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Importance of learning paths' design in MOOCs: An analysis under the socio-cultural vision of education lens

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Abstract

Massive Open Online Courses (MOOCs) have profoundly influenced online education, offering innovative approaches to learning and teaching that focus on autonomous work and carefully structured curricula. This study examines the relationship between adherence to a proposed learning path in a coding MOOC and students' performance in the course. A key component of MOOCs is learning processes which are organized activities intended to guide learners. However, the factors determining their success or failure have received little attention. An analytical method was used to collect, clean, analyze, and visualize data from the learning pathways in the course. A subsequent analysis was conducted to interpret the results grounded in the socio-cultural theory of education. The findings indicate that students who adhered to the proposed learning path performed significantly better than those who chose alternative navigation routes. This effectiveness is explained through the socio-cultural concepts of participation and reification which illustrate how the sequence of activities supports an environment conducive to meaningful knowledge construction. These results offer practical implications for the design and implementation of MOOCs, underscoring the importance of creating structured learning paths to enhance student engagement, performance, and overall learning outcomes. This study highlights the pedagogical value of intentional course design in digital education.

Keywords: Active digital learning, Massive open online course (MOOC) Evaluation, Online curricular design.

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1. Introduction

A plethora of courses have been available through the Internet for many years. However, a massive interest in online education has been growing among students and teachers worldwide. Such renewal of interest is a consequence of the arrival of Massive Open Online Courses (MOOCs). According to Jansenet al. [1], MOOCs can be defined as "online courses designed for large numbers of participants accessible by anyone and anywhere as long as they have an Internet connection are open to everyone without entry qualifications and offer a full or complete course experience online for free". Dissemination of MOOCs is outstanding. Thousands of participants are enrolled in a single course with over 7,000 in the few past years [2].

Information and Communication Technologies (ICT) evolve frequently and provide innovation in multiple services and functionalities for the design and implementation of MOOCs. One such innovation is the Learning Management Systems (LMS) which helps teachers to administrate, document, track down, report, automatize and deliver educational courses in e-learning environments [3]. A key component of an LMS is the denominated learning path which is defined by De Smet et al. [4] as "the LMS functionality to order several learning objects in such a way that they result in a road map for learners. Within a learning path, learning steps are structured in a general way (as a navigation map or a table of contents) or in a very specific sequenced way (e.g., complete first step 1 before moving on to step 2)" (p. 2). Learning paths enclose the potential to improve the interaction in the processes of teaching and learning between teachers and students, an interaction embedded in a digital environment. Therefore, in this study, we determine the effect of a determined learning path of a programming MOOC on the performance of students with a subsequent analysis framed by concepts belonging to the socio-cultural vision of education theory.

2. Literature Review

2.1. MOOCs in Higher Education

The widespread enrolment of MOOCs is a somewhat recent phenomenon starting in 2008 that obtained high acceleration around 2011 and 2012 [5] offering a scalable, sustainable and viable alternative form for teaching and learning in higher education [6]. Some stakeholders and teachers consider this sort of online course to be a keystone of transformation holding the potential of democratizing the higher education system [7]. In fact, such transformation can be evidenced in Dillahunt et al. [8] who identified that learners cannot afford formal higher education completion rates if they were motivated by the obtention of a certificate. Moreover, it has been elucidated that in 2014, students from 194 countries were involved in this sort of digital course [9].

MOOCs have also faced multiple criticisms from professionals in higher education and multiple sectors of education. Some researchers have declared that this type of courses was created looking for the benefit of universities as thousands of students might be enrolled with a lower number of teachers and learner interactions leading to a self-regulated and self-engaged learning environment [10]. Learners frequently have difficulty in such environments although this structure and lack of instructional support are not normal learning situations [11]. Therefore, the hot issues on MOOCs in present years are oriented to their differences, teaching methods and ideas and their potential effects in the current higher education models [12]. Furthermore, assessing the implications of MOOCs for learning becomes very challenging due to the large number of MOOCs available. There are some courses that are more well received by students than others leading to important questions on what makes a MOOC better than others at the time of promoting engagement in the online learning experience [13].

