Implementing an Active Learning Platform to Support Student Learning in a Numerical Analysis Course

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***Abstract*— Classroom instruction in the 21st century needs to incorporate innovative, research-based pedagogies. The engineering classroom is currently experiencing a shift towards more active learning activities due to both advances in educational research, and advances in technologies that enable practices such as the flipped classroom model. Given that course transformation is a gradual process that begins at the level of the instructor, educators need access to the essential tools and training in order to introduce these changes into the curricula. This paper introduces a course re-design based on Self-Determination Theory and Constructivism; and outlines effectively implemented active learning strategies using the flipped classroom model. The data were collected from a Numerical Analysis course, which is an important course across several engineering disciplines at Universidad EAFIT. This course enables engineering students to solve complex problems using mathematical and computational methods. This paper describes the implementation of an online active learning platform called "*Numérico Interactivo*" for two related engineering courses: Numerical Analysis (NA) and Numerical Processes (NP). The platform was available to all students, but only NA implemented it using a flipped classroom model. NP made the platform available as an optional course tool. Informed by SDT principles, "*Numérico Interactivo*" includes a variety of instructional materials such as explanations, examples, frequently asked questions (FAQ), self-assessment tools, and evaluation. This study compares the two courses in terms of: (1) students' perceptions about the instructional materials of the course; (2) students' use of the platform; and (3) students' perceived usefulness of the different elements within the platform. Results suggest that students in the NA course found the classroom sessions and the homework assignments more useful as compared to the students enrolled in the NP course. In addition, in the NA course students used the platform more often for class preparation and to study before each module. The way in which the platform was implemented in NA also increased student motivation in the course. Overall, the results suggest that "*Numérico Interactivo*" is useful to implement course re-designs into engineering and computing education courses, but such tools need to be guided by active learning practices so that students can fully benefit from them.**

Keywords—active learning; numerical analysis; numérico interactivo; flipped classroom;

I. Introduction

The technological developments, the novel approaches to learning, and the current global conditions compel us to change methods, pedagogies and styles in order to organize the learning environment. These can be enriched by incorporating more dynamics and appealing/strong tools for the integral formation of our students. In general, traditional environments are organized so that students understand the topics of the class. Following the new approaches of active learning, the classroom could also develop other processes of knowledge and integral formation such as: applications, refutations, defining new alternatives, performing in various contexts, etc.

As Mitchell [8] notes, the flipped classroom model was conceived many years ago, however its implementation was challenging given the state of Teaching and Learning Technologies (TLT) in the past. New advances have made it possible to better implement this model; this paper presents an example of how an online numerical analysis platform was used to implement a flipped classroom re-design. The flipped model structures learning in a fundamentally different way than in the traditional classroom model. The traditional model consists of in-class lectures, discussions and activities. The students practice the concepts learned in the lectures doing homework or projects afterwards. In the flipped model, the time spent for direct instruction and completing content-related activities for homework is "flipped". That is, students are assigned online activities in preparation for class and in-class time is spent doing hands-on activities (what would traditionally be homework) with the instructor as a guide. This allows for in-class active learning, questions, collaboration, discussion, and completing assignments. Students spend more class time working with their peers in a collaborative, student-centered environment. In other words, in the flipped classrooms model there is a greater focus on the challenging content during the live classroom and instructors develop meaningful discussions. An implementation of flipped classroom model in the context of Numerical Methods has been described in [6][7].

This paper explores the implementation of an online platform called "*Numérico Interactivo*" into two engineering courses focused on introducing numerical analysis tools: Numerical Analysis (NA) and Numerical Processes (NP). The platform resulted in different experiences and experiments which have been addressed in order to optimize the designed outcomes for the course. Some of them are web pages, blogs, student projects sites, complementary videos, wiki, internet lessons, and PowerPoint with audio. The platform integrated some of these experiences in a framework which can be used as a method and a strategy for any course. The online platform was

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implemented using a flipped classroom approach in the NA course, but not in the NP course.

