Table 1).

Table 1. Average scores in the TUG-K objective test

	Pre-test N=19	**Post-test N=19**	**Beichner (1994) N=524**
Average score	26% *	42% *	40%
Standard Deviation	19%	22%	22%

*The difference between the two averages is statistically significant ($p<0.05$)

Table 2 includes the average scores of the opinion survey based on a 10-point scale where 1 is "very low" and 10 is "very high". It was conducted on Week 2 (start) and Week 11 (end). The last column includes the percent difference between Weeks 2 and 11.

Table 2. Average scores of the opinion survey at the start (Week 2) and end (Week 11) of the SRL activities. It is based on a 10-point scale: 1 is "very low" and 10 is "very high".

#	Item	Start (Week 2)	End (Week 11)	% Diff
1	Level of understanding of Self-Regulated Learning	7.9	7.8	-1%
2	Level of self-efficacy, i.e., how adequate, competent, and efficient you feel when facing a challenge.	7.2 *	8.3 *	15%
3	Level of self-control as measured by your capacity for delayed gratification, i.e., the ability to postpone an immediate reward for a larger reward in the future.	7.1 *	8.1 *	15%
4	Level of metacognitive skills, i.e., awareness of your mental process as you conduct a learning session.	7.5	7.4	-1%
5	Level of satisfaction that you feel when overcoming the obstacles that get in the way of reaching your learning goals.	8.9	8.4	-6%
6	Level of intrinsic motivation in learning kinematics graphs interpretation.	6.7	6.8	1%
7	Level of extrinsic motivation in learning kinematics graphs interpretation.	8.3	8.0	-4%
8	Level of confidence in learning SRL and kinematics graphs interpretation.	7.1	6.9	-3%

*The difference between the start and end averages is statistically significant ($p < 0.05$)

Table 3 shows the average scores of the final survey (Week 11) regarding the three experiments with the surroundings. It is based on a 10-point scale: 1 is "very low" and 10 is "very high". The table also includes the calculation of the percent difference between the two options.

Table 3. Average scores of the final survey (Week 11) regarding the three experiments with the surroundings. It is based on a 10-point scale: 1 is "very low" and 10 is "very high".

	Option 1 I prefer studying…	**Option 2 I prefer studying…**	**% Diff.**
Case 1	In silence	With music	
Average Score	8.4	5.7	47%
Case 2	Sitting down	Lying down	

Average Score	8.4	5.8	45%
Case 3	Alone	In a group	
Average Score	8.6	7.2	19%

On Week 11, students were asked to comment on what they liked most about the activity, and what they liked least. These can be used to obtain a sense of the activity and to improve the manual (Morales, 2021) and the ranking tasks book (Morales, 2020b). They are listed below.

1. ***Liked Most*: Comments related to SRL**
    a) Seeing what worked best for me when learning on my own.
    b) It helped improve my learning organization.
    c) I studied when I felt focused and that I had to organize myself and find different strategies to understand the material.
    d) I loved that I was able to do everything on my own and learn by myself. At first it was just because of the class but, at the end, the satisfaction of relearning a topic that I had mostly forgotten.
    e) The level of help and teaching about self-regulated learning.
    f) I liked everything about this activity. I learned many things and improved my learning. I will be implementing everything I learned in my professional career.
    g) Assist with growing our insight and productivity.
    h) The surveys.
    i) It was good to learn something new but was very difficult.
    j) Filling out the surveys.
    k) It was something different that helped expand our knowledge and efficiency.

2. ***Liked Most*: Comments related to kinematics graphs**
    a) Reinforce and see in a broader way the topic of kinematics graphs. I had forgotten some concepts. Also, learning to differentiate all the parameters that can be placed in a kinematics graph.
    b) The activity is good because it helps us to understand things that we forgot or that we thought we knew well, but in reality we did not know well.
    c) A well needed relearning experience of kinematics graphs. I enjoyed it as a whole.
    d) Aron's table to relate the graph to a concrete and visual experience. Also, the appreciation of graphs and all the concepts that we had to apply.

e) Improve my knowledge with these types of graphs.

3. *Liked Least*: Comments related to time.

a) Time. It was difficult to do with all the other work from other courses.
b) How long each activity was, how time consuming it was.
c) Took a long time to complete and, accumulated with other courses, I could not focus 100% on the assignments.
d) Time to complete the tasks. Difficult with other courses.
e) Change the due date for the weekend. It gives an extra day or two for those with busy weeks.
f) The time-consuming activities given the current academic load.
g) With all due respect, I think that I wasted too much time completing the activities.
h) Time. Maybe I did not know how to handle time but I felt that I did not have enough time to do things.