In all learning schemes, including online learning, student engagement has been considered an essential element for building knowledge and skill development [14]. Previous research has pointed out that student engagement manifests impacts in both short- and long-term development. According to research, participation significantly affects grades and behaviour in the earlier condition [15-17]. Concerning the latter, engagement has been linked to individual academic accomplishment, socially appropriate behaviors and self-esteem [18, 19]. Due to the vast and diversified student group, student involvement in MOOCs has become more challenging [13]. There are multiple student scenarios ranging from the ones who find engagement due to curiosity, personal interest or the possibility of an extrinsic value for work advancement [20] to the ones who are unable to engage and drop out before the completion of the course. Hence, the quality of a MOOC should be determined by the learning experience and the achievement of objectives of learning given that both can be good predictors of student engagement.

2.2. MOOCs and Learning Paths

Learning paths rely on a sort of building blocks normally identified as learning objects. Kay and Knaack [21] describe them as "interactive web-based tools that support the learning of specific concepts by enhancing, amplifying, and guiding the cognitive processes of learners". Learning objects within a learning path might display a variety of features and functionalities such as appearance, context, animation, content, structure and behavior. Hence, professors and teachers often decide the use of learning paths based on their multimedia nature [4]. Highly interactive learning objects might guarantee engagement among learners as they feel attracted to dive into the content and activities through multimedia channels [22]. A learner may demonstrate cognitive processes that select sounds or pictures, form mental models, and combine experiences with previous knowledge as they progress in the learning path. Such processes support cognitivist learning as they promote the development of abstract schemas of thinking which subsequently increase the learning performance [23].

Learning paths play a key role in the curricular alignment of MOOCs given that their design directly impacts the levels of engagement of students. Curricular alignment guides the curriculum design of a course by articulating learning objectives stated as clear actions that learners need to put into practice. These objectives are then developed through teaching and learning activities designed under pedagogical principles and teaching methods, ultimately providing well-designed learning paths to learners [24]. It has been discussed that a successful curricular alignment based on learning paths, combined with evaluation tasks designed to assess comprehension and deliver adequate feedback leads to the successful completion of a MOOC [14].

Some investigations have been developed in e-learning and intelligent tutoring communities regarding the impact of learning paths in digital education [25, 26]. However, little is known about its impact in MOOCs [23]. Empirical evidence has shown that multiple reasons lead learners to adhere to proposed learning paths in MOOCs such as lack of time, learning styles, engagement among others [27] but there is no further analysis of the impacts of such decision on performance. Therefore, it becomes evident that there is a lack of extensive study on the factors influencing the success or failure of learning path design in MOOCs framed by clearly defined educational ideas from recognised learning theories.

2.3. A Socio-Cultural Vision of Education under Learning Paths

Learning is defined as a process where knowledge is created through the transformation of experience [28]. Experiences lead to a cognitive transformation in the learner's mind through reflection and theoretical support providing active schemes for the building of knowledge. Conformable to the socio-cultural vision of education, learning must not be envisioned as an individual and isolated process in which the learner is able to enroll in a learning environment as a "receptor" and somehow create knowledge by passively interacting with a pedagogical scheme or through the repetition of specific actions [29]. Instead, such theory of education proposes that knowledge is created through active and complex interactions [30] as well as processes of recontextualization [31]. On the one hand, according to Wenger's [32] theories, students must participate in two types of interactions: participation and reification. The former involves actively interacting and creating identity in a community of learning, meaning that the learner must be involved in pedagogical actions so he or she can take an active part in the learning process. The latter addresses that learners should continuously be immersed in the process of transforming abstract information into real artefacts, so they can build their own constructs through experience. Students would be able to build significant learning by dynamically performing participation and reification. On the other hand, according to Van [31], recontextualization can be seen as the process in which the actions and meanings of a person become less determined by the aspects from the context in which they were originally learnt. Hence, significant learning can be fully developed when students are able to *recontextualize* actions and concepts from an original situation to new scenarios.

The success of a learning path can be conceived as how much the pedagogical scheme of it is able to deliver multiple and dynamic moments of participation and reification as well as deliver carefully designed processes of recontextualization. Such actions arise as critical in virtual environments as generating them might result in a challenging task taking into account the absence of face-to-face interaction. Nevertheless, professors must ensure the curricular alignment of the course contemplates such actions given that MOOC students navigate through learning paths in each course week and week after week. Therefore, the purpose of this paper is to describe the experiences of a case study MOOC of Java programming, focusing on the deployment of learning paths and explaining its success framed by the ideas of the socio-cultural vision of education.

2.4. Research Questions

- Does the structure of a learning path affect the success rate of students enrolled in a programming MOOC?
- How do socio-cultural concepts explain the success of a determined learning path?