The guiding research question for this study is: *How do students' perceptions about the usefulness of an online learning platform differ when implemented in a flipped classroom?*

The next section (II) describes the theoretical framework. Section III briefly describes the tool "*Numérico Interactivo".* Section IV describes the methods we used to answer our research question. Sections V and VI present the results and discussion of these findings correspondingly. The paper finishes with the conclusions and future work.

II. THEORETICAL FRAMEWORK

Research on teaching and learning provide evidence that active learning and collaboration is more effective than traditional lecture [9][12][17]. Applying this research to improve undergraduate education starts by incorporating more effective pedagogical techniques across disciplines. Active learning is defined by Michael [10] as the "process of having students engage in some activity that forces them to reflect upon ideas and how they are using those ideas" (p.160). The learning theory that gave rise to active learning pedagogies is Constructivism. This theory was founded on the observation and scientific study about how people learn. The overall concept behind constructivism is that human learning is constructed and built upon previous knowledge [4]. The theory has its roots in philosophy, psychology, sociology, and education [4], and it was founded on subsets of research within cognitive psychology and social psychology [5]. Currently, there are various forms of constructivism, like cognitive constructivism and social constructivism; however, the key common aspect of the theory states that adaptive behavior is produced by the individual's processing of stimuli from the environment and the resulting cognitive structures [5]. Cognitive constructivism is derived from the work of Piaget [11], who described learning as an act of accommodation, assimilation, and equilibration. Brandon and All [1] note that constructivism theory encourages learners to be active creators of their own knowledge. From this view, the role of the student is to select and transform information, construct ideas, and make decisions, while relying on cognitive structures. Thus, conceptual growth comes from sharing various perspectives and changing the student's internal representations in response to those perspectives; as well as from their previous experience [4]. In this type of learning environment, students invent solutions and construct knowledge in the learning process, instead of fully relying the instructor's knowledge/textbooks for solving problems. The student and the instructor engage in an active dialogue, and the instructor encourages students to discover principles by themselves. The instructor is then charged with designing a learning environment that aligns with the student's current state of knowledge and which fosters a student-centered environment. These notions were of great influence as we planed the current re-design.

In order to create a more holistic approach to our redesign, Self-Determination Theory (SDT) [2][3][13][14][15][16] was also taken into account. While Constructivism allows us to design activities that foster active learning, SDT serves as a complement to address student motivation and to examine how the creation of a student-centered learning environment promotes the satisfaction of the three basic psychological needs postulated by the theory: autonomy (self-choice), competence (mastery learning), and relatedness (connections/relating to the real world), [13]. SDT establishes that when a learning environment promotes autonomy, students are able to take decisions about their learning by volition/freedom of choice, endorse their own behavior, and own the learning process. As a consequence, students take responsibility of their own learning (i.e. active learning). When the learning environment promotes competence, the students progressively become proficient and acquire mastery in the subject. Finally, when the learning environment promotes relatedness, students are able to establish relationships with others in the class (fellow students and instructors), as well as relate learned material to their lives and the real world. As the *Numérico Interactivo* platform was re-designed, we also took into account how each module addresses each of these basic psychological needs. We propose that in order for the flipped model to be successful, students must be self-motivated to learn and use the tool before coming to class. SDT allows us to better understand which aspects encourage student motivation.

III. THE TOOL

"Numérico Interactivo" is an interactive tool designed to support student learning of numerical methods in engineering programs. *Numérico Interactivo* can be used by instructors and students before, during, and after the class. The interactive tool is divided in chapters. Each chapter is divided in sections, which are structured and articulated in order to follow the goal of each chapter. Each section is divided in elements and all elements of the interactive tool are defined with: one purpose, one topic, some pedagogical strategies, and consideration of the three main basic needs of SDT (competence, relatedness and autonomy).