4. *Liked Least*: Comments related to SRL.

a) It took time to get used to the appendices in the SRL manual.
b) At first, I could not understand the material and I had a hard time focusing to achieve independent study.
c) At first, the attitude was like "UGH, I just have to do all this work" . Also, it was a little frustrating when I was caught in a situation where I did not know exactly what was going on and had to read more because I was distracted by other situations. But overall, the experience was very cool! Thank you!

5. *Liked Least*: Comments related to kinematics graphs

a) The kinematics graphs problems.
b) The last four exercises in Chapter 5 of the Ranking Tasks book were the most complicated. I do not know if a little more information is lacking for those. Internet had almost no information on this type of problem to obtain more information to clarify doubts.
c) Some questions were kind of tricky and the exercises were very similar.
d) More different types of exercises but only because some of them are repetitive.
e) This was homework. I did not like it.
f) Have more time in class to see the solutions of graphs that we did not understand because I do not know if I was doing the right thing in the exercises.
g) Sometimes some things tended to confuse me and I sometimes had a little doubt when interpreting the kinematics graphs.

h) Completing the ranking tasks exercises.
i) There was nothing wrong, everything seemed fine to me.
j) Too many questions, but it also helped me to understand the subject.

Discussion of Results

Table 1 shows a statistically significant ($p < 0.05$) gain in the average test score of 62% which provides a positive outlook for using SRL. However, there is a sense of dissatisfaction regarding the fact that the result of the post-test (42%) was only slightly higher than the 40% average score reported by Beichner (1994).

Table 2 shows a statistically significant ($p < 0.05$) improvement of 15% regarding the students' own sense of self-efficacy, and their capacity for delayed gratification (self-control). All the other items did not show a statistically significant difference between the start and end averages.

Table 3 indicates that students, in general, prefer to conduct learning sessions while alone, in silence, and sitting down (versus learning in a group, with music, and while lying down).

There were eleven positive comments about SRL (1a – 1k). These give an indication that many students grasped the idea of SRL and valued its advantages.

There were five positive comments about kinematics graphs (2a – 2e). It was satisfying to read that Arons' table was mentioned because this kinesthetic activity addresses one of the three root causes of difficulties (*The student cannot connect the kinematics graphs to a concrete and visible experience*).

There were eight negative comments related to the insufficiency of time (3a – 3h). These comments have proven valuable. The Manual for SRL of Kinematics Graphs (Morales, 2021) will be shortened.

There were three negative comments related to the SRL experience (4a – 4c). The comments were related to the initial shock of confronting a new topic (SRL plus the "ranking tasks" format of the exercises), and the shock of realizing that learning would be based on self-instruction.

There were 10 negative comments related to the process of interpreting kinematics graphs (5a – 5j). Although the "ranking tasks" type of problems were useful, students found them repetitive. Adding diverse types of exercises would be more appropriate. It is also clear that students require more feedback with these problems.

Limitations

The main limitation of this study was the small number of participants (N=19). However, the small number of students did not affect the quality of the comments which the author will use to revise the two books used in the study.

Conclusions

These initial results provide a positive outlook that the development of SRL skills contributes to improvements in online instruction. Students showed gains interpreting kinematics graphs and in developing intra-personal skills.

The two books used in the study proved to be useful for improving the students' SRL skills and improving the skill of interpreting kinematics graphs. However, student comments indicate that the SRL manual should be shortened. Also, that the graph workbook should include additional types of problems that are of a different nature than "ranking tasks" type problems. This would avoid repetitiousness and make the activity more attractive.

Most students reacted positively to the self-instruction style (independent study) that was requested of them. However, the comments show that adding explanatory videos of the materials, and videos that show solutions to some problems (including Arons' table), will improve the learning experience when conducted in this self-instruction style.

Further research

In this study, the SRL manual was embedded within the topic of kinematics graphs. It seems appropriate to prepare a shorter document that develops SRL skills independently of any topic. It could then be used (with a companion video) for any learning situation. A research study would be required to determine its effectiveness. It would still have surveys and other activities which were proven in this study to be useful to students. These activities assist students in monitoring their progress as they master the SRL skills.

In addition, it seems evident that the development of SRL skills promotes the use of an inverted (or flipped) classroom because SRL skills foster self-instruction. Therefore, instead of using class hours for lectures, the instructor could use the time to provide feedback, to give written exams, and to give individual oral exams that would thoroughly assess students' knowledge and eliminate any doubts regarding the progress of each student. The author is planning a research study to determine the effectiveness of this methodology.

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