3. Method

3.1. Setting

The case study chosen to determine the influence of the learning path on participants in the MOOC *Introduction to object-oriented programming in Java* was provided by Universidad de los Andes through Coursera in August 2017. This MOOC aims to address some well-known difficulties that students have while learning to program such as motivational problems and lack of balance between two key aspects involved in programming: algorithmic thinking and coding. The MOOC intends to contribute to the overcoming of these difficulties by means of 1. An active learning approach based on problems. 2. A balance between abstraction and programming skills development. 3. A pedagogical methodology highly supported by Information and Communications Technology (ICT) tools to help students learn to program in a structured way. This MOOC seeks to provide a highly interactive way to learn how to program under the object-oriented programming paradigm which allows students to validate not only their theoretical knowledge but also their coding skills. What is innovative about this course is that it gives real-time feedback to students on their performance on specific programming tasks as well as provides feedback to students on how well they code, what mistakes they make and why their solution is incorrect. Therefore, students understand their difficulties and correct their code as many times as they need as the principal axis of a learning path.

The learning path designed for this MOOC starts by introducing theoretical concepts to learners. Then, students' transit from theory to practice in a dynamic way throughout coding video lectures. Subsequent coding challenges are presented to participants with real-life problem situations at different difficulty levels (basic, medium and advanced) where they are encouraged to test and improve their coding skills. Afterwards, the teacher engages the learners in the building of a relatively complex solution for a real-life problem through software development. Finally, a process of evaluation is carried out to obtain information about the level of theoretical and practical knowledge that students have acquired. It is important to highlight that such a learning path is encompassed with active learning elements all the time. Examples of tools used to support active learning are CupiExámenes (https://cupiexamenes.virtual.uniandes.edu.co/), CupiTips (https://cupitips.virtual.uniandes.edu.co/#/) and an in-house developed eBook (https://universidad-de-los-andes.gitbooks.io/fundamentos-de-programacion/content/). CupiExámenes is a web application that enables the creation, solution, and automatic grading of programming assessments based on carefully designed study cases. CupiTips is another web application in which students can interact with the most common mistakes made while programming in Java. For each identified mistake, it is possible for the student to consult the associated topic, the description of the mistake and several examples. Students must correct the mistakes in the code and obtain feedback to create a reflection learning environment. Lastly, the eBook arises as a complementary tool within the learning process in which students are encouraged to explore theoretical concepts in depth.

Overall, the MOOC consists of five modules each to be developed within 1-2 weeks. Most of the modules were developed with the same didactic structure consisting of a motivational video, a recommended reading from the eBook, a group of well-organized and sequential theoretical video-lectures, three programming challenges and a theoretical and practical assessment. In total, the course comprises 81 videos, 33 readings, 12 challenges (distributed as one basic, one medium and one advanced over the first four modules), four automatically graded theoretical exams, four automatically graded practical exams, five peer-review assignments, and 5 forum discussions (1 per module). Module five does not include challenges or assessments as it is focused on the integration of knowledge. Considering that interaction in the learning process, understood as a planned opportunity for knowledge construction with others within a community for practice and learning has been claimed as critical for digital environments [33]. Two pedagogical spaces have been dedicated for it. First, there are academic or technical consultation forums and the open-reflection forums created for each module where peers interact both among them and with the course instructor. Second, students dive into peer-reviewed activities in which they can apply what they have learned following specific guidelines designed by the teacher.

3.2. Data Sources

Two different data sources were used to extract data for analyzing the results of the course in regard to the research questions established. On the one hand, MOOC data measures were collected from all MOOC activities such as videos, readings, challenges, practical and theoretical assessments, peer-review assignments, and visualization of concept maps (only developed in modules 1 and 2). This resulted in a total of 24 variables. The order of MOOC activities (timestamps) was also retrieved. This information is available on the platform as Coursera CSV (Comma Separated Value) files which include all the data that Coursera stores about the course and user's activity. On the other hand, students' performance on programming, measured as grades of challenges and practical assessments on CupiExámenes was used to obtain insights into the effects of the proposed learning path. CupiExámenes information consisted of a grades database (PostgreSQL relational database) and an activity log (an unstructured text file of approximately 3 GB (gigabytes) that stores entries for every activity graded by the tool).