The instructors can organize each session according to the learning goals, by integrating different elements and resources from the tool. Similarly, the students can find resources on demand. In this way, the same learning environment is defined by all actors and it is assumed as an articulated system with other components in backward and forward direction. The elements comprised by *Numérico Interactivo* within a given instructional design are described below:

- **Purpose**. Each session was defined to address one learning goal. This goal can be related to student understanding of specific concepts or methods, or to their proficiency with an ability or skill.
- **Pre-work**. Students and instructor prepare the session using the book, the platform, and other resources. The pre-work is used for preparation, as a diagnostic tool, and as a motivational driver before the class. Before the class, the student had attained general and basic ideas and questions about the content of the actual session. Moreover, as the students make progress, the pre-work becomes more complete and important. The available resources include: videos, slides, background knowledge, diagnostics, and existing applications of the given knowledge. The *pre-work is* key component to implement the flipped classroom approach.

- **Development**. The elements of this module include practical activities, FAQ, examples, concept maps, the description of numerical methods, and connections with other resources of the course. These elements can be used by the instructor and the students in different ways based on their preferences and the goal of the activity. For instance, one group of students can solve a challenge using these resources in the classroom while the instructor provides scaffolding. Some components are discretionary while other are required. The platform offers interactive content, methods, techniques and instructions about of specific processes in numerical analysis.
- **Projection and consolidation**. This module allows students and instructors to consolidate, evaluate, and provide feedback for a given session. The module contains two assessment components for the student. The first one, *process assessment* is useful for providing interactive feedback using of problems solving. Some problems have suggestions for the students: ideas, methods, solution sketches, answers, or recommendations. The second component is called *conceptual assessment* and provides interactive feedback through tests and questions that have following formats: true-false, multiple choice question, assertion-reason, multiple response and fill-in-the-blank questions. Each question has one correct answer with automatic feedback.

In summary, the tool support the implementation process of pedagogical strategies such as active learning or flipped classroom. The structure of Numérico Interactivo can also be applied to others courses. Each element has a function in the tool but these can be redefined based on the different needs of different courses.

IV. Methods

A. Participants and Procedures

110 Students participated in this study. 79 students were enrolled in a course called Numerical Processes (NP) and 31 students were enrolled in a course called Numerical Analysis (NA). The platform *Numérico Interactivo* was available for both groups of students, but only the groups in NA followed a flipped classroom approach. This approach consisted of having students review the elements of the platform for a given week, before coming to the classroom session. The classroom session started with a quiz that was designed to validate whether students had review the materials or not. After the quiz, the course instructor answered any questions students had and students worked collaboratively to solve practice exercises. The NP course did not use any specific instructional approach to implement the platform. Instead, students were given access to the platform, and they could use it as they preferred.

B. Data Collection

At the end of the semester, students completed a survey with 62 questions that were intended to identify the three elements of the self-determination theory as related to the platform: autonomy (self-choice), competence (mastery learning), and relatedness (connections/relating to the real world). For the scope of this paper, we explore the following scale questions in the context of the two courses:

In a scale 1-10, please rate the usefulness of the following course materials for your learning process:

- Classroom Sessions
- Textbook
- Course project
- Homework Assignments
- Additional practice exercises
- *Numérico Interactivo*
- Lecture notes
- Past Exams

In a scale 1-10, please rate the degree in which you used *Numérico Interactivo*:

- To prepare for the class activities
- To reinforce what I learned during class
- To prepare for the exams
- To complete the course project.

In a scale 1-10, please rate the degree in which the use of *Numérico Interactivo* increased your motivation about:

- The course
- The classroom sessions
- The exams
- Your academic program

C. Data Analysis

The analysis process of the survey data started by looking at the descriptive statistics (i.e. mean and standard deviation) of each question for each group. An average value between 1 and 3.5 was considered a negative perceived usefulness; values between 3.5 and 7 were considered to be a neutral perception, and an average value higher than seven was considered a positive perceived usefulness.

The second step in the data analysis corresponded to the use of inferential statistics to identify significant differences between the two groups that used *Numérico Interactivo*. We used a two-sample t-test with an alpha level of 0.05 to reject the null hypothesis. The null hypothesis was that there were no significant differences between the groups.