3.3. Data Pre-Processing

We concentrate on preparing the data once it has been collected to properly arrange it before loading it into the analytics tools. In this phase, an ETL (Extraction, Transform and Load) process was performed [34] in which the raw data was extracted from the sources, cleaned and consolidated using software developed on Java, Python and Tableau. The resulting data was stored in CSV files that were later loaded into the analytics tools. Hence, data from *CupiExámenes'* database was extracted through in house-developed Java software to clean, standardize and store information about the grades obtained by all students in each practical activity in CSV files. Then, using Python software, the IDs (Unique User Identifiers) for every user were obtained from the log to map CupiExámenes users to their corresponding Coursera ID. The generated files were consolidated with the Coursera exports through the students' ID (especially with the course progress that stores the timestamp for every attempt a student has made for each activity) to generate consolidated CSV files that were used as input for the analytics tools using Tableau software. Data from modules one to four was consolidated through this process. Data from module five was discarded since it does not include challenges or assessments. The preprocessing process is illustrated in Figure 1.

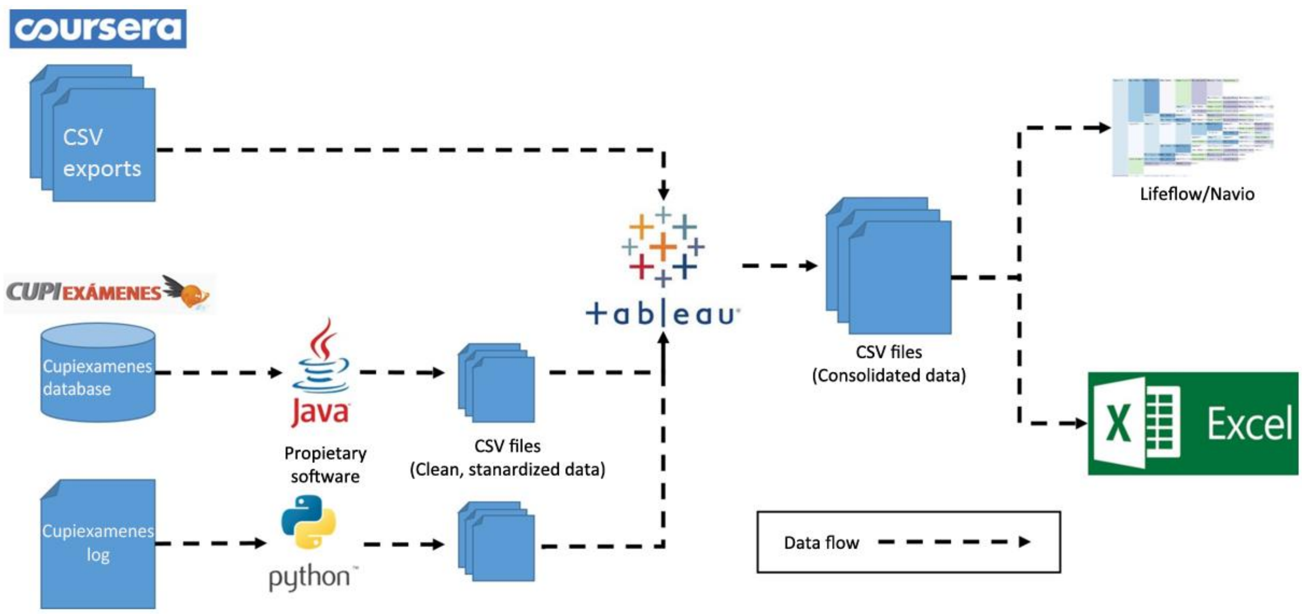

Figure 1.
Preprocessing phases. ETL (Extract, Transform and Load) process for the data.

After data preprocessing consolidation, the volume of data obtained for the analyses in a number of records was 346,062 when considering all students, 113,382 for paid users of the course and 43,197 for completers. Additionally, the data indicated that each student attempts 162 times throughout all course activities.

3.4. Tools for Data Analysis

Two approaches were developed to explore the preprocessed data. In the first one, we used multiple tools for data visualization that make use of EventFlow [35] and Navio (https://navio.dev/). EventFlow, which is an evolution of Lifeflow [36] is a visual analytics tool for temporal categorical data developed at the Human-Computer Interaction Lab (HCIL) of the University of Maryland. The tool was designed to support summarization, exploration and querying of event sequences across time derived from the categorical properties of the data. It introduced clever visualization techniques that summarize thousands of records into an Icicle-like tree structure [37]. The tree aggregates all the possible sequences present in the records making the visualization able to represent them as aggregated bars arranged in the vertical axis. On the other hand, Navio is a visualization widget that summarizes large multivariate data into a single tabular representation which also allows for dynamic queries. The data is presented initially in the natural order it comes in, but the user can easily sort it by attributes. Additionally, once an interesting pattern is identified, the user can create range filters or categorical filters. The user can also combine filters with additions or negations. Once each filter is applied, a new Navio is presented to the user showing the subset of data filtered while keeping the original one for context. Then, the user can perform nested queries just with simple visual interactions while keeping the context visible.

Regarding the second approach, we soon realized that Event Flow was good for the initial explorations, since the data was composed of a series of time-based (categorical) events in the course as well as the main analysis was to understand and compare the overall paths followed by the students. However, we encounter an absence of functionalities for allowing users to quickly explore and query the original data in a dynamic way. To alleviate such a lack, a custom in-house prototype was built that combines a basic implementation of the tree summarization technique of Event Flow with the query flexibility of Navio. In a notebook-based platform for prototyping in JavaScript, when data is loaded the tool displays a visual summary of it using Navio. Users are subsequently able to query for specific subsets of the data. Each time a query is made, the tool displays a summary of all the common paths for that specific query, using a custom-made Event Flow summary visualization (without including the time parameter). This strategy allowed us to compare paths for different subsets of the data and enabled us to generate and quickly test hypotheses. Furthermore, inspired by other projects such as Similian [38], a simple querying system was implemented that finds all the paths that include a particular event without filtering out all the other events (e.g., show all the activities taken by students who took the module 2 exam).

3.5. Data Analysis

Tableau and Excel were used to obtain grades' statistics and create diagrams while LifeFlow/Navio strategy was used to report the students' learning paths. The following two student groups were defined given common characteristics of MOOCs to analyze such paths: students who finished the course and students who did not. Each one of them was also classified according to their average practical activities' grade (theoretical grades were ignored as they did not show a significant difference between students). Additionally, learning paths were analyzed for each course module.

After loading the CSV file with the information of all students, a filter on the average (filter by grade) was applied to obtain those above 4 over 5. A second filter (filter by module) was used to isolate data for module 1, obtaining a total of 50,915 records. It was then necessary to order them by timestamp to obtain the learning paths as displayed in Figure 2.

Figure 2.
An example of resulting learning paths in our LifeFlow prototype

Each of the bars in the learning paths represents an activity or an aggregated activity to simplify the analysis as in the case of videos. The bar's height represents a number of students following that particular path. For instance, the root in Figure 2 displays the number 453 meaning that a number of students started module 1 with an average grade above 4.0. From those students, 372 continue their paths by taking the entrance assessment and 355 continue to watch a video. Such analysis allowed us to determine the most common paths for each specific group of students and to identify emerging patterns.

We were also interested in the analysis of student's performance on challenges, practical and theoretical assessments. These measures were calculated for all active students who took challenges as well as for the paid students who developed challenges, theoretical and practical assessments on each module of the course. Finally, we decided to explore the behaviors of the students with the best and worst results who have completed the course. Their particular paths were studied with a twofold purpose: looking for emerging patterns that could be related to their performance and comparing them with the paths analyzed for the above-mentioned groups.

4. Results

Statistical analysis made over the grades indicated that all students who presented the theoretical assessments obtained higher results (4.49 average). Therefore, such results were discarded as a filter for learning path analysis. Additionally, we found a notable difference in the performance of students in practical activities (challenges and assessments) leading us to select these activities as a filter for determining students' learning paths. Furthermore, all students were divided into three groups by the average graded obtained in practical activities: *i)* high performance (students who obtained a grade of 4.0 or higher), *ii)* average performance (students who obtained a grade between 3.0 and 4.0) and *iii)* low performance (students who obtained a grade of 3.0 or below). The diagrams obtained for modules 2, 3 and 4 are illustrated in Figure 3 to illustrate the learning path analysis results in terms of those groups.