V. Results

Fifty-four students completed the survey instrument at the end of the fall semester 2016. Sixteen of these students were enrolled in the course Numerical Analysis (NA), and 38 students were part of Numerical Processes (NP). Table 1 presents both the descriptive and inferential statistics for the first set of questions, related to the course materials. Overall, students in the course that implemented the flipped classroom showed a positive perceived usefulness for the classroom sessions, the course project, the homework assignments, the practice exercises, the platform, and the lecture notes, and a neutral perception for the textbook and the exams. These students perceived the classroom classes, homework assignment, the platform, and the lecture notes to be the most useful components of the course (i.e., average value larger than 8). Conversely, the students in the NP course showed a positive perceived usefulness only for the course project and the practice exercises, and a neutral one for the rest of the course components.

The research team used Bonferroni correction for the two-sample t-test in order to reduce the probability of type I error. Thus, a significant difference should have a p-value less than 0.0063 (i.e., 0.05/8). Students in the NA course reported a significantly higher perceived usefulness for the classroom lectures and the homework assignments compared to students in the NP course. This result suggests that students exposed to the flipped classroom approach found the activities within the classroom to be more useful than students with traditional classroom lectures.

TABLE I. STUDENTS' PERCEIVED USEFULNESS OF THE COURSE MATERIALS

Course Material	Measure	NA	NP	t(52)	P-value
Classroom Sessions	Mean	8.69	6.42	3.10 [a]	0.003 [a]
	SD	2.02	3.25		
Textbook	Mean	6.5	6.34	0.18	0.86
	SD	3.12	2.92		
Course Project	Mean	7.75	7.45	0.42	0.67
	SD	2.32	2.42		
Homework Assignments	Mean	8.5	5.89	3.67	0.0005 [a]
	SD	1.75	2.60		
Additional Practice Exercises	Mean	7.31	7.03	0.34	0.74
	SD	3.05	2.75		
Numerico Interactivo	Mean	8.38	6.82	1.81	0.076
	SD	2.60	3.00		
Lecture notes	Mean	8.25	6.79	1.81	0.075
	SD	2.54	2.76		
Past Exams	Mean	4.5	5.21	-0.68	0.497
	SD	3.27	3.58		

a. Statistical significant difference with Bonferroni correction, p-value<0.006

Table 2 presents the descriptive and inferential statistics for the questions regarding the use of *Numérico Interactivo*. Students in the NA course used the platform *Numérico Interactivo* significantly more than students in the NP course to prepare the classroom activities. Students in the NA course, which used the flipped classroom approach, also reported that *Numérico Interactivo* increased their motivation in the classroom session. This result was close to be statistically significant (p-value=0.007) with Bonferroni correction (alpha=0.006) when compared to the lecture-based course (NP).

TABLE II. STUDENTS' USE AND EFFECT OF NUMERICO INTERACTIVO

Variable		Measure	NA	NP	t(52)	P-value
Use	To prepare for the classroom activities	Mean	8.63	3	8.490	<0.00 [a]
		SD	1.54	2.69		
	To reinforce what I learned during class	Mean	7.75	7.6	0.174	0.864
		SD	3.04	2.04		
	To prepare for the exams	Mean	9.31	8.4	1.834	0.074
		SD	1.14	2.04		
	To complete the course project.	Mean	6.56	5.04	1.466	0.152
		SD	3.22	3.27		
Increases Motiva-tion	The course	Mean	7.38	6.92	0.562	0.579
		SD	2.68	2.27		
	The classroom sessions	Mean	7.75	5.56	2.898	0.007
		SD	2.44	2.24		
	The exams	Mean	8	6.96	1.332	0.192
		SD	2.34	2.59		
	Your academic program	Mean	6.69	5.64	1.187	0.243
		SD	2.60	2.98		

a. Statistical significant difference with Bonferroni correction, p-value<0.006

Overall, these results suggest that students exposed to a flipped classroom approach were able to take more advantage of *Numérico Interactivo*. This benefited their perceived usefulness of the classroom activities, as well as their motivation to perform these activities. The NA students gave greater importance to the activities involving the tool before, during, and after the class sessions. On average, although not always statistically significant, all reported uses and changes in motivation were higher in the NA courses compared to NP courses.