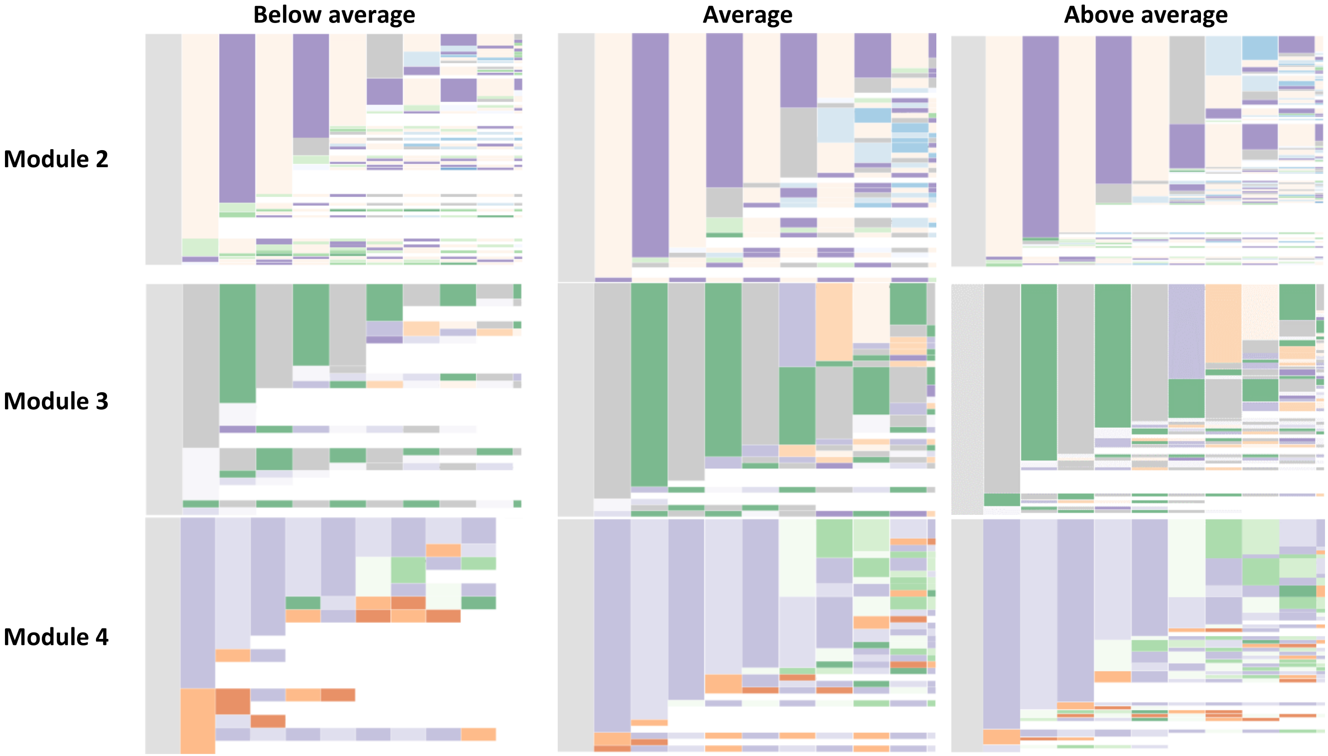

Figure 3.
Learning path analysis for low, average and high performance.

Overall, learning path analysis from modules 2, 3 and 4 allowed us to obtain interesting patterns observed in students. First, data indicates that most of the high-performance students followed the proposed learning path which included the competition of the three levels of difficulty challenges (basic, medium and advanced) with the subsequent development of theoretical and practical exams.

We found that some students had to use more time going back and forth with videos and readings, but they eventually moved on to the development of challenges and assessments as the rest of the group. Second, some students belonging to the average group showed similar behavior in their learning paths as those with high performance. However, the latest ones displayed a high variability in their learning paths.

Third, we established that most of the students with low performance followed the proposed learning path for videos and readings; nonetheless they only developed the challenges catalogued as of basic difficulty leaving unresolved medium and advanced challenges.

Additionally, those who developed the basic challenge often returned to videos and readings before retaking the challenge. Finally, data analysis showed that in every performance group analyzed, there are some outliers who in each of the modules, developed the theoretical assessment first and then proceeded with videos and readings, to sometimes retake the assessment. In this case we found there is a higher rate of dropouts.

Regarding the case analysis of the best and worst completers, their learning path results were almost identical to their corresponding performance group patterns (see Figure 4). Since the space in the images for this paper can be too restrictive to read the labels, please refer to the color legend (see Figure 5) to help you matching the colors to activities.

We found a particular and significant difference, nevertheless, as the number of attempts on activities along the course result in more than 300 extra attempts in the case of the worst completer in comparison with the best. This data shows that a high-performance student does not need to retake too many activities to complete the course as someone with a low performance does, a phenomenon also observed in the groups' learning paths.

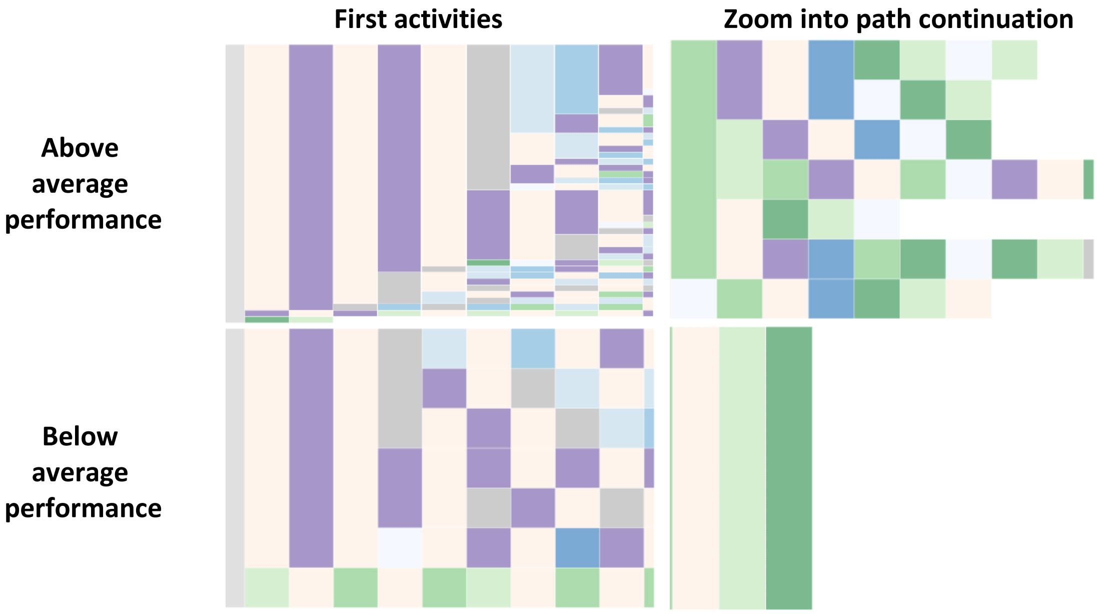

Figure 4.
An example of learning paths from the best and worst completers in module 2.

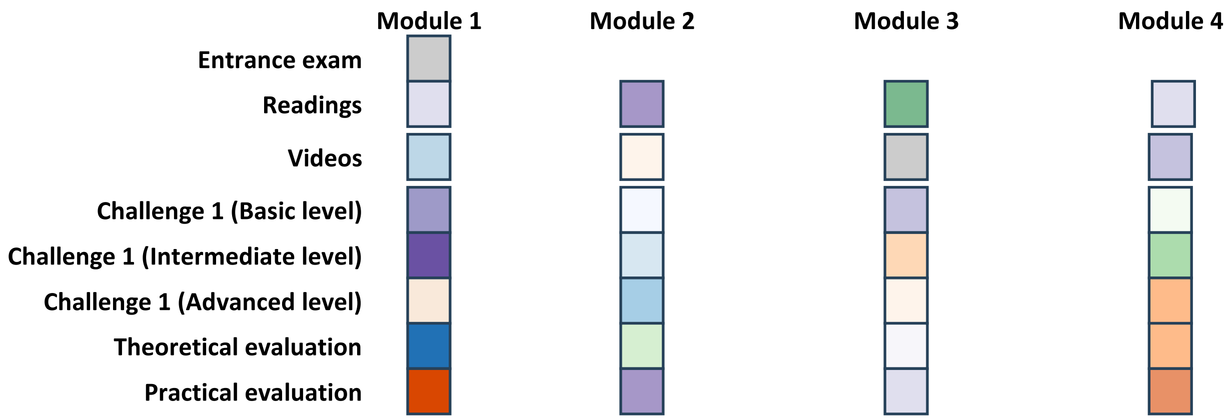

Figure 5.
Color legend for the images. In the prototype, interactive labels were provided that let the user identify each activity more easily.