VI. Discussion

This study explored the differences on students' perceptions between two groups that used an online active learning platform. One group used a flipped classroom approach, while the other group was able to access these resources on demand. Specifically, the research team aimed to answer: *How do students' perceptions about the usefulness of an online learning platform differ when implemented in a flipped classroom?*

The findings from this study suggest that using a flipped classroom approach to implement *Numérico Interactivo* helped students to value the classroom activities and the homework assignments as more useful. This approach also helped students to prepare for the classroom activities, and to increase their motivation to attend the classroom sessions. These results support the premise of Self-Determination Theory (SDT). As per the theory, if the learning environment promotes active learning and the course and tools are designed in a student-centered manner; this environment is likely to nurture and satisfy the three basic psychological needs: competence, autonomy, and relatedness. When these needs are satisfied, student motivation becomes more self-determined and this leads to the type of student behavior and appreciation for the content observed in the current study. Self-determined motivation are forms of motivation which guide behaviors that are valued and chosen by individuals (without external pressure). In contrast, non self-determined types of motivation generate behaviors that are coerced or pressured by others. As stated in the previous section, the students exposed to the flipped classroom model took greater advantage of *Numérico Interactivo*, perceived the classroom activities as more useful, and reported greater overall motivation than those who were not part of that learning environment.

VII. Conclusions, Limitations, and Future work.

This study explored the classroom implementation of an online active learning platform in the context of two engineering courses of numerical analysis. One of the courses used a flipped classroom approach while the other simply opened the platform for students to decide when and how to use it. This study found that using the flipped classroom approach has an effect on students' perceived usefulness of the classroom sessions as well as the homework assignments. This strategy also had a positive effect on the student motivation for the classroom activities, and had students using the platform more often to prepare for these sessions.

In summary, we present some recommendations about how to incorporate new alternatives in a learning environment. Our approach includes technological tools, pedagogical strategies, educational frameworks and other resources in order to guaranty a modern learning environment which includes a more multifarious formative process that goes deeper than the surface understanding process. We consider that a modern classroom learning environment should encourage processes such as: analysis, searching for alternatives, designing new methods, abstraction, self-learning, self-evaluation, confronting misunderstanding, facing new challenges, etc.

The main limitation of this study is that students completed the survey voluntarily and therefore, not all the students in these groups reported their perceptions. A second limitation is that our tests are not controlling for the effect of different instructors on students' perceptions.

In the future, we will address these limitations by encouraging all students to complete the survey, and controlling for variables that could affect students' perceptions. In addition, we will incorporate relevant SDT validated scales to the survey instrument to further assess the students' fulfillment of the basic psychological needs, their perception of the learning climate in terms of autonomy support, and their self-regulated motivation. Furthermore, we will explore nuances for the implementation of the flipped-classroom approach, to provide formal recommendations for this instructional practice. Other instructors could also contribute with contents in different way. For instance, it is possible to translate the platform content into another language; right now the content is in Spanish.

To end, it is important to note that this study was only possible given the great institutional support that we received. We believe that teaching and learning innovations such as *Numérico Interactivo* should ideally be accompanied with support to help develop and maintain the teaching and learning technology (TLT). Equally important is to provide the necessary guidance and professional development to faculty and instructors for its successful implementation, for scaling it up, and for sustainability. Ultimately, TLTs are just tools that aid the instructor in creating and fostering student-centered learning environments; and this study shows that a combination of technology with innovative classroom pedagogies that are facilitated by instructors who are motivated to test new teaching approaches, make a difference in the students' learning experience.

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