5. Discussion

The research strategy described was elaborated to establish whether the deployment of a carefully designed learning path positively influences the learning outcomes of the programming MOOC. Following a well-structured quantitative approach, data indicates a strong difference in performance between those students who follow the proposed learning paths along the development of the MOOC and those who attempt to follow another self-made route for the competition of the course. The results obtained in this study provide a strong insight into how our pedagogical design successfully generates an educational construct that improves how students approach online education which derives in a better understanding of programming concepts and an efficacious development of programming skills throughout the MOOC.

Such success of the proposed learning path can be explained under participation and reification concepts proposed by Wenger [32] in the socio-cultural vision of education. Regarding the former concept, participation is enriched throughout all the proposed learning paths as students navigate from theory to practice getting involved in multiple challenges as well as being encouraged to test and debug for improving coding skills. Moreover, facing real-life problem situations leads to participation processes given that an active pedagogical atmosphere is created where students are able to analyze, inquire, discuss, and evaluate multiple scenarios with alternative complex solutions. Consequently, students were able to interact with multiple forms of participation during the MOOC, promoting action and connection between theoretical programming notions and coding practices.

In terms of the latter concept, reification was fostered in students through a three-fold approach. First, the act of transform ideas into code itself is a powerful way of reification, giving those fragments of code becomes objects that represent the understanding of students which is manifested through specific computational commands and concepts. Therefore, the different levels of difficulty of exercises, carefully designed by professors, help the students to move from basic to complex cognitive constructs through reification processes. Second, students reify as they were encouraging to draft step-by-step the solution proposed for the real-life problem situations exposed in the course. Third, examinations allowed the learners to challenge their knowledge and represent it as objects in defiant scenarios, triggering complex processes of reification in scenarios under pressure.

Overall, students who followed the proposed path of learning displayed a better performance throughout the course. Such performance arises as a consequence of the multiple moments in which participation and reification were synergically generated by the course design. According to Wenger [32], when participation and reification are present, learners are able to build significant meaning leading to a more enriched learning experience. Moreover, students were exposed to multiple recontextualization scenarios as they successfully travelled through the established learning path. Learners were able to recontextualize knowledge in new contexts as an effective way for increasing their expertise and improving their skills taking into account the well-design set of exercises in each of the levels of the course [31]. Furthermore, data analysis showed that our learning path improves the processes of teaching and learning between students and teachers in a MOOC, a key aspect in digital environments [4]. Each of the blocks of the course and its paths favored engagement and active interaction, increasing abstract schemes of thinking and stimulating building of knowledge [23].

6. Conclusion

Under MOOCs design, learning paths have become key curricular components for facilitating the transit of students and enriching their experience throughout the development of the course. Multiple pedagogical components must be taken into account to elaborate an adequate structure in a learning path, envisioning this educational tool in a learning digital experience. As such, we proposed and implemented a learning path for a programming MOOC to evaluate its impact on students' performance. Data indicates a strong relationship between following the suggested learning path and performance in the course showing that the pedagogical structure envisioned by the course professors successfully leads to programming learning and computational skill development. Additionally, data proved that those students who did not fully follow the learning path established struggled in accomplishing the objectives of learning of the course.

A deep analysis based on concepts from the socio-cultural vision of education allowed us to expose the reasons that lead to success on our learning path. Those students who dedicatedly followed the learning path suggested for the course had the opportunity to experience multiple moments of participation and reification articulated in the curriculum as precise activities to develop. Such active pedagogical actions offered high-quality moments in which learners were able to build knowledge and recontextualize concepts and skills in different scenarios. We handle evaluating how a MOOC learning path facilitates the navigation of students through objectives of learning by the explicit use of well-established educational concepts.

This study presented encloses the potential to improve learning paths not only in the field of programming and computer systems but in any field as it holds a latent prospect for positively influencing curricular design and active learning. Therefore, we encourage professors to include socio-cultural concepts in their courses for enhancing the pedagogical experiences offered in MOOCs.

7. Limitations to the Study and Future Research

The analytical power of the approach described could be enhanced by a larger sample from future cohorts for longitudinal analysis. This would provide enough data to provide a definitive final statement about the scope of the approach herein described. A larger sample might find significant differences among learning paths that could enlighten improvements for the established pedagogical approach used in our programming MOOC. Moreover, this study has been focused on a specific programming MOOC designed in our institution. The analysis of learning paths in other programming MOOCs might enhance the analysis of the scope and limitations of our proposal as well as provide a more general framework for the successful inclusion of learning paths through not only programming MOOCs but also courses designed in almost any area to obtain a more comprehensive picture of the power of the learning path proposed.